UK Informative Inventory Report (1990 to 2016)

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Executive Summary

This is the 13th Informative Inventory Report (IIR) from the UK National Atmospheric Emissions Inventory (NAEI) Programme. The report accompanies the UK's 2018 data submission under the revised EU Directive 2016/2284/EU on National Emissions Ceilings (NECD) and 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 quality 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 NECD and the CLRTAP.

The scope of emissions reported under the CLRTAP covers anthropogenic emissions to atmosphere from the UK and Gibraltar from sources defined under the CLRTAP. Reporting requirements under the revised NECD (which entered into force on 31 December 2016) are closely aligned with those of the CLRTAP, including a common scope of reporting of pollutant inventories. The UK submission to the NECD[1] and the CLRTAP[2] comprises annual emission estimates presented in Nomenclature for Reporting (NFR14) format, for:

- Nitrogen oxides (NO_x (as NO_2)), carbon monoxide (CO), ammonia (NH_3), sulphur dioxide (SO_x (as SO_2)), non-methane volatile organic compounds (NMVOCs), particulate matter (PM), persistent organic pollutants, and heavy metals (1990 to 2016).

Both the NECD and the Gothenburg Protocol to the UNECE CLRTAP set 2010 emissions ceilings for NO_x, SO_x, NMVOCs and NH_3. The Gothenburg Protocol was revised in May 2012 to set more stringent emission reduction obligations from 2020. This Protocol has also been extended to set emission reductions for $PM_{2.5}$[3]. The revised NECD sets ceilings for 2020 (in line with Gothenburg Protocol ceilings) and 2030 for the same air pollutants. The UK Government is currently developing its comprehensive Clean Air Strategy, which will be published for consultation in 2018 and will set out how it will work towards these new emission reduction commitments. The emission projections take account of measures in place as far as that is possible, given the data available, but do not reflect measures under development for the Clean Air Strategy.

An overview of emissions from 1990-2016 by source sector for each of these pollutants is provided in Figure ES.1-1 through to Figure ES.1-4. The codes accompanying the definition of each source category in these figures refer to the NFR14 codes for the source sectors shown.

[1] See http://ec.europa.eu/environment/air/pollutants/ceilings.htm for Information on the new NEC Directive (2016/2284/EU)
[2] See http://www.ceip.at/reporting-instructions/reporting-programme/ for reporting requirements set up by TFEIP/UNECE Guidelines for estimating and reporting emissions data under CLRTAP.
[3] $PM_{2.5}$ refers to particulate matter with an aerodynamic diameter less than 2.5μm, PM_{10} refers to particulate matter with an aerodynamic diameter less than 10μm

Figure ES.1-1 Total UK Emissions by Source Sectors of Oxides of Nitrogen (NO_x as NO_2), 1990-2016.

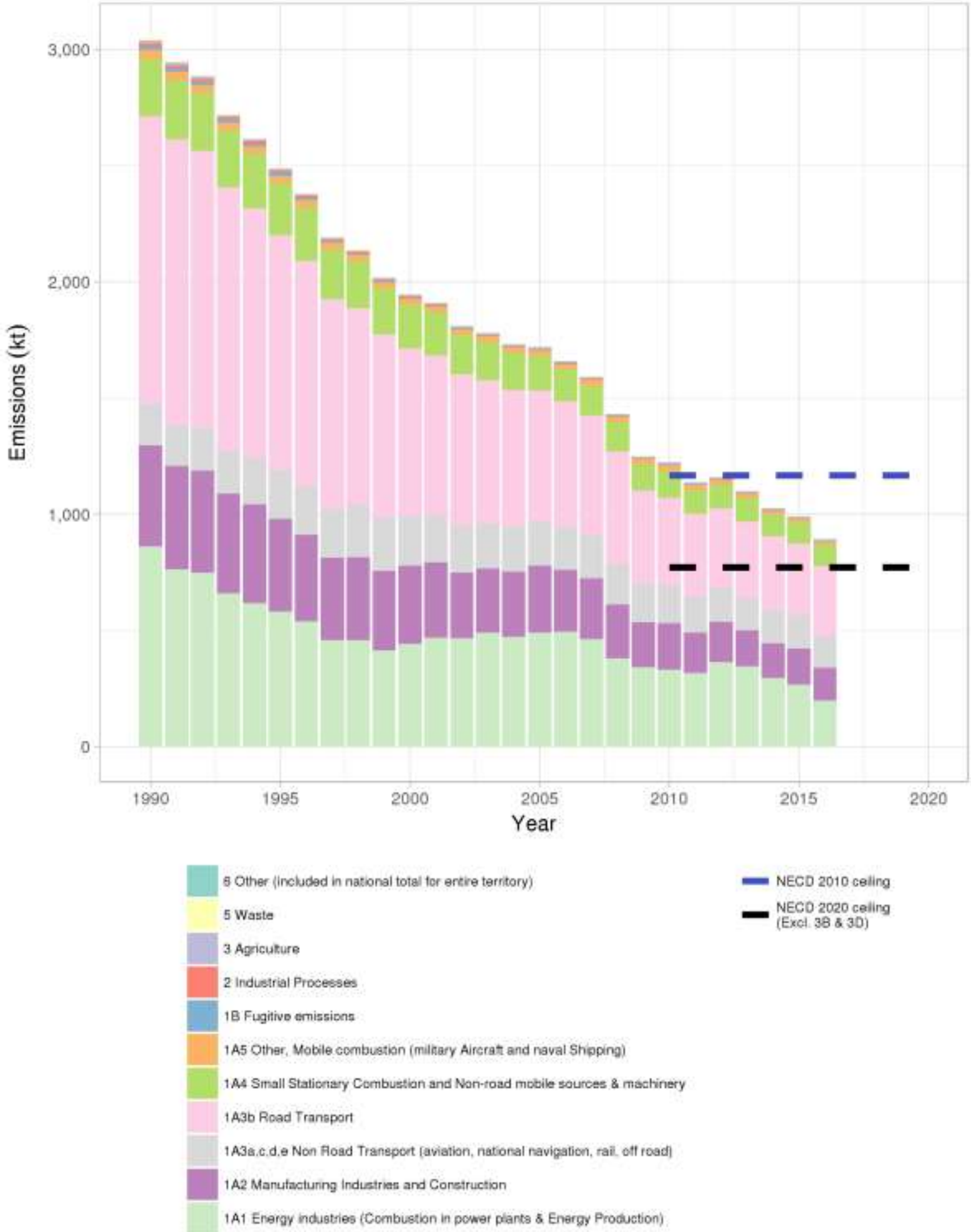


Figure ES.1-2 Total UK Emissions by Source Sectors of Non-Methane Volatile Organic Compounds (NMVOCs), 1990-2016.

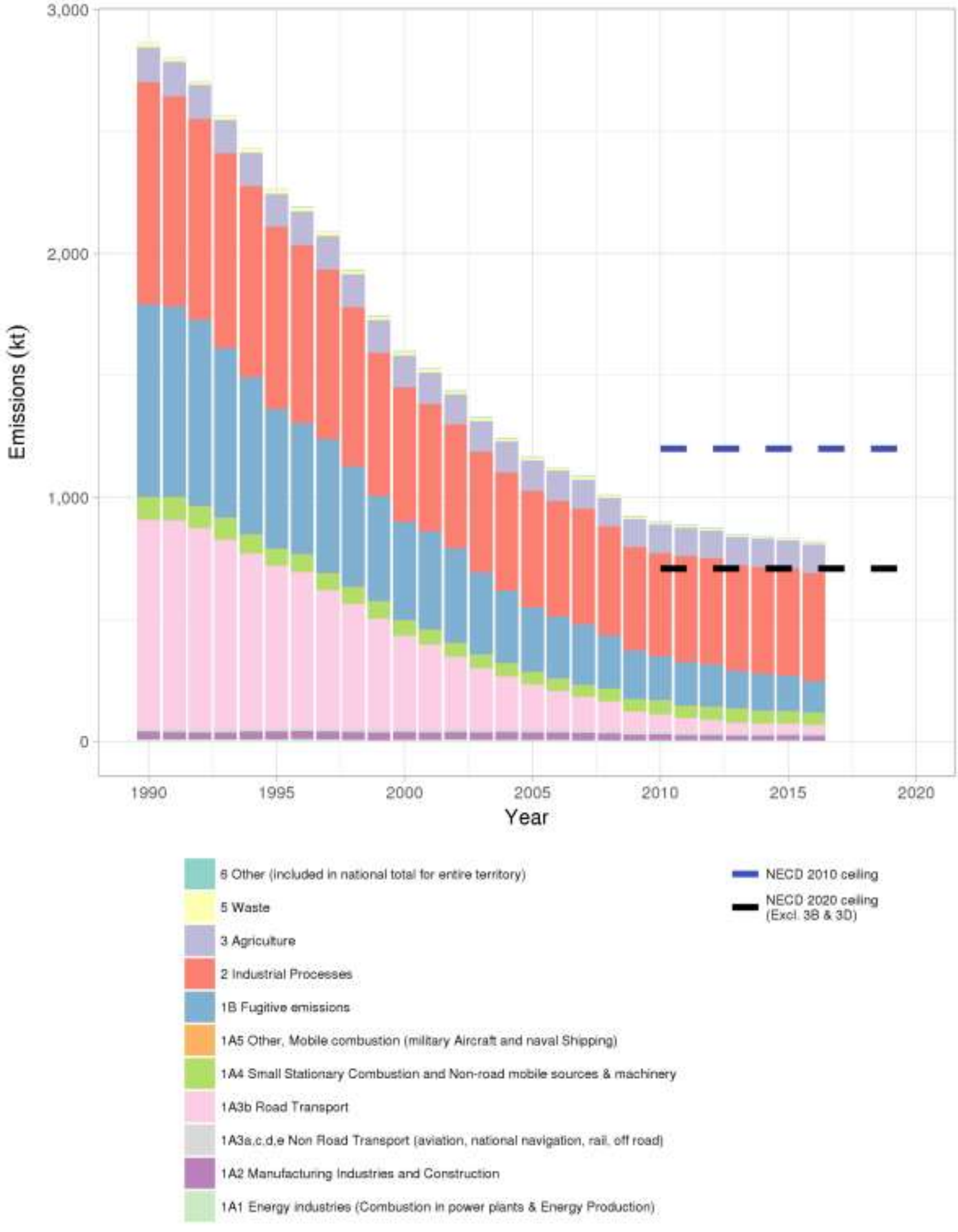


Figure ES.1-3 Total UK Emissions by Source Sectors of Sulphur Dioxide (SO_x as SO_2), 1990-2016

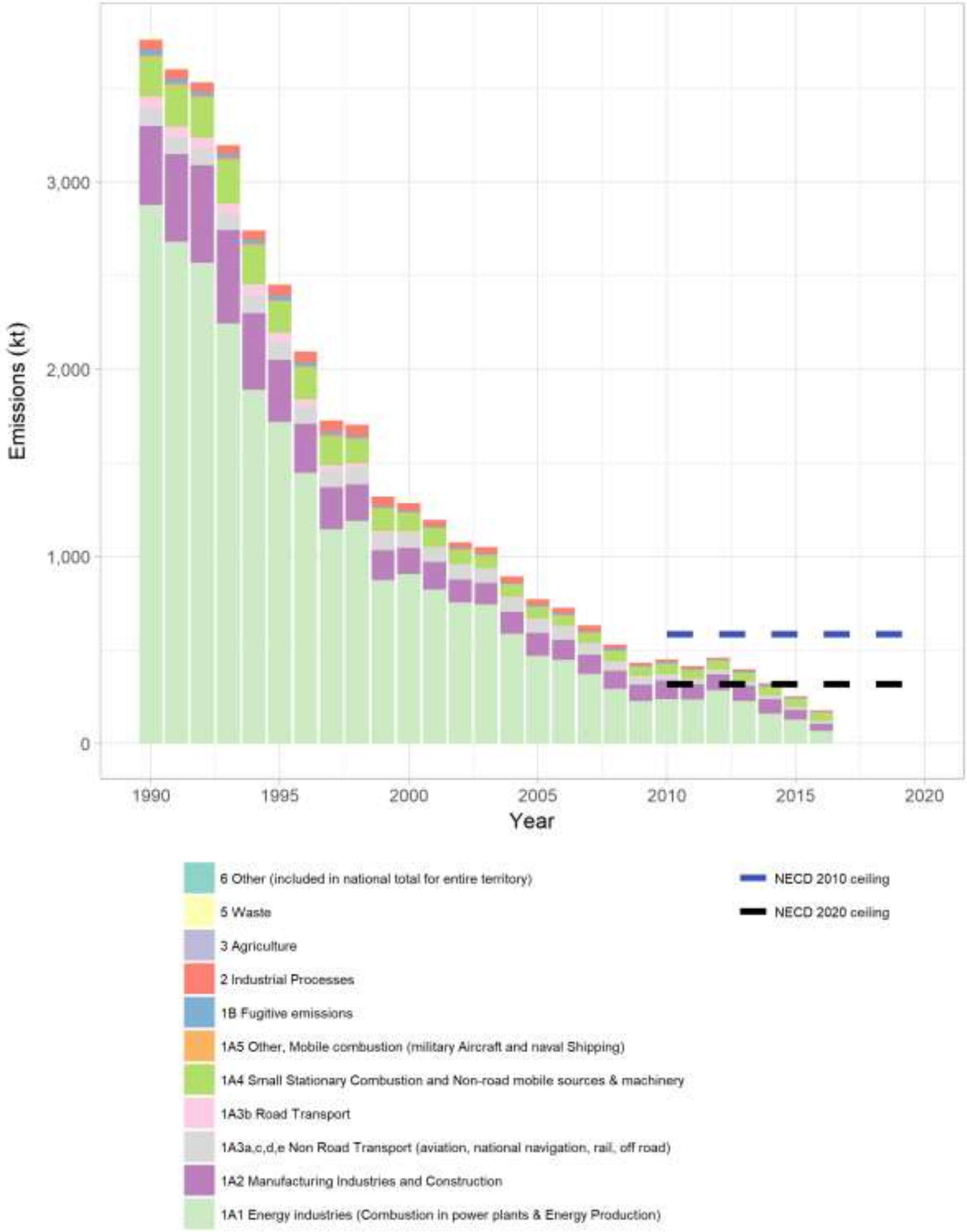
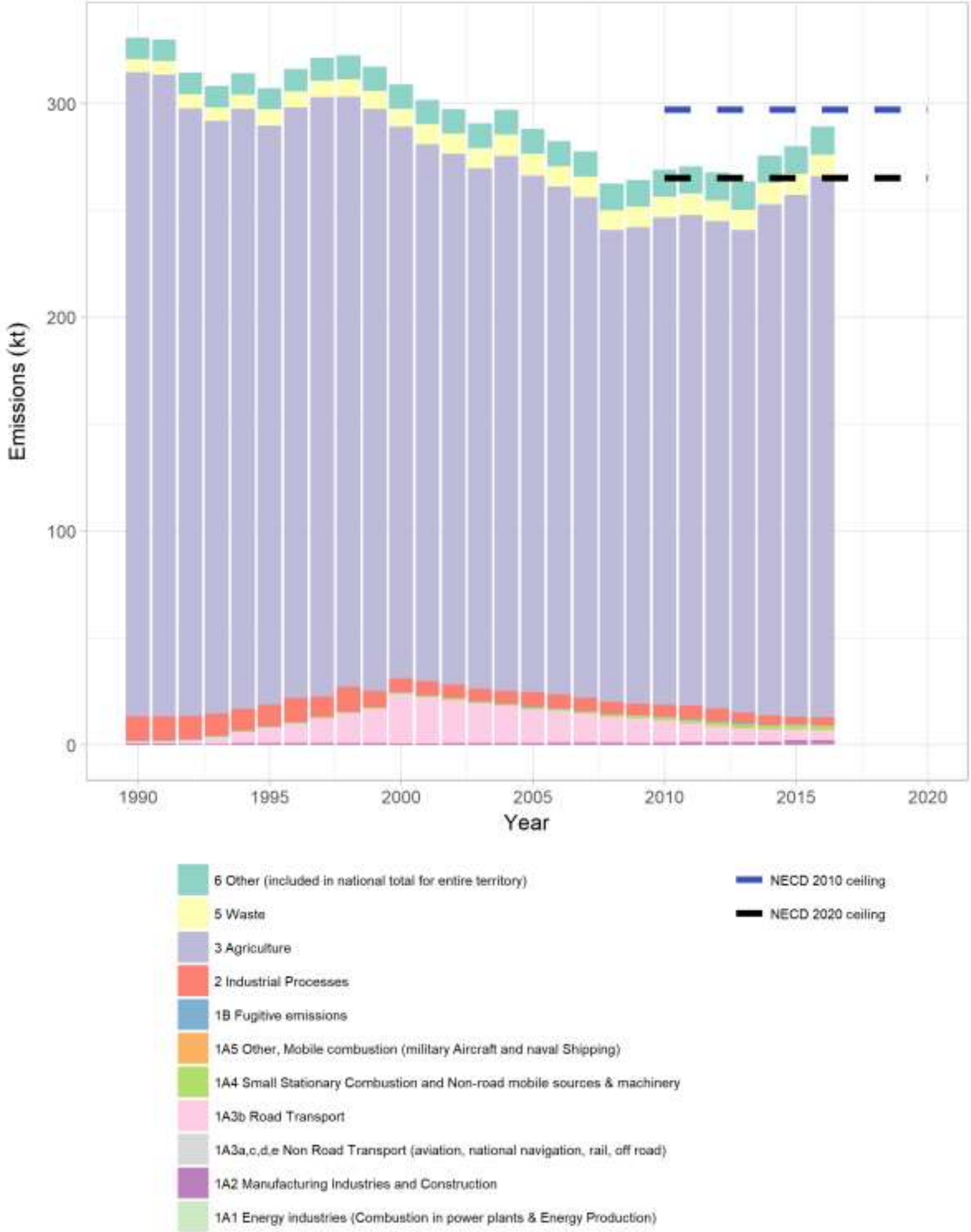


Figure ES.1-4 Total UK Emissions by Source Sectors Ammonia (NH_3), 1990-2016.



Total percentage reductions in emissions of these pollutants from 1990-2016 are summarised in Table ES.1-1.

Table ES.1-1 Air Quality Pollutant Emission Reductions between 1990 and 2016

Pollutant	% Change from 1990 to 2016
NO_x (as NO_2)	-71%
SO_x (as SO_2)	-95%
NH_3	-13%
NMVOC	-71%
CO	-79%
PM_{10}	-55%
$PM_{2.5}$	-54%

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 NFR14 codes. However, in accordance with international guidelines[4] 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 differ because the sources included in the national totals differ under the CLRTAP[5] and the UNFCCC reporting guidelines. The historical time-series of emissions data from the 2016 inventory submitted under the CLRTAP and the NECD are identical.

The purpose of this report is to:

1. Present an overview of institutional arrangements and the emission inventory compilation process in the UK;
2. Present the emission estimates for each pollutant up to 2016 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 NECD and CLRTAP data submissions.

Information contained in this report is derived from the UK National Atmospheric Emissions Inventory (NAEI) emissions inventory programme, which includes the UK Greenhouse Gas Inventory, used for reporting to the UNFCCC. The compilation of the inventories for the pollutants reported to the NECD, 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 NECD and CLRTAP submission. The latest emission factors used to compile emissions

[4] http://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions/reporting_programme/
[5] Includes the United Kingdom (England, Scotland, Wales, Northern Ireland) and Gibraltar only

estimates and the estimates themselves will be made available at http://naei.defra.gov.uk/data_warehouse.php in summer 2018. The complete 2018 UK NECD and CLRTAP submission templates are available from the European Environment Information and Observation Network (EIONET) under the following folders respectively:

- http://cdr.eionet.europa.eu/gb/eu/nec_revised/inventories/envwnwqzg/
- http://cdr.eionet.europa.eu/gb/un/clrtap/inventories/envwnwqhw/

Emission trends for key source sectors are given and discussed in Chapter 2, whilst revisions in source data or estimation methodology are summarised for each NFR14 source sector in 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 and some of the planned improvements that were outlined within the previous Informative Inventory Report (1990 to 2015) have been addressed in the 2016 inventory. Planned improvements for future national inventory compilation cycles are discussed at the end of each Chapter on each NFR14 source sector.

Table ES.1-2 compares overall emission estimates for each pollutant between the 2017 and 2018 (current) submissions, summarising any differences in emissions for the calendar year 2015 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 year 2015 between the 2017 and 2018 CLRTAP Submissions, and emissions data for year 2016 from the 2018 CLRTAP Submission.

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
NO_x (as NO_2)	918.3	991.9	892.9	kt	8%	The most significant recalculations have been made to the shipping sector as a result of improvement work using Automatic Identification System (AIS) vessel movement data. The upward revision is largely due to increased estimates of fuel consumed from domestic shipping calculated by the new shipping emissions model. Emissions from agriculture have also been added for the first time.
CO	1645.1	1668.5	1512.2	kt	1%	NAEI 2016 totals have been revised upward for most years since 1993, chiefly affected by a revision to emission factors for domestic combustion of petroleum coke to use a tier 2 technology specific approach. In addition, there are notable increases in emission estimates for later years due to improvements in the compilation approach for shipping and domestic aviation emissions from small aircraft. Emission estimates from primary steelmaking installations in the UK have also been revised for 2013-15, increasing emissions from blast furnaces and decreasing emissions from sinter production, with a net positive effect on overall emissions.
NMVOC	835.4	835.1	818.6	kt	0%	Estimates of NMVOC emissions from the use of solvents have been reviewed following research to gather new information. As a result of data provided by the European Solvent Industry Group, and British Coatings Federation in particular, emissions have been revised, and whilst there have been increases in estimates for some sub-categories, overall emissions from the 2D3 sector are now approximately 10% lower for recent years. Since solvent use is a major contributor to NMVOC emissions, this is a significant change. However, this decrease has been cancelled out by an increase in emissions from other sources, mainly agriculture emissions, which have been calculated using a Tier 1

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
						methodology in the new agriculture model. Road transport emissions have also increased due to a revised estimate of evaporative emissions from vehicles, leaving total emissions at a very similar level to last year's inventory (<1% difference for the year 2015).
SO_x (as SO_2)	236.1	253.3	179.2	kt	7%	Total SO_2 has been revised upward for all years, mainly due to the improvements made to the shipping inventory. Specifically, new modelling has facilitated improved estimates of time spent by ships in sulphur control areas and better informed judgements on the split of high/low sulphur fuel/gas oil.
NH_3	292.8	280.0	289.1	kt	-4%	Significant changes to the inventory model for calculating emissions from the agricultural sector were introduced for the 1990-2016 submission. In particular, this has implemented a combined ammonia and greenhouse gas inventory model with greatly improved spatial, temporal and sectoral resolution. Whilst most ammonia emission factors have remained unchanged, those for nitrogen fertiliser applications, which are spatially and temporally sensitive, have changed as a result of the finer model resolution, and the introduction of dynamic modelling of N excretion by ruminant livestock. Derivation of this finer resolution has come from more detailed data that relates diet and production characteristics.
TSP	206.5	359.4	375.4	kt	74%	Emissions have increased due to a number of factors including revision to the Emission Factors to align with the 2016 EMEP/EEA Guidebook for various sources (fireworks, quarrying, construction), removal of opencast coal extraction activity data (now included in NFR 1B), adding emissions from cigarettes and revisions to operator data for several industry sub sectors. The methodology for total particulate matter from construction has been updated to the 2016 Guidebook method, having previously been based on the 2013 edition. As a result, we now estimate emissions for four categories of construction (houses,

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
						apartments, other buildings, roads), rather than the single category used previously, and emission estimates for construction are now significantly higher for all years.
PM_{10}	145.5	173.7	170.4	kt	19%	Emissions have increased due to a number of factors including revision to the Emission Factors to align with the 2016 EMEP/EEA Guidebook for various sources (fireworks, quarrying, construction), removal of opencast coal extraction activity data (now included in NFR 1B), adding emissions from cigarettes and revisions to operator data for several industry sub sectors. The methodology for particulate matter from construction has been updated to the 2016 EMEP/EEA Guidebook method, having previously been based on the 2013 edition. As a result, estimates of emissions for four categories of construction (houses, apartments, other buildings, roads) are provided, rather than the single category used previously. Emission estimates for construction are now significantly higher for all years e.g. about 2.5 times higher in 2005 and 4 times higher in 2015.
$PM_{2.5}$	104.8	112.1	107.9	kt	7%	Emissions have increased due to a number of factors including revision to the Emission Factors to align with the 2016 EMEP/EEA Guidebook for various sources (fireworks, quarrying, construction), removal of opencast coal extraction activity data (now included in NFR 1B), adding emissions from cigarettes and revisions to operator data for several industry sub sectors. The methodology for particulate matter from construction has been updated to the 2016 EMEP/EEA Guidebook method, having previously been based on the 2013 edition. As a result, we now estimate emissions for four categories of construction (houses, apartments, other buildings, roads), rather than the single category used previously. Emission estimates for construction are now significantly higher for all years e.g. about 2.5 times higher in 2005 and 4 times higher in 2015.

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
BC	17.8	19.0	17.7	kt	7%	Changes BC are largely reflective of those for the $PM_{2.5}$ inventory. In response to 2017 NECD recommendation, we have changed the $PM_{2.5}/PM_{10}$ ratio from 0.95 to 1 for the road transport sectors 1A3bi-iv (to be in line with the 2016 EMEP/EEA Guidebook), and as a result, $PM_{2.5}$ and BC exhaust emissions have been uplifted by 5% across the timeseries.
Pb	65.1	77.0	64.4	tonnes	18%	The revisions are mainly due to inclusion of emissions from fireworks (in response to the recommendation from the 2016 CLRTAP Stage 3 Review) and to a lesser extent, the inclusion of additional E-PRTR data for emissions from one specific chipboard production plant
Cd	3.5	3.8	3.5	tonnes	7%	The revisions are mainly due to inclusion of emissions from cigarette smoking (in response to the recommendation from the 2016 CLRTAP Stage 3 Review) and updated emissions data provided for steelworks installations for 2015
Hg	4.8	4.8	4.0	tonnes	1%	The small revisions are mainly due to the improvements in shipping emissions estimates (with both activity and emission factors being revised upward) and revised emission factor and activity data for the foundries-castings source category.
As	16.4	16.7	15.1	tonnes	2%	Marginal increases in emission are largely as the result of the improvements in shipping emissions estimates (with both activity and emission factors being revised upwards) and the emissions factors used now being taken from the 2016 EMEP/EEA Emission Inventory Guidebook. There have also been revisions to 2015 site data for wood product manufacture.
Cr	27.8	25.6	25.0	tonnes	-8%	Emissions for one chemical production plant have been removed from the inventory as the site closed in 2009. There have also been revisions to UK Energy Statistics estimates of other industrial combustion of wood. These have been partially offset by correction to the assignment of UK Energy Statistics categories to straw combustion

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
Cu	51.5	54.6	51.0	tonnes	6%	Marginal increases in emission are largely as the result of the improvements in shipping emissions estimates (with both activity and emission factors being revised upwards) and the emissions factors used now being taken from the 2016 EMEP/EEA Emission Inventory Guidebook.
Ni	85.5	92.4	88.2	tonnes	8%	Marginal increases in emissions are largely as the result of the improvements in shipping emissions estimates (with both activity and emission factors being revised upwards) and the emissions factors used now being taken from the 2016 EMEP/EEA Emission Inventory Guidebook.
Se	13.5	13.5	8.8	tonnes	1%	Data for the 2016 inventory are very similar to the 2015 inventory.
Zn	453.4	468.1	441.1	tonnes	3%	Marginal increases are due to revisions to the waste oil/lubricant combustion calculations and some modifications for how straw combustion is mapped to UK Energy Statistics categories have been made.
PCB	622.9	608.5	547.0	kg	-2%	Emissions have been revised downward for all years, primarily affected by revisions to the Emissions factors used. We are now following the 2016 EMEP/ EEA Guidebook.
PCDD/PCDF (dioxins/furans)	210.6	193.3	180.0	grams TEQ	-8%	Revisions to activity data for wood and straw have resulted in large reductions in emission estimates for 2015. This is offset somewhat by the addition of estimates for sectors/fuels which were not previously included but for which the 2016 EMEP/EEA Guidebook now provides suitable emission factors. Most of these estimates are for the use of gaseous fuels and lighter oils, and emissions are trivial, so the change to the biomass activity data is the dominant change.
benzo(a)pyrene	7.5	7.7	7.6	tonnes	2%	Increases have resulted from the addition of estimates for sectors/fuels which were not included previously but for which the 2016 EMEP/EEA Guidebook provides suitable emission factors. Most of these estimates were for the use of gaseous fuels and lighter oils, and these additions increase the UK total in 2015 by a few percent. Emission factors for field burning and a handful of

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
						other sources were updated to Emission Factors given in the Guidebook, and the change for field burning has a large impact on the early years of the time-series. UK emission totals for the 1990-1992 have increased period by a factor of 4.
benzo(b) fluoranthene	6.9	7.0	6.8	tonnes	1%	Increases have resulted from the addition of estimates for sectors/fuels which were not included previously but for which the 2016 EMEP/EEA Guidebook provides suitable emission factors. Most of these estimates were for the use of gaseous fuels and lighter oils, and the additions increase the UK total in 2015 in the current inventory by about 1% compared to last year's 2015 emissions. Emission factors for field burning and a handful of other sources were updated to defaults given in the Guidebook, and the change for field burning has a large impact on the early years of the time-series UK emission totals for the 1990-1992 have increased period by a factor of 8.
benzo(k) fluoranthene	2.9	2.9	2.8	tonnes	1%	Increases have resulted from the addition of estimates for sectors/fuels which were not included in the NAEI previously but for which the 2016 EMEP/EEA Guidebook provides suitable emission factors. Most of these estimates were for the use of gaseous fuels and lighter oils, and the additions increase the UK total in 2015 in the current inventory by about 1% compared to 2015 emissions in last year's inventory. Emission factors for field burning and a handful of other sources were updated to defaults given in the Guidebook and the change for field burning has a large impact on the early years of the time-series UK emission totals for the 1990-1992 have increased period by a factor of 7.
Indeno(1,2,3-cd) pyrene	4.4	4.4	4.3	tonnes	1%	Increases have resulted from the addition of estimates for sectors/fuels which were not included in the NAEI previously but for which the 2016 EMEP/EEA Guidebook provides suitable emission factors. Most of these estimates were for the use of gaseous fuels and lighter oils, and the additions increase the UK total in 2015 by about 1%. Emission factors for field burning and

Pollutant	2017 Submission 2015	2018 Submission 2015	2018 Submission 2016	Units	(% change for 2015 values)	Comment/Explanation (changes between the 2017 and 2018 CLRTAP Submissions)
						a handful of other sources were updated to defaults given in the Guidebook, and the change for field burning has a large impact on the early years of the time-series.UK emission totals for the 1990-1992 have increased period by a factor of 6.
HCB	27.4	27.5	30.8	kg	0%	Emissions totals for the early part of the time series (1990-1998) totals have been revised downward. This is largely driven by revising downward activity data from aluminium production that are extrapolated from data reported in the EA Pollution Inventory. In recent years, changes in DUKES entries for non-biodegradable waste used for heat added to MSW incineration activity data are responsible for small upward revision of the NAEI16 totals.

(I) Contacts and Acknowledgements

The National Atmospheric Emission Inventory is prepared by Ricardo Energy & Environment under the National Atmospheric Emissions Inventory contract to the Department for Business, Energy and Industrial Strategy (BEIS).

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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 (CEH) Edinburgh.

NH_3 emissions from agriculture are provided to Defra under a separate contract by a consortium led by Rothamsted Research in Okehampton, Devon.

A copy of this report and related documentation may be found on the NAEI website maintained by Ricardo Energy & Environment on behalf of BEIS and Defra: http://naei.defra.gov.uk/.

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(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.

Acronyms and Definitions

ABI	Annual Business Inquiry
ACEA	European Automobile Manufacturers' Association
AD	Anaerobic digestion
AIS	Automatic identification System
ANPR	Automatic Number Plate Recognition
AQEG	Air Quality Expert Group
AQPI	Air Quality Pollutant Inventory
AS	Aviation Spirit
ATF	Aviation Turbine Fuel
ATM	Air Traffic Movement
ATOC	Association of Train Operating Companies
APU	Auxiliary Power Unit
AP-42	Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors
BAMA	British Aerosol Manufacturers Association
BASA	British Adhesives & Sealants Association
BAU	Business as usual
BCA	British Cement Association
BCF	Bureau for Computer Facilities
BEIS	Department for Business, Energy and Industrial Strategy
BERR	Department for Business, Enterprise & Regulatory Reform
BGS	British Geological Survey
BSOG	DfT's Bus Services Operators Grant
BREF	Best Available Technology Reference
BMW	Biodegradable Municipal Waste
CAA	Civil Aviation Authority
CCA	Climate Change Agreement
CCGT	Combined Cycle Gas Turbine
CD	Crown Dependency
CEH	Centre for Ecology and Hydrology
CEIP	Centre on Emissions Inventories and Projections
CHP	Combined Heat and Power
CLRTAP	Convention on Long-Range Transboundary Air Pollution
COPERT	Computer Programme to calculate Emissions from Road Transport
CSRGT	Continuing Survey of Road Goods Transport
CTPA	Cosmetics, Toiletries and Perfumery Association
DAERA	Northern Ireland's Department of Agriculture, Environment and Rural Affairs
DECC	Department of Energy & Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DERV	Road diesel fuel
DoENI	Department of Environment Northern Ireland
DRDNI	Department for Regional Development Northern Ireland
DPF	Diesel Particulate Filters

DUKES	Digest of UK Energy Statistics
DVLA	Devolved Administration-country specific vehicle licensing data
EA	Environment Agency
EE	Energy Efficiency
EEMS	Environmental Emissions Monitoring System
EF	Emission Factors
EfW	Energy from Waste
EGR	Exhaust Gas Recirculation
EIONET	European Environment Information and Observation Network
EMEP/CORINAIR	After 1999 called EMEP/EEA
EMEP/EEA	European Monitoring and Evaluation Program Emission Inventory Guidebook
EPR	Environmental Permitting Regulations
E-PRTR	European Pollutant Release and Transfer Register
ESIG	European Solvents Industry Group
EU ETS	European Union Emissions Trading System
FERA	Food and Environmental Research Agency
FGD	Flue gas desulphurisation
FYM	Farm Yard Manure
GCV	Gross Calorific Value
GHG	Greenhouse gases
GHGI	Greenhouse gas inventory
GWh	Giga Watt Hour (unit of energy)
GWP	Global Warming Potential
HGV	Heavy Goods Vehicles
HMIP	Her Majesty's Inspectorate of Pollution (former name for regulatory agency in England and Wales, its functions now carried out by the Environment Agency and Natural Resources Wales)
ICAO	International Civil Aviation Organisation
IED	Industrial Emissions Directive
IEF	Implied Emission Factor
IIR	Informative Inventory Report
IPPC	Integrated Pollution Prevention and Control
ISR	Inventory of Statutory Releases (DoENI)
ISSB	Iron and Steel Statistics Bureau
kt	Kilotonne
ktC	Kilotonne of Carbon
ktC-e	Kilotonne of Carbon-equivalent (taking account of GWP)
LA-IPPC	Local Authority Integrated Pollution Prevention and Control
LAPC	Local air pollution control
LCPD	Large Combustion Plant Directive
LEZ	Low Emission Zone
LGV	Light Goods Vehicles
LPG	Liquefied petroleum gas
LRC	London Research Centre
LTO	Landing & Take Off
LULUCF	Land Use, Land-Use Change and Forestry
MoD	Ministry of Defence
MPA	Mineral Products Association
MPP	Major Power Producers (i.e. large power station operators)
MPG	miles per gallon
MSW	Municipal Solid Waste
Mt	Megatonne
Mtherms	Megatherms
NFR14	2014 Reporting Guidelines Nomenclature for Reporting
NHS	National Health Service
NAEI	National Atmospheric Emissions Inventory
NECD	National Emission Ceiling Directive
NCSC	National Center for Climate Change Strategy and International Cooperation
NIEA	Northern Ireland Environment Agency
NIPI	Northern Ireland Pollution Inventory

NRMM	Non-Road Mobile Machinery
NRTY	National Rail Trends Yearbook
NRW	Natural Resources Wales
OCGT	Open Cycle Gas Turbine
OFWAT	The Water Industry Regulator for England and Wales
OGUK	Oil and Gas UK (trade association for upstream oil and gas industry)
ONS	Office for National Statistics
OPG	Other petroleum gases
ORR	Office of Rail and Road
OT	Overseas Territories
PAMs	Policies and Measures
PI	Pollution Inventory (of the Environment Agency and Natural Resources Wales)
POC	Port of call
POPs	Persistent Organic Pollutants
ppm	Parts per million
PPRS	Petroleum Production Reporting System
PRODCOM	PRODuction COMmunautaire
PSDH	Project for the Sustainable Development of Heathrow
QA/QC	Quality assurance and quality control
RASCO	Regional Air Services Co-ordination
RDF	Refuse-Derived Fuel
REM	Rail Emissions Model
RESTATs	Renewable Energy Statistics (published by BEIS)
RTFO	Renewable Transport Fuels Obligation
RVP	Reid Vapour Pressure
SCCP	Short Chain Chlorinated Paraffins
SCR	Selective Catalytic Reduction
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
SSI	Sahaviriya Steel Industries (UK)
SWA	Scotch Whisky Association
TCCCA	Transparency, Completeness, Consistency, Comparability and Accuracy
TfL	Transport for London
THC	Total Hydrocarbons
TSP	Total Suspended Particulate
TRL	Transport Research Laboratory
TFEIP	Task Force on Emission Inventories and Projections
UEP	Updated Energy Projection (UK energy forecasts produced by BEIS)
UKCCP	UK Climate Change Programme
UKD	UK Gas Distributors
UKMY	UK Minerals Yearbook
UKOOA	UK Offshore Operators Association (now Oil and Gas UK)
UKPIA	UK Petroleum Industries Association
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environment Protection Agency
USLP	Ultra-low Sulphur Petrol
WEI	Welsh Emissions Inventory
WID	Waste Incineration Directive
WML	Waste Management Licensing

Abbreviations for Chemical Compounds covered in the UK Air Quality Inventory

Chemical Name	Abbreviation
Nitrogen Oxides	NO_x as NO_2
Sulphur Dioxide	SO_x as SO_2
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
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

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1. Introduction

This chapter provides an overview of the management and delivery of the UK emissions inventory 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 UK inventory.
- Section 1.6 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 emissions inventory compiles annual pollutant emission estimates from 1970 to the most current inventory year for the majority of pollutants. A number of pollutants are estimated only from 1990 or 2000 to the most current inventory year due to the lack of adequate data prior to these dates, but this does not affect the UK's ability to submit a full and complete submission under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and EU National Emission Ceilings Directive (NECD). The pollutants that are required to be reported to the CLRTAP and NECD 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 newly introduced legislation that sets limits on total emissions and/or requires quantitative information on this to be reported. However, the UK government continues to take a pro-active approach to the inventory programme, enabling the national Inventory Agency to be typically able to prepare, review and improve pollutant emission estimates before they become a reporting obligation (see Section 1.2 on the Institutional Arrangements for Inventory Preparation).

In addition, the UK's national inventory programme 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, generating emission estimates of base cations (sodium, potassium, calcium and magnesium) enables air pollution models to better recreate real world atmospheric processes and 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 national inventory programme are listed in Table 1-1.

The national inventory programme operates a continuous improvement programme. 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 a central part of the 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 can then be implemented (depending on resources) in time for the next inventory cycle.

Table 1-1 Scope of UK Inventory Reporting: Pollutants by Type, Time series

Pollutant	Reported under CLRTAP/NECD	Inventory Time series[1]	Type of Pollutant[2]
Nitrogen Oxides	✓	1970-2016	NAQS, AC, IGHG, O, E
Sulphur Dioxide	✓	1970-2016	NAQS, AC, IGHG
Carbon Monoxide	✓	1970-2016	NAQS, O, IGHG
Non-Methane Volatile Organic Compounds *	✓	1970-2016	NAQS, O, IGHG
Black Smoke		1970-2016	NAQS
Black Carbon	✓	1970-2016	-
Particulates < 10 μm	✓	1970-2016	NAQS
Particulates < 2.5 μm	✓	1970-2016	NAQS
Particulates < 1 μm		1970-2016	-
Particulates < 0.1 μm		1970-2016	-
Total Suspended Particulates	✓	1970-2016	-
Ammonia	✓	1980-2016	AC, E
Hydrogen Chloride		1970-2016	AC
Hydrogen Fluoride		1970-2016	AC
Lead	✓	1970-2016	NAQS, TP
Cadmium	✓	1970-2016	TP
Mercury **	✓	1970-2016	TP
Copper	✓	1970-2016	TP
Zinc	✓	1970-2016	TP
Nickel **	✓	1970-2016	TP
Chromium **	✓	1970-2016	TP
Arsenic	✓	1970-2016	TP
Selenium	✓	1970-2016	TP
Vanadium		1970-2016	TP
Beryllium		2000-2016	TP
Manganese		2000-2016	TP
Tin		2000-2016	TP
Polycyclic Aromatic Hydrocarbons *	✓	1990-2016	TP
PCDDs and PCDFs	✓	1990-2016	TP
Polychlorinated Biphenyls *	✓	1990-2016	TP
Hexachlorocyclohexane (HCH)[3]		1990-2013	TP
Pentachlorophenol		1990-2016	TP
Hexachlorobenzene	✓	1990-2016	TP
Short-chain chlorinated paraffins		1990-2016	TP
Polychlorinated Naphthalene		NE	TP
Polybrominated diphenyl ethers		SE	TP
Sodium		1990-2016	BC
Potassium		1990-2016	BC
Calcium		1990-2016	BC
Magnesium		1990-2016	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
AC	Acid gas	**TP**	Heavy metals and POPs are generally referred to as "Toxic Pollutants"
BC	Base cation	(although other pollutants also have toxic properties)	
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 Reporting Requirements: NECD and CLRTAP

The UK Air Quality 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 European Commission under the EU National Emissions Ceilings Directive (NECD) and to the UNECE Secretariat under the CLRTAP.

NECD

The revised NECD (2016/2284/EU)[6], which entered into force on 31 December 2016, sets new emission reduction commitments (ERCs) for each Member State for the total emissions of NO_x, SO_x, NMVOC, NH_3 and $PM_{2.5}$ in 2020 and 2030. The new Directive repeals and replaces Directive 2001/81/EC. These pollutants contribute to acidification and eutrophication of ecosystems whilst also playing a major role in the formation of ground-level ozone. EU Member States are required to prepare and annually update national emissions inventories for these and a number of other air pollutants.

The 2018 UK inventory submission shows the UK is compliant with all EU and international emission ceilings from 2011 onwards. The UK Government will publish its Clean Air Strategy later this year setting out how it will work towards its 2020 and 2030 ERCs. This will be followed by a National Air Pollution Control Programme by 1 April 2019, as required under the revised NECD.

The revised NECD submission uses the latest CLRTAP reporting templates (as requested by the European Environment Agency), including a common scope of reporting of pollutant inventories) and similar reporting timeframe, as shown in Table 1-2.

The deadlines for NECD 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[7];
- Spatially-disaggregated emissions (gridded emissions) – 1St May 2017 and every four years thereafter (CLRTAP only)
- Large point source (LPS) emissions – 1St May 2017 and every four years thereafter (CLRTAP only)

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 2018 UK inventory submission to the NECD and Gothenburg Protocol has been compiled in line with the revised Gothenburg Protocol Guidance[8].

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

[6] http://ec.europa.eu/environment/air/pollutants/ceilings.htm

[7] Under the CLRTAP, Parties are required to update their projections and report every four years from 15th March 2015 onward their updated projections.

[8] http://www.ceip.at/fileadmin/inhalte/emep/2014_Guidelines/ece.eb.air.125_ADVANCE_VERSION_reporting_guidelines_2013.pdf

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

Group	Pollutant	Required reporting years	Reported years in 2018 UK submission
Main Pollutants	Nitrogen Oxides	1990 – reporting year minus 2	1990-2016
	Sulphur Dioxide		
	Carbon Monoxide		
	Non-Methane Volatile Organic Compounds		
	Ammonia		
Particulate Matter	Particulates < 10 µm	2000 – reporting year minus 2	1990-2016
	Particulates < 2.5 µm		
	Total Suspended Particulates		
	Black Carbon (voluntary)		
Priority Heavy Metals	Lead	1990 – reporting years minus 2	1990-2016
	Cadmium		
	Mercury		
Other Heavy Metals	Copper (voluntary)	1990 – reporting year minus 2	1990-2016
	Zinc (voluntary)		
	Nickel (voluntary)		
	Chromium (voluntary)		
	Arsenic (voluntary)		
	Selenium (voluntary)		
Persistent Organic Pollutants	Benzo[a]pyrene	1990 – reporting year minus 2	1990-2016
	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	1990-2016

Emission Projections and Spatially-Referenced Data Submissions:
Every two years, starting in 2017, under the NECD EU Member States must report projected emissions for key pollutants SO_2, NO_X, NMVOC, NH_3, $PM_{2.5}$, and BC if available, for the years 2020, 2025 and 2030 and, where available, also for 2040 and 2050. In contrast, projections for the same pollutants and years must be reported to the LRTAP Convention every four years (starting in 2015). The UK has decided to report updated projections as part of the 2018 CLRTAP and NECD submissions. The emission projections take account of measures in place as far as that is possible, given the data available, but do not reflect measures under development for the Clean Air Strategy.

Starting in 2017, EU Member States 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 CLTRAP 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. As these data were reported in 2017 the UK will not be reporting updated gridded data in its 2018 submission.

A summary of the 2 yearly and 4-yearly reporting requirements, and the UK provision, is included in Table 1-3 below.

Table 1-3 Summary of two yearly and four yearly reporting requirements for estimating and reporting emissions under the CLRTAP and the revised NECD

Group	Pollutant	Required reporting years starting in 2017	Reported years in the 2018 UK submission
Gridded data in the new EMEP grid (0.1° × 0.1° long-lat)	SO_x as SO_2, NO_x as NO_2, NH_3, NMVOC, 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 to report in 2018
Emissions from large-point sources (LPS)	SO_x as SO_2, NO_x as NO_2, NH_3, NMVOC, 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 to report in 2018
Projected emissions	SO_x as SO_2, NO_x as NO_2, NH_3, NMVOC, $PM_{2.5}$, BC (voluntary)	**NECD**: report every two years from 2017 onwards, for years 2020, 2025, 2030, (2040 and 2050 if available) **LRTAP**: report every four years from 2015 onwards, for years 2020, 2025, 2030, (2040 and 2050 if available)	2016, 2020, 2025, 2030
Quantitative information on parameters underlying emission projections		Reported for the projection target year and the historic year chosen as the starting year for the projections	2020, 2025, 2030

Table 1-4 to Table 1-6 provide a summary of the emission targets set under the revised NECD and Gothenburg Protocol. Based on the current 2016 inventory, the UK met all of its 2010 targets and all subsequent years with the exception for NO_x for the year 2010. Under both the revised NECD and Gothenburg Protocol, an adjustment mechanism has been established to address some of the issues associated with the incorporation of additional sources or revised methods within emissions inventories after national emission reduction commitments have been set. For the 2018 submission, the UK has submitted an inventory adjustment application for NO_x (see further details in Chapter 10 – Adjustment).

Table 1-4 Comparison of UK 2016 national emissions with 2010 NECD and Gothenburg Protocol emission ceilings for UK

Pollutant	NH_3	NO_x as NO_2	SO_x as SO_2	NMVOCs
UK NECD 2010 Ceiling, kilotonnes	297	1167	585	1200
2010 Gothenburg Protocol Ceiling, kilotonnes	297	1181	625	1200
UK 2016 National Total, kilotonnes	289	893	179	819
Percentage of NECD 2010 ceiling, %	97%	77%	31%	68%

Table 1-5 Comparison of UK 2016 national emissions with 2020 NECD and Gothenburg emission targets (Emission values have been rounded)

Pollutant	NH_3	NO_x (as NO_2) (include 3B and 3D)[b]	NO_x (as NO_2) (exclude 3B and 3D)[c]	SO_x (as SO_2)	NMVOC (include 3B and 3D)[b]	NMVOC (exclude 3B and 3D)[c]	$PM_{2.5}$
2005 National Total, kilotonnes	288.11	1721.57	1714.11	772.75	1166.95	1042.49	127.27
2016 National Total, kilotonnes	289.06	892.91	885.70	179.16	818.57	701.10	107.91
Emission reduction commitment	8%	NR[d]	55%	59%	NR	32%	30%
2020 target, kilotonnes[a]	265.06	NR	771.35	316.83	NR	708.90	89.09
Progress to date towards 2020 reductions	-4%	NR	88%	130%	NR	102%	51%
Emission reduction required from 2016, kilotonnes	24.01	NR	114.35	0.00	NR	0.00	18.82
Projected 2020 National Total, kilotonnes	298.17	NR	735.29	126.45	NR	685.86	103.55
Above or below 2020 targets by, kilotonnes	33.11	NR	-36.06	-190.38	NR	-23.04	14.46

Table 1-6 Comparison of UK 2016 national emissions with 2030 NECD emission targets (Emission values have been rounded)

Pollutant	NH_3	NO_x (as NO_2) (include 3B and 3D)[b]	NO_x (as NO_2) (exclude 3B and 3D)[c]	SO_x (as SO_2)	NMVOC (include 3B and 3D)[b]	NMVOC (exclude 3B and 3D)[c]	$PM_{2.5}$
2005 National Total, kilotonnes	288.11	1721.57	1714.11	772.75	1166.95	1042.49	127.27
2016 National Total, kilotonnes	289.06	892.91	885.70	179.16	818.57	701.10	107.91
Emission reduction commitment	16%	NR	73%	88%	NR	39%	46%
2030 target, kilotonnes[a]	242.01	NR	462.81	92.73	NR	635.92	68.72
Progress to date towards 2030 reductions	-2%	NR	66%	87%	NR	84%	33%
Emission reduction required from 2016, kilotonnes	47.06	NR	422.89	86.43	NR	65.18	39.19
Projected 2030 National Total, kilotonnes	295.84	NR	557.66	96.69	NR	719.26	99.42
Above or below 2030 targets by, kilotonnes	53.83	NR	94.85	3.96	NR	83.34	30.70

[a] The 2020 and 2030 emission targets have been calculated using the 2005 emissions of the current inventory submission as the base year.
[b] The NMVOCs and NO_x figures quoted in this column include emissions from 3B and 3D, which are the currently reported national totals for NO_x and NMVOCs consistent with the Defra national statistics (Table 1[9]) and the recent NECD/CLRTAP submissions in February 2018. This is to be in line with the reporting requirement for the current (2010) emission ceiling.
[c] Under the revised NECD, NMVOCs and NO_x emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020 (or 2030) emission reduction commitments.
[d] NR = not relevant

In addition to the reporting under the NECD and the CLRTAP, the UK National Atmospheric Emissions Inventory team reports GHG emissions to the United Nations Framework Convention on Climate Change (UNFCCC). This is to comply with UNFCCC reporting requirements and the Kyoto Protocol commitments on behalf of the UK Government. There are some differences between the scope of emissions that must be reported for each of the NECD, CLRTAP and UNFCCC. The major differences between the source sector coverage are highlighted in Table 1-7, although there are also differences in the geographical coverage (see Section 1.1.4).

Table 1-7 Scope of UK Emissions Inventory Reporting under the CLRTAP, NECD and UNFCCC

Sector category	CLRTAP/NECD (included)	UNFCCC (included)
Domestic aviation (cruise)	No	Yes
International aviation (LTO)	Yes	No
International inland waterways	Yes	No

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/681445/Emissions_of_air_pollutants_statistical_release_FINALv4.pdf

1.1.3 Emission Sources Reported in the UK Inventory

In principle, the UK emissions inventory makes estimates of all GHG and air pollutant emissions to the atmosphere at the highest level of disaggregation possible. However, in accordance with international guidelines[10] 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). Only anthropogenic emission sources are reported.
- The inventory 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.
- 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. Overseas Territories (OTs), other than Gibraltar, and Crown Dependencies (CDs) are excluded.

Under the UNFCCC[11], 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 leads to differences in the NO_x (as NO_2) and NMVOCs emissions reported to the NECD/CLRTAP and the UNFCCC, where they are reported as indirect GHGs.

[10] http://www.ceip.at/fileadmin/inhalte/emep/2014_Guidelines/ece.eb.air.125_ADVANCE_VERSION_reporting_guidelines_2013.pdf
[11] Under the EU Monitoring Mechanism emissions are reported for the United Kingdom and Gibraltar only.

1.2 Institutional Arrangements for Inventory Preparation

The NAEI is maintained under contract to the Science and Innovation Climate and Energy (SICE) Division at the Department for Business, Energy and Industrial Strategy (BEIS) and the National Air Quality Evidence Team), of the Department for Environment, Food and Rural Affairs (Defra). The NAEI work programme is also co-funded by the Scottish Government, Welsh Government and Northern Ireland Department of Environment.

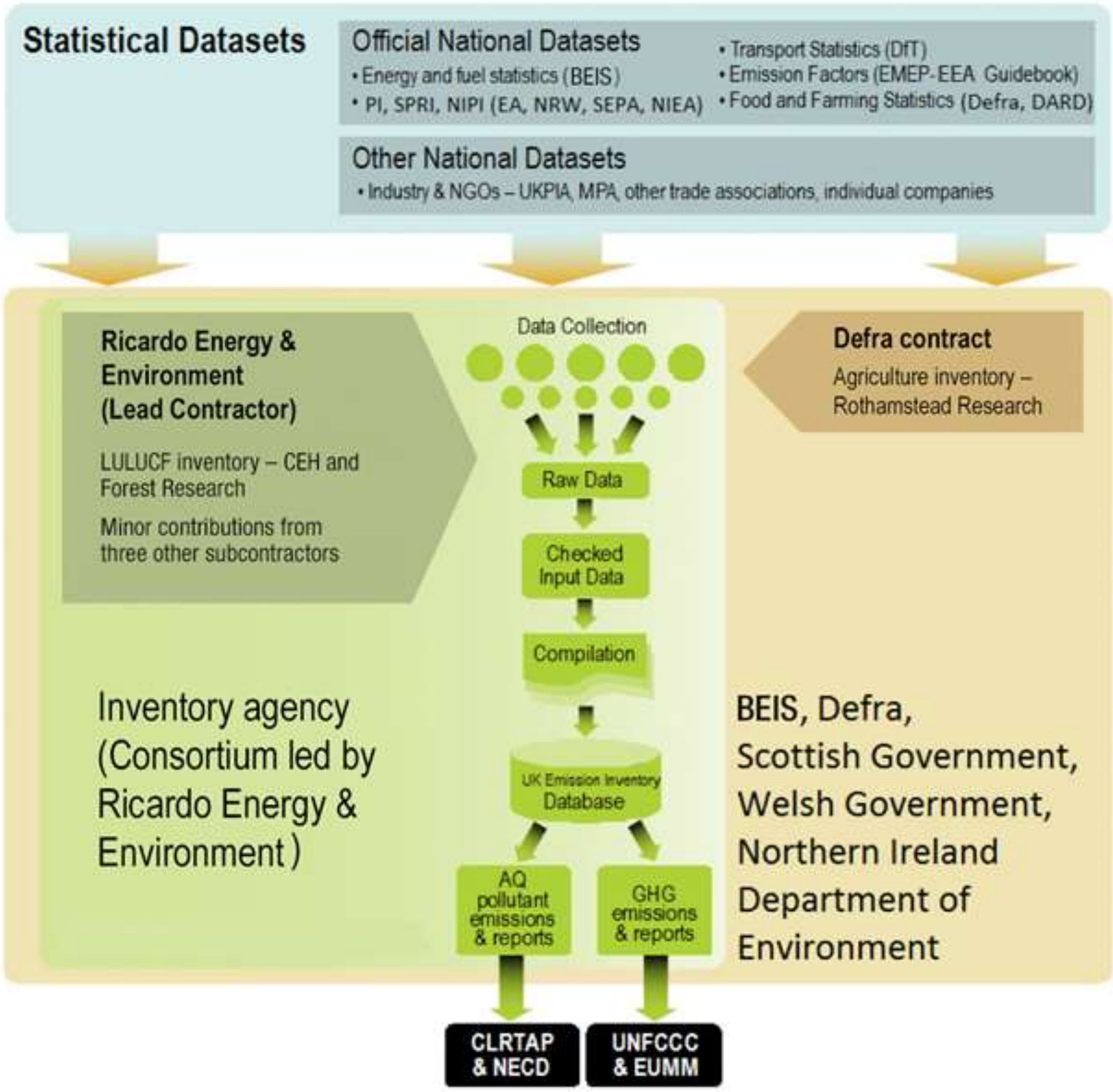
The UK emission inventories are compiled and maintained by the National Atmospheric Emissions Inventory (NAEI) team, led by Ricardo Energy & Environment (the Inventory Agency).

Rothamsted Research compiles emissions of air quality pollutants and GHGs from agricultural emission sources under a separate contract to Defra. Rothamsted Research provides the agriculture inventory data to Ricardo Energy & Environment for inclusion within the UK inventory submissions.

An overview of the organisational structures, roles and responsibilities within the NAEI work programme 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.
Key Data Providers to the NAEI work programme include:

- Government departments, such as BEIS and Department for Transport (DfT);
- Devolved Governments of Scotland, Wales and Northern Ireland
- Non-departmental public bodies such as the Environment Agency (EA), Natural Resources Wales (NRW), the Scottish Environment Protection Agency (SEPA), the Northern Ireland Environment Agency (NIEA), the Office of National Statistics (ONS)
- Other Inventory Agency partners and contractors including the Centre for Ecology and Hydrology (CEH) and Rothamsted Research;
- Private companies such as Tata Steel, BP Chemicals, gas network operators, water companies; and
- Business organisations such as UK Petroleum Industry Association (UKPIA), the Mineral Products Association (MPA), the Iron and Steel Statistics Bureau (ISSB) and Oil & Gas UK.

Figure 1-1 Overview of the Roles within the Inventory Programme



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 & Planning

- Overall control of the inventory programme development & function;
- Procurement and management of contracts which deliver and report emissions inventories;

Development of Legal & Contractual Infrastructure

- Review and evolution of legal & organisational structure;
- Implementation of legal instruments and contractual developments as required, to meet guidelines.

1.2.2 Ricardo Energy & Environment

As the UK's Inventory Agency, the NAEI team, led by Ricardo Energy & Environment, 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 BEIS to compile and deliver the emission inventories 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 & identification of developments required to improve the inventory data quality.

Management

- Documentation & secure archiving of data and relevant information;
- Dissemination of information to inventory 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 emission inventory 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 Energy & Environment 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 Rothamsted Research, 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 official national statistics. 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, giving 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 Warehouse: -** 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.

- **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/data/gis-mapping.

- **Reports: -** The most recent reports compiled by the inventory team, covering a range of topics and tasks undertaken as part of the NAEI programme, are made available in electronic format.

- **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 web-pages 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 sites can be found at:

http://uk-air.defra.gov.uk/

Information Archiving and Electronic Back-ups

The UK emissions inventory team also have the responsibility of maintaining an archive of reference material and previously conducted work. This archive is both in paper format (held on site at the Ricardo Energy & Environment office in Oxfordshire), and in electronic format.

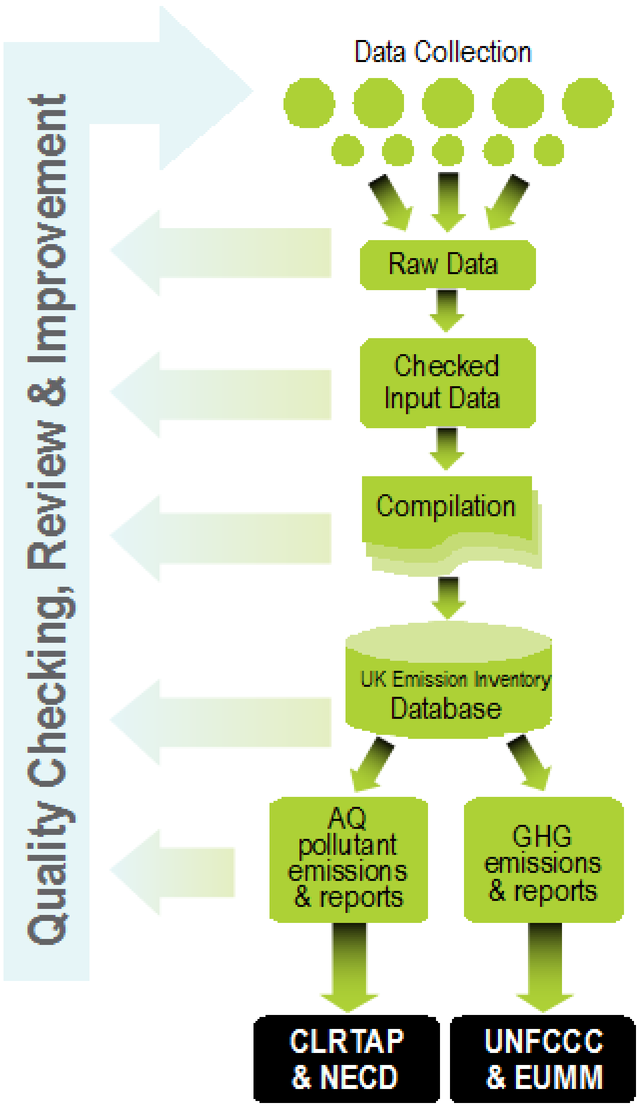
Electronic information is held on networked servers. This allows efficient access and maintains good version control. The data on the servers are mirrored to a second server situated at a different location to ensure data security, with incremental tape backups performed to maintain currency. The data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

1.3 Inventory Preparation

1.3.1 Introduction

Figure 1-2 shows the main elements of the UK emissions inventory 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

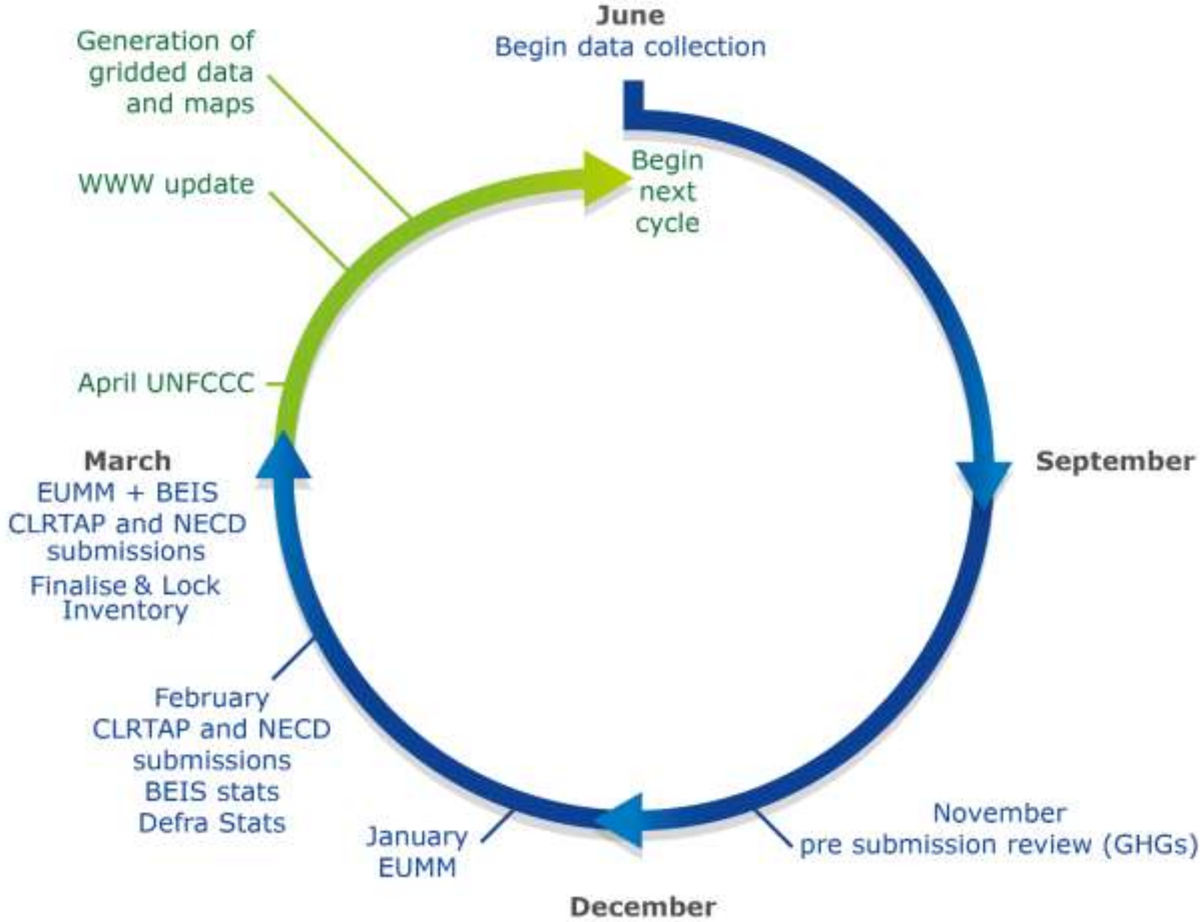
The activities outlined above in Figure 1-2 comprise the annual cycle of NAEI delivery from data acquisition, method selection and development through to reporting. Each year the latest data are added to the inventory and the whole time series is updated to take account of improved data and any advances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

- The full 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 inventory estimates for a given source are calculated using a consistent approach across the full time-series and the full scope of pollutants;
- All of the NAEI data are subject to an annual review, and findings of all internal & 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 UK inventory data are compiled and reported to meet all quality requirements and reporting timescales of the UNECE, other international fora and for UK and Devolved Government publications of inventory data.

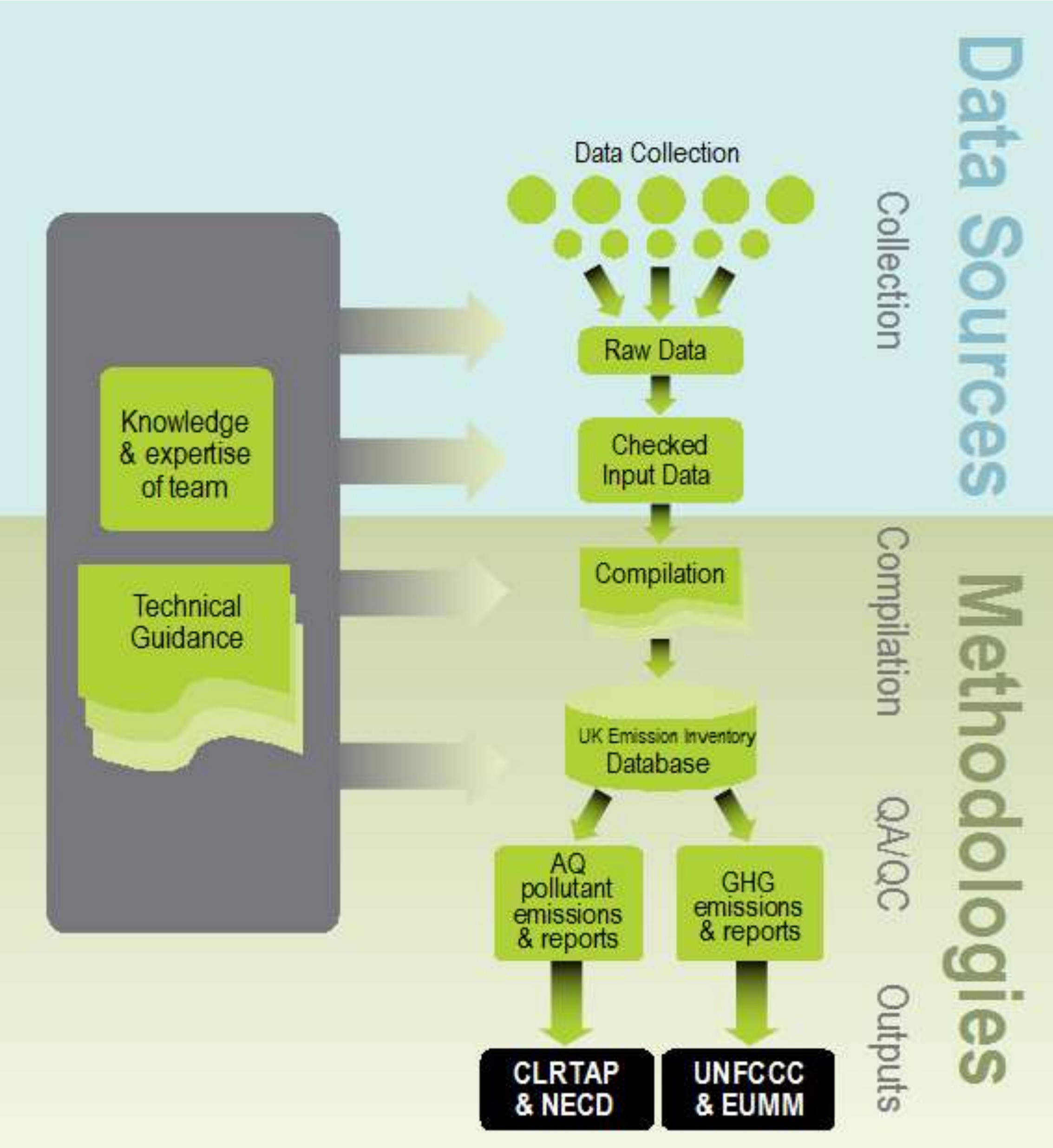
Figure 1-3 The Annual Inventory Cycle in the UK



1.3.3 The UK Inventory Compilation System

The compilation of the UK inventory 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 UK Inventory data flows



The compilation method can be summarised as follows:

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

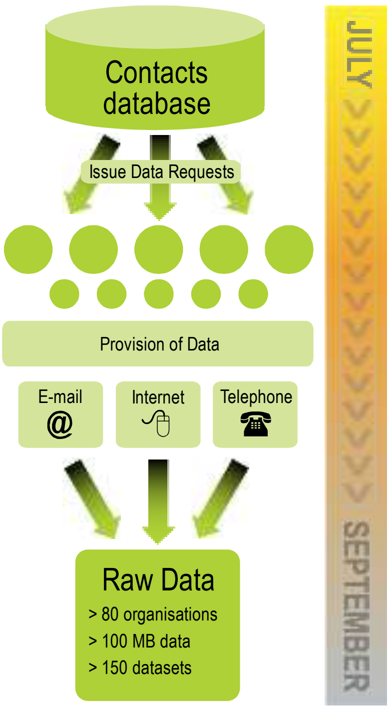
Each of these stages are explained in more detail in the following sections and the QA/QC programme that operates across the inventory programme is explained in Section 1.6. After finalisation, all different aspects of the compilation process are reviewed for improvement e.g. quality of the input data, 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 inventory cycle.

1.3.4 Stage 1: Data Collection

1.3.4.1 Data Management

Figure 1-5 describes the data collection process for core inventory compilation. Requests to data providers are made by letter, 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 inventory compilation



A wide variety of organisations provide data that is essential for the UK inventories to be compiled 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

Whilst there are legal provisions[12] in place in the UK to secure the data provision to the emissions inventory (via the GHG inventory), there is currently no obligation for organisations to provide data pertinent specifically to the air quality pollutant inventories. However, the key data providers to the emissions inventory are encouraged to undertake the following commitments relating to data quality, data formats, timeliness of provision and data security:

- Delivery of source data in appropriate format and in time for inventory 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 BEIS, the Inventory Agency and their peers / members to help to disseminate information.

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

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 for England;
- Natural Resources Wales's Pollution Inventory for Wales
- The Scottish Environment Protection Agency's European Pollution Emissions Register;
- The Northern Ireland Environment Agency's Inventory of Statutory Releases; and
- EU Emissions Trading System (*EU ETS data are provided by BEIS*).

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 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:

- BEIS Offshore Inspectorate provides data on activities and emissions from upstream oil and gas operators;
- DfT provides annual transport statistics for different modes of transport;
- The Ministry of Housing, Communities & Local Government (formerly the Department for Communities and Local Government) 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 UK inventory programme include:

- Rothamsted Research compiles the inventory for agricultural emissions using agricultural statistics from Defra and the Northern Ireland Department of Agriculture and Rural Development (DARDNI).

- The Centre of Ecology and Hydrology (CEH) compiles NH_3 emission estimates for sources in the natural and waste sectors, and provides information for mapping NH_3 emissions.

[12] Greenhouse Gas Emissions Trading System (Amendment) and National Emissions Inventory Regulations 2005, available at: http://www.opsi.gov.uk/si/si2005/20052903.htm

- Trade associations, statistical agencies and individual companies such as:
  - Tata Steel and British Steel
  - UK Petroleum Industries Association
  - Iron and Steel Statistics Bureau
  - Mineral Products Association
  - Civil Aviation Authority
  - British Geological Survey

Defra also funds research to provide emission estimates for certain sources. The results of all research thought to be of use are investigated to determine whether they can usefully contribute to the UK emissions inventory.

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.

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 the detailed installation-specific energy and emissions data from the EU Emissions Trading System and the England Pollution Inventory / Wales Pollution Inventory/ Scottish Pollutant Release Inventory / Northern Ireland Pollution Inventory into data that are in the correct units and format for use within the NAEI spreadsheet system.

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: Spreadsheet Compilation

Raw data are compiled into a series of data processing spreadsheets. These spreadsheets 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 spreadsheets 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 spreadsheets as detailed in Section 1.6. All data are ultimately transferred into the central NAEI database.

1.3.7 Stage 4: Database Population

A core 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 for revised emission factors and methods. The transfer of data to the database from the compilation spreadsheets is automated 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 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. This referencing identifies the underlying data and data sources as well as any assumptions required to generate the estimates.

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 NECD submissions, data for the relevant pollutants and years are extracted from the database in NFR14 format, with post-processing then conducted in a spreadsheet which is set-up to enable automated population of reporting forms. The NFR14 reporting templates are then populated automatically, and a number of manual amendments are then required before the data are thoroughly checked and submitted.

1.4 Methods and Data Sources

The UK emission inventories are compiled according to international good practice guidance for national inventories; for air quality pollutant inventories the inventory methodological guidance is the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016[13], whilst for Greenhouse Gas inventories the latest guidance is the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[14].

Each year the emission inventories are updated to include the latest data available and any new research to improve the emission estimation methods. Improvements to the inventory methodology are made and backdated to ensure a consistent time series for emissions reporting. 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 BEIS. Information on improvements and recalculations can be found throughout this report, in Chapters 3 to 7, which describe the methods used in the different source sectors.

This section provides an overview of the UK inventory 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 UK Inventory Data and Methods Overview

Overview information on primary data providers and methodologies has been included in the above sections. Table 1-8 indicates where UK-specific data are used in the emissions inventory, 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 inventory source within each NFR category.

Table 1-8 UK Emissions Inventory Compilation Methodologies by NFR14

NFR14 Category	Activity Data	Emission Factors
1A1a Public Electricity & Heat Production	UK statistics (DUKES), EU ETS	Operator reporting under IED/E-PRTR; default EFs (UK research, EMEP/EEA, USEPA)
1A1b Petroleum refining	UK statistics (DUKES), EU ETS	Operator reporting under IED/E-PRTR; default EFs (UK research, EMEP/EEA, USEPA)
1A1c Manufacture of Solid Fuels etc.	UK statistics (DUKES), EU ETS	Operator reporting under IED/E-PRTR and EEMS; default EFs (UK research, EMEP/EEA, USEPA)
1A2a Iron & Steel	UK statistics (DUKES), ISSB, EU ETS	Operator - Majority of EFs reported from Tata Steel and SSI Steel; several EFs from fuel analysis or default EFs (UK research, EMEP/EEA, USEPA)
1A2b Non-ferrous Metals	UK statistics (DUKES), EU ETS	Fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research).
1A2c Chemicals	UK statistics (DUKES), EU ETS	Fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research); Operator reporting under IED/E-PRTR

[13] http://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook
[14] http://www.ipcc-nggip.iges.or.jp/public/2006gl

NFR14 Category	Activity Data	Emission Factors
1A2d Pulp, Paper & Print	UK statistics (DUKES)	Fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research).
1A2e Food Processing, Beverages & Tobacco	UK statistics (DUKES)	Fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research).
1A2f Non-metallic minerals	UK statistics (DUKES), EU ETS	Operator reporting under IED/E-PRTR; fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research).
1A2g Other	UK statistics (DUKES)	Fuel analysis or default EFs (USEPA, EMEP/EEA, UK-specific research).
1A3ai(i) International Aviation (LTO)	UK statistics (CAA)	UK Literature sources
1A3aii(i) Civil Aviation (Domestic, LTO)	UK statistics (CAA)	UK Literature sources
1A3b Road Transportation	UK statistics (DfT)	Literature sources and UK factors
1A3c Railways	UK statistics (ORR) and estimated	UK factors
1A3di (ii) International inland waterways	NA	NA
1A3d ii 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)	UK factors
1A4b i Residential	UK statistics (DUKES)	Literature sources and UK factors
1A4b ii Household & gardening (mobile)	Estimated	Literature sources
1A4c i Agriculture/Forestry/Fishing: Stationary	UK statistics (DUKES)	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), EU ETS	Operator reporting under IED/E-PRTR, literature sources
1B1c Other	IE *(Emissions are reported under 1B1b)*	
1B2Oil & natural gas	UK statistics & Industry, EU ETS, EEMS.	Operator reporting under IED/E-PRTR and via EEMS, data from UKPIA, data from UK gas network operators and from BEIS
2 A Mineral Products	Industry & Estimated, EU ETS	USEPA factors for slag cement grinding; UK and literature factors for glass and brick/ceramics manufacture; EMEP/EEA Guidebook for construction and quarrying
2 B Chemical Industry	Industry & Estimated, EU ETS	Operator reporting under IED/E-PRTR and literature factors for some specialist chemical processes
2 C Metal Production	UK statistics & Industry, ISSB, EU ETS	Industry & Operator reporting under IED/E-PRTR; literature factors, including EMEP/EEA Guidebook for some processes
2 D Solvents	Industry	Mostly UK-specific emissions data from trade bodies, individual operators, and regulators. Some use of EMEP/EEA Guidebook factors for minor sources.
2 G Other product use	UK statistics	EMEP/EEA Guidebook
2 H Pulp and paper industry, Food and beverages industry	UK statistics & Industry	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.

NFR14 Category	Activity Data	Emission Factors
2 I Wood processing	UK statistics & Industry	Literature sources, EMEP/EEA Guidebook, and operator reporting under IED/E-PRTR.
2 J Production of POPs	NA	NA
2 K Consumption of POPs and heavy metals	Industry	Literature sources and UK-specific methods
2 L 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 under IED/E-PRTR & 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
1A3aii(ii) Civil Aviation (Domestic, Cruise)	UK statistics (CAA)	UK Literature sources
1A3ai(ii) International Aviation (Cruise)	UK statistics (CAA)	UK Literature sources
1A3di(i) International maritime Navigation	UK statistics and sector research (Entec, 2010)	Literature sources and UK factors
6B Other (Memo)	UK statistics	UK factors
11 Other (Memo)	Estimated	UK factors

The terms used to summarise the data and methods in the table 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 Iron and Steel Statistics Bureau (ISSB), the UK Minerals Yearbook provided by the British Geological Survey (BGS), energy use data from the EU Emissions Trading System (EU ETS).
- **Industry**: Process operators or trade associations provide activity data directly, for example from the UK Petroleum Industries Association (UKPIA), the Mineral Products Association (MPA), the British Coatings Federation.
- **Estimated**: Activity data have been estimated by the Inventory Agency (or other external organisations). This approach is necessary where UK statistics are not available or are available only for a limited number of years or sites. The estimates are based on 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.

- **Estimated**: Emissions have been estimated by the Inventory Agency, based on parameters such as: plant design and abatement systems, reported solvent use, plant-specific operational 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 EMEP/EEA Guidebook 2016, the USEPA AP-42 and IPCC Guidelines or Good Practice Guide (GPG). Other useful resources are sector-specific operator reporting guidance such as BREF notes produced by the EU IPPC bureau, or the API Compendium for oil and gas emission estimates.

The specific emission factors used in the calculation for all sources and pollutants for the latest inventory are available at the data warehouse of the NAEI website: http://naei.beis.gov.uk/data/ef-all

1.4.2 National Energy Statistics

BEIS provides the majority of the energy statistics required for compilation of the NAEI and the GHGI. These statistics are obtained from the BEIS publication – *The Digest of UK Energy Statistics* (DUKES) – 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.

DUKES is available at:
https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

The BEIS 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, BEIS 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. BEIS also uses an energy balance approach to verify that individual returns are sensible. Any queries are followed up with the reporting companies. BEIS depends 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 UK inventory may not exactly match the fuel consumption figures given in DUKES and other national statistics. This occurs for one of four reasons:

1) Data in DUKES and other national statistics are not always available to the level of detail required for inventory reporting. *For example, activity data within DUKES do 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 UK inventory.*
2) Data in DUKES other national 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 EU Emissions Trading System provides more accurate fuel use data for several high-emitting industrial sectors, which is used in preference to DUKES data.*
3) DUKES and other national 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.*
4) Where the BEIS DUKES team make improvements to national energy statistics, they typically do not revise the whole time series of data; usually the DUKES data is 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

BEIS energy statistics team to derive a defensible historic time series back to at least 1990 for use in the UK inventory. *For example, residential wood use in 1990-2012 has been estimated by the Inventory Agency in light of new research that led to significantly higher estimates derived for 2008 onwards, within DUKES 2015, which was subsequently revised further for 2013 onwards in DUKES 2016, with minor revisions also then applied in DUKES 2017.*

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 is most significant in the case of gas oil and fuel oil, especially for fuel use in the shipping sector. This fuel is used in off-road machinery engines (e.g. agricultural and construction machinery), railway locomotives, marine engines, stationary engines and other stationary combustion plants 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 plant 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, 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.

Other fuels with significant 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 EU Emissions Trading System (EU ETS). These EU ETS data undergo third party verification as part of the EU 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 EU ETS data provides complete coverage of fuel use within a specific economic sector, the EU ETS data by installation are aggregated and applied within the UK inventory.
- 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 EUETS 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 own gas use by these installations based on oil and gas production data from the BEIS energy statistics 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 EU ETS;

- Residential wood use in 1990-2012 has been estimated by the Inventory Agency in light of new research that led to significantly higher estimates derived for 2008 onwards, within DUKES 2015, which was subsequently revised further for 2013 onwards in DUKES 2016 and DUKES 2017. Given the significance of this source for emissions in the UK of particulate matter and other air quality pollutants, a revised historic time series for this fuel use has been estimated. However, this estimation has itself been based on more up-to-date information that is already included in DUKES from 2013 onwards.
- Estimates for the consumption of petroleum coke in various energy and non-energy applications are made based on EU ETS and other data, In the years 1990-1991, 1999, 2001 and 2005-2007, 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, and 2010) 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 AQ pollutants.
- A new methodology for estimating emissions from national navigation has been developed and adopted by the inventory for the first time 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. BEIS have acknowledged that the allocation of fuel to national navigation in DUKES is highly 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 separate from international navigation consistent with the definition of domestic navigation in the EMEP/EEA Emissions Inventory Guidebook (2016) and IPCC (2016) GHG inventory guidelines. It is suggested that a reason for the higher allocation of fuel to national navigation derived by the bottom-up approach in comparison to what appears in DUKES is due to some fuel used by ships undertaking UK domestic movements being sourced from overseas. BEIS have 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.

1.4.3 Industrial Process Emissions Data

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

The Environment Agency, Natural Resources Wales - Pollution Inventory
The Environment Agency and Natural Resources Wales compile a Pollution Inventory (PI) of emissions from around 2,000 major point sources in England and Wales. This requires the extensive compilation of data from a large number of different source sectors. This valuable source of information is incorporated into the inventory wherever possible, as either emissions data, or surrogate data for particular source sectors. The information held in the PI is 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 PI allows access to air emissions through postcode interrogation with a map facility on the Environment Agency website:

https://www.gov.uk/check-local-environmental-data

The Scottish Environment Protection Agency – SPRI Inventory
The Scottish Environment Protection Agency (SEPA) compiles an emissions inventory for emissions reporting under the Industrial Emissions Directive (IED) 2010/75/EU and the European Pollutant Release and Transfer Register (E-PRTR). The reporting of emissions is required for all activities listed in Annex I of the IED. 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 data from the EA and NRW Pollution Inventory, 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 E-PRTR and 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.

1.4.4 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 UK inventory 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 1.1.1) 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;
- EU ETS data;
- emissions data given in the PI/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 UK inventory improvement plan is constantly under review by Defra and BEIS, 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 1-9 provides an overview of the most important sources for selected pollutants, for the year 2016, reported under the CLRTAP in the 2018 inventory submission. Key sources are those which, when summed up in descending order of magnitude, cumulatively add up to 80 % of the total level, as per reporting guidance[15]. Due to rounding, the sum of the % emissions by row may not equal the value given in the “Total (%)” column in Table 1-9.

For NO_x (as NO_2), the dominant source is 1A3b Road transport (including cars, light and heavy duty vehicles and buses) contributing collectively 35% of emissions. Six of the seven key sources for NH_3 are from the agriculture sector, with 21% of the emissions from livestock manures applied to soils. The largest source of NMVOC emissions is from the use of domestic solvents including fungicides. 1A4bi (residential stationary combustion) remains as the dominant source of Cd, CO, PM_{10}, $PM_{2.5}$, PAH, and PCDD/PCDF emissions. 1A4bi and 1A1a (electricity and heat production) are the dominant sources of SO_x (as SO_2), emissions, although this should be viewed against a significantly reduced national total over the time series. TSP is now dominated by 2A5b (construction) instead of 1A4bi, as was the case for 2015, due to revisions to the methodology used for calculating emissions from construction sources (detailed in section 4.4).

Sinter production in the iron and steel production sector is the dominant source for Pb emissions in 2016. There are only two key source categories for HCBs, which are from public electricity and heat production and the use of pesticides in the agriculture sector.

[15] http://www.ceip.at/fileadmin/inhalte/emep/pdf/2014/Methodology_Report_2014_final.pdf

Table 1-9 Key NFR14 Sources of Air Quality Pollutants in the UK in 2016 (that together contribute at least 80% to the pollutant emissions totals). 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 (%)
SO_x	1A4bi 22%	1A1a 21%	1A1b 15%	1A2gviii 10%	1A3dii 7%	1A2a 5%	2A6 3%									82.9
NO_x	1A3bi 17%	1A1a 14%	1A3bii 12%	1A3dii 10%	1A2gviii 7%	1A3biii 6%	1A1c 6%	1A3c 4%	1A4bi 4%	1A2gvii 3%						82.6
NH_3	3Da2a 21%	3Da1 19%	3B1b 13%	3B1a 12%	3Da3 6%	3B3 5%	6A 5%									81.2
NMVOC	2D3a 18%	2H2 12%	2D3d 10%	2D3i 8%	3B1b 6%	1A4bi 5%	1B2ai 4%	1B2c 3%	1B2b 3%	3B1a 3%	1B2av 3%	1B2aiv 3%	1A2gvii 2%	1A3bv 2%		81.0
CO	1A4bi 27%	1A3bi 15%	1A2gvii 15%	1A2a 7%	2C1 5%	1A4bii 5%	1A2gviii 4%	1A1a 3%	1A3dii 3%							82.3
TSP	2A5b 46%	1A4bi 12%	2A5a 5%	1A3bvi 4%	1A2gviii 4%	1A3bvii 3%	3Dc 3%	2C1 2%	2D3d 2%							81.0
PM_{10}	1A4bi 26%	2A5b 14%	1A2gviii 8%	1A3bvi 6%	2A5a 6%	2D3d 4%	1A3bvii 3%	3Dc 3%	2C1 3%	1A1a 2%	1A3bi 2%	1A2gvii 2%	1A3dii 1%	3B4giv 1%	3B4gii 1%	81.1
$PM_{2.5}$	1A4bi 40%	1A2gviii 12%	1A3bvi 5%	1A3bi 3%	1A2gvii 3%	1A3bvii 3%	2D3d 3%	2C1 3%	1A1a 3%	2A5b 2%	1A3dii 2%	5E 2%	1A3bii 2%			80.5
Pb	2C1 31%	1A2gviii 15%	2G 13%	2B10a 7%	1A4bi 7%	2C7c 5%	2I 5%									82.4
Hg	1A1a 22%	5C1bv 15%	1A2gviii 10%	2C1 9%	5A 9%	2C7c 5%	1A4bi 5%	1A2f 4%	1A3bi 4%							83.0
Cd	1A4bi 29%	1A2gviii 26%	2C1 12%	1A3bi 6%	2G 5%	1A1a 5%										83.2
PCDD/F	1A4bi 34%	2C1 13%	5E 13%	1A2gviii 11%	5C2 8%	5C1bv 6%										85.6
PAH	1A4bi 86%															85.9
HCB	1A1a 68%	3Df 29%														97.6

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 EMEP/EEA Emissions Inventory Guidebook (GB), 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 Energy & Environment (the Inventory Agency) is fully certified to BS EN ISO 9001:2008 (see Box 1 below). This certification provides assurance that through application of the ISO 9001 standard by Ricardo Energy & Environment, we will continue to ensure a consistent quality approach across all aspects of the inventory project. We will also conform to good practice in project management.

Box 1: BS EN ISO 9001:2008:
In addition to the UK's own AQPI specific QA/QC system, through Ricardo Energy & Environment, the Inventory has been subject to ISO 9000 since 1994 and is now subject to BS EN ISO 9001:2008. It is audited by Lloyds Register Quality Assurance (LRQA) and the Ricardo Energy & Environment internal QA auditors. The NAEI has been audited favourably by LRQA on five occasions in the last 14 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 Energy & Environment is currently accredited to BS EN ISO 9001:2008. Lloyds Register Quality Assurance carried out a three-yearly recertification audit of Ricardo Energy & Environment which was completed in September 2017. Ricardo Energy & Environment successfully passed the recertification, with zero major non-compliances, and a new Ricardo group certificate was issued in December 2017. Under the Ricardo group certification Ricardo Energy & Environment is currently certificated both for the Quality Assurance ISO 9001:2008 and Environmental Management System ISO 14001 standard.

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

- There is an Inventory Agency (consortium managed by Ricardo Energy & Environment)
- 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 UK inventory 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 3 to 7 of this report.

1.6.1 Description of the current Inventory QA/QC system

The National Atmospheric Emissions Inventory and the UK Greenhouse Gas Inventory are compiled and maintained together by Ricardo Energy & Environment (the Inventory Agency), on behalf of the UK Department for Business, Energy & Industrial Strategy (BEIS) and the Department for Food and Rural Affairs (Defra).

Most of the data received by the Inventory Agency for the UK inventory compilation come from other government departments, agencies, research establishments or consultants working on behalf of UK government or for trade associations. Several of the organisations (e.g. BEIS, the Office of National Statistics and British Geological Survey) qualify as the UK's National Statistical Agencies referred to in IPCC Guidance and abide by strict statistical QA/QC standards. Other organisations (e.g. the Environment Agency, providing regulated point source data) supply important datasets for the Inventory and have their own comprehensive QA/QC systems. The data compilation for some source sectors of the UK inventory is performed by other contractors (i.e. Rothamsted Research compile the inventory for the agriculture sector). The Inventory Agency takes the scope and priorities of the QA/QC systems of upstream organisations into account when designing and implementing inventory-wide QA/QC activities. For example, the statistical protocols for UK agencies in some cases limit recalculations in national datasets to the latest 3 or 5 years, or the quality control of reported emissions data by environmental regulators may focus resources towards specific pollutants or emission sources. The Inventory Agency consults with the data provider organisations in order to ensure that inventory time series consistency and QC across sources and pollutants is maintained, and feeds back findings from inventory compilation QC to the source organisations in order to support future QA/QC improvements in those upstream agencies.
Whilst these organisations have their own QA/QC systems, Ricardo Energy & Environment is responsible for co-ordinating inventory-wide QA/QC activities relating to the submitted datasets. In addition, Ricardo Energy & Environment is working continuously with organisations supplying data to the NAEI to encourage them to demonstrate their own levels of QA/QC that comply with either 2006 IPCC Guidelines or the UK's National Statistics standards.

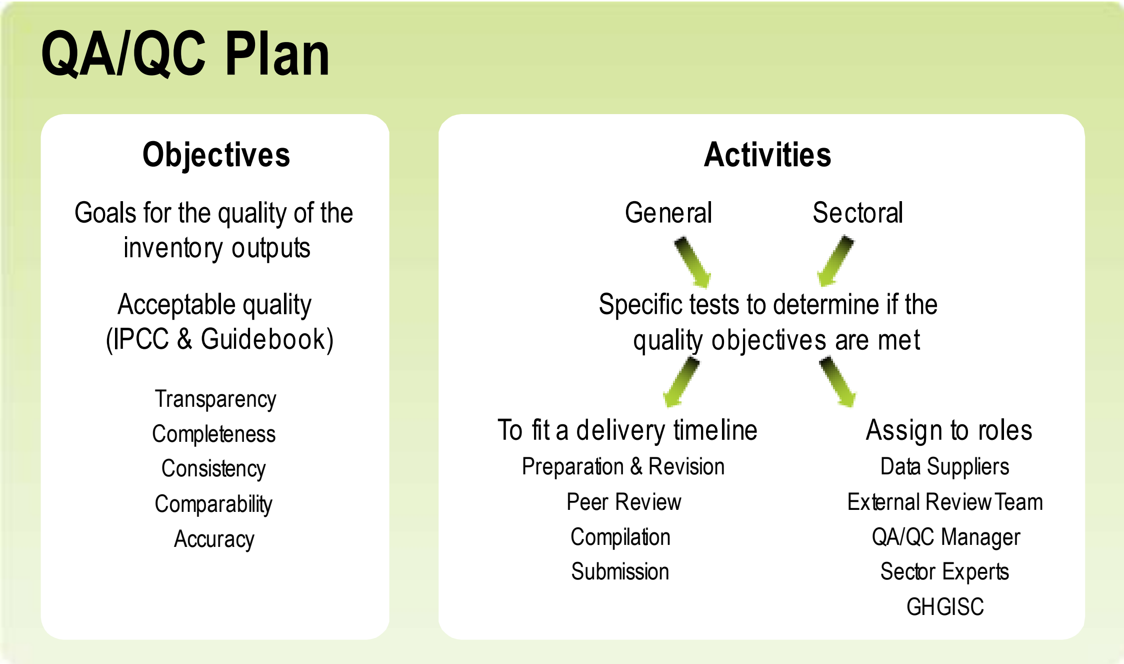
The UK inventory QA/QC system encompasses a wide range of activities to cover:

- planning tasks, including: *review of historic data and methods, identification of improvement priorities, data and method selection, 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, 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, emission factor checks*; and,
- QA review tasks, including: *pre-submission reviews, post-submission reviews, peer reviews, bilateral reviews, expert reviews*.

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

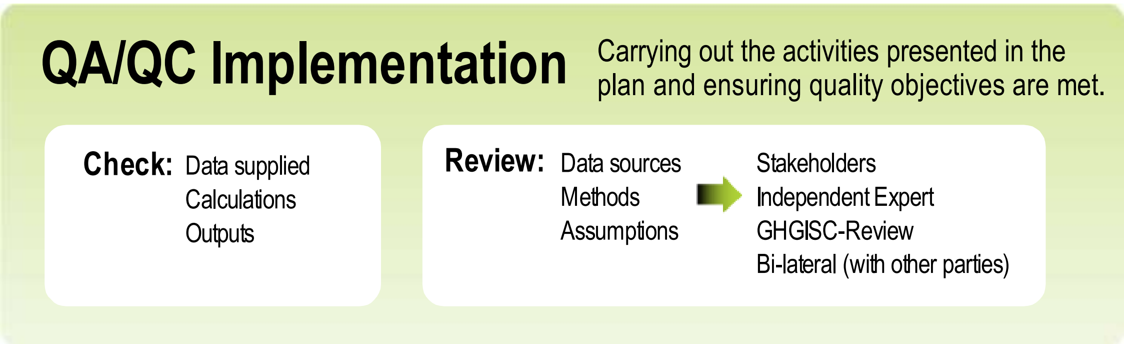
1. A QA/QC Plan is maintained by the Inventory Agency's QA/QC manager and defines the specific Quality Objectives and QA/QC activities required in undertaking the compilation and reporting of the inventory estimates. The plan sets out source-specific and general (cross-cutting) activities to ensure that quality objectives are met within the required inventory reporting time-frame. 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



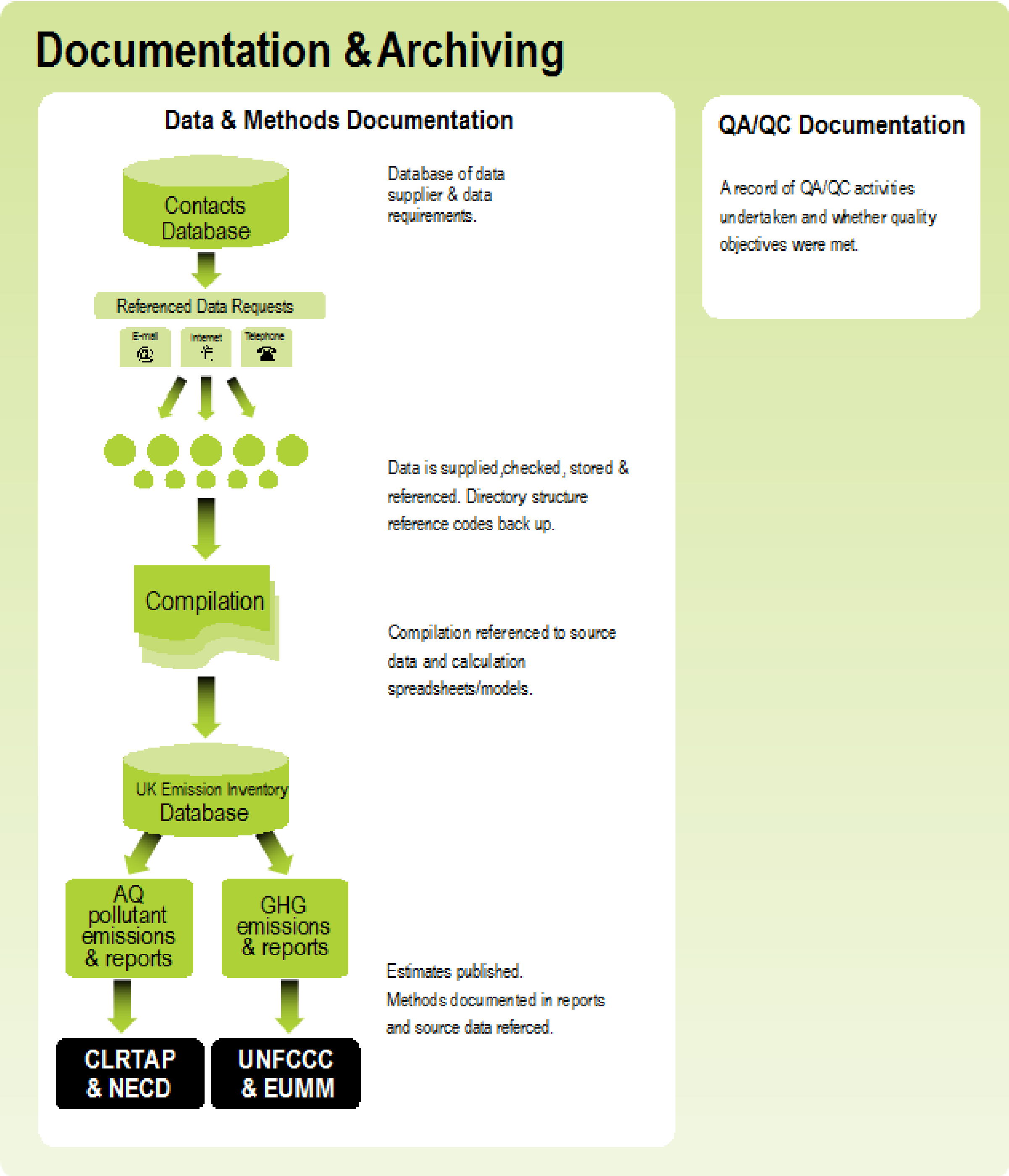
2. QA/QC implementation includes the physical undertaking of the QA/QC activities throughout the data gathering, compilation and reporting phases of the annual emission estimation cycle and in accordance with the QA/QC plan, and as agreed with Defra. A number of systems and tools for QA/QC implementation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

Figure 1-7 QA/QC Implementation



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 (NIR) and Air Quality Pollutants (IIR) 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



Improvements made to the UK inventory QAQC system for the 2018 submission include:

- Development of improved pollutant-specific checking templates that facilitate a more consistent checking procedure for the inventories for GHGs and air quality pollutants, and to collect information on recalculations and reported trends in a more systematic, prioritised way;
- Further improvements to inventory model design to ensure consistent and transparent documentation of model compilation, QC, version control, providing supporting guidance to the inventory compilation team, including the development of an NAEI overview document and greater use of graphical visualisation of data time series to identify outliers;
- Model upgrades for a number of inventory models, to re-build and test inventory models against UK Government QA guidelines, primarily focusing on inventory models that generate the time series of activity data for key UK fuels;

- Consolidation of a range of models used to derive emission factors on a mass basis (as used in the UK inventory database) from various data sources (often presenting factors on an energy basis), in order to ensure a more consistent approach to the selection of default factors and their conversion from energy to mass units. Aggregating these models into one common database has reduced the risk of inconsistent assumptions being applied (e.g. selection of the most appropriate default factor from reference sources) or of errors in conversion calculations;

1.6.2 Quality Objectives

The key objectives of the QA/QC plan are to ensure that the estimates in the GHG and air pollutant inventories are of a suitably high quality and will meet the methodological and reporting requirements for UK submissions to the UNECE, UNFCCC and EU, as set out within national inventory reporting guidance from the Intergovernmental Panel on Climate Change (IPCC)[16] and European Environment Agency (EEA)[17]. 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 EU wide assumptions (e.g. source category detail and the split between EU ETS and non EU ETS sources, implementation of policies and measures, carbon contents of fuels, site specific estimates, national 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, gases 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 EU ETS and non EU ETS sources, scenarios, units for parameters and of input parameters with EU 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 EU wide assumptions.

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

The inventory QA/QC system also reflects that quality is one of three often competing attributes for a given project scope. These are quality (for which comprehensive QA/QC is crucial), 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

[16] 2006 IPCC Guidelines for National Greenhouse Gas Inventories: http://www.ipcc-nggip.iges.or.jp/public/2006gl/
[17] EMEP/EEA air pollutant emission inventory guidebook – 2016: http://www.eea.europa.eu/publications/emep-eea-guidebook-2016

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 inventory 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 UK inventory QA/QC plan:

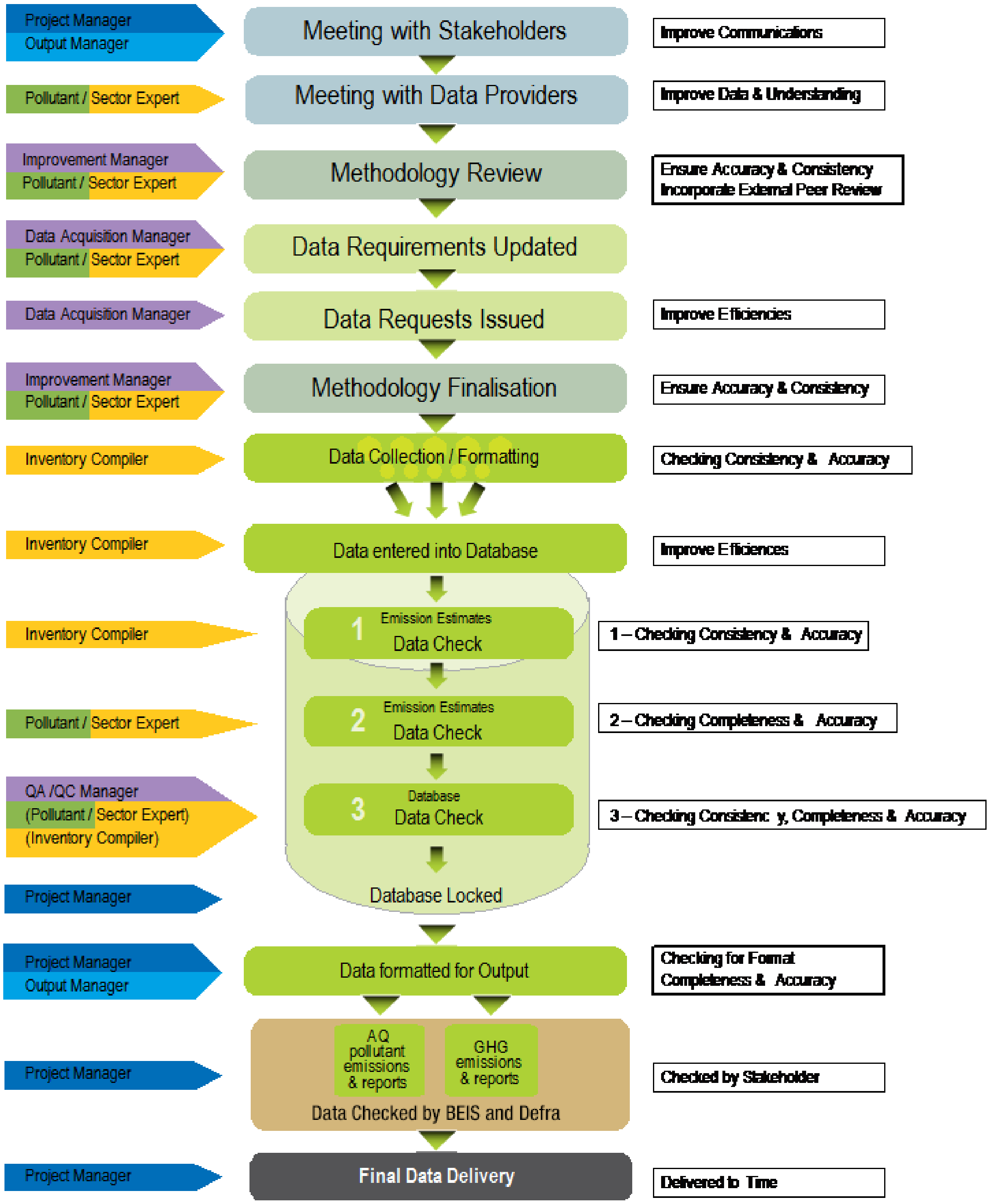
- **QA/QC Manager**: Co-ordinates all QA/QC activities and manages contributions from data suppliers, sector experts and independent experts and undertakes cross cutting QA/QC activities. Maintains the QA/QC plan, co-ordinates action across the team to: set quality objectives, communicate and implement QA/QC activities, 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 BEIS, 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 QAQC improvements by sharing best practice and engaging in team communication activities.
- **External Review Experts**: Provide expert/peer review of emission estimates / 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 Inventory Cycle

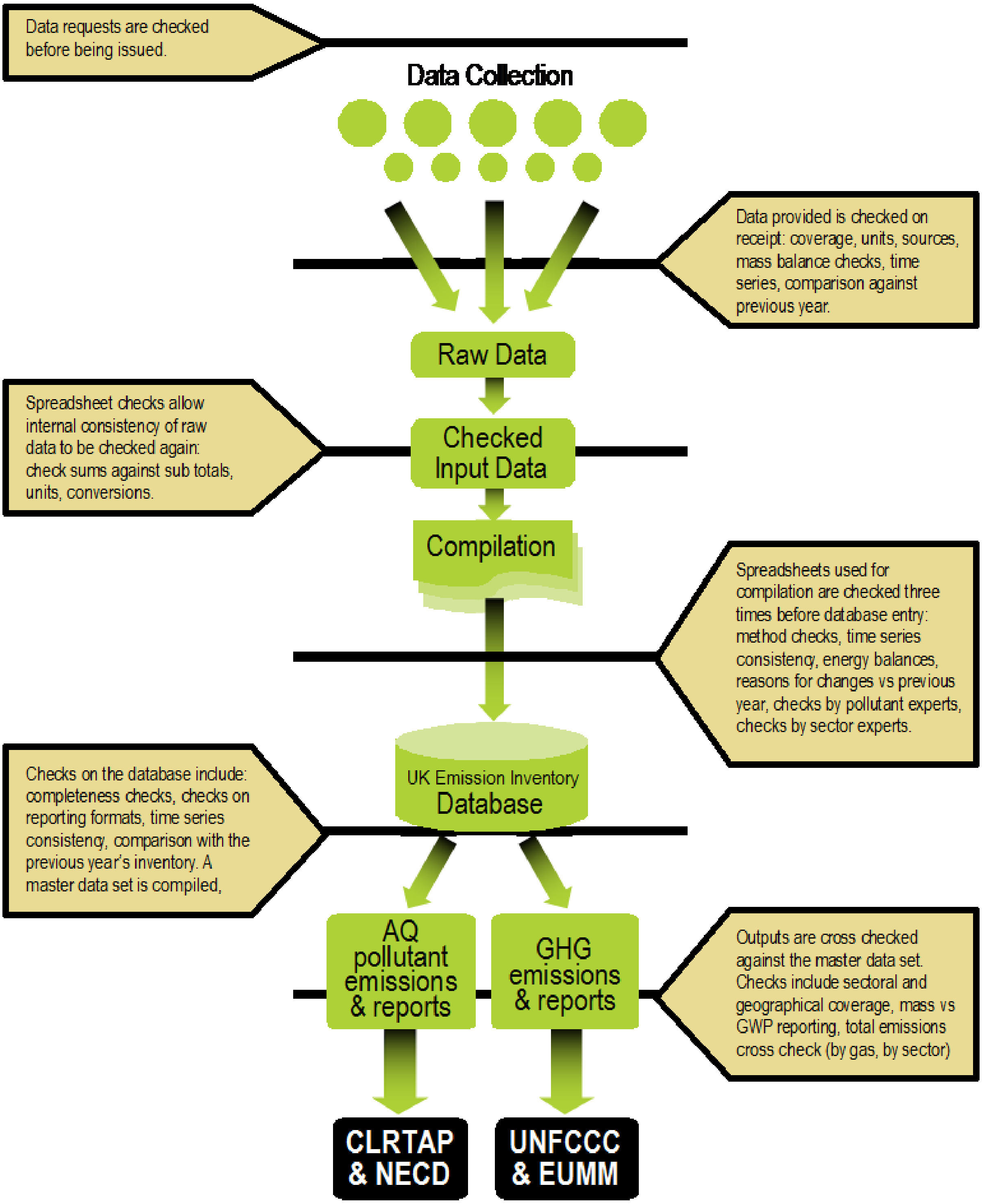


1.6.4.1 Quality Control and Documentation

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 UK inventory compilation cycle. The horizontal bars 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 for recent 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 for recent 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 EU 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 National 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 significant 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 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 EMEP-EEA Guidebook) or for any missing emission sources compared to previous submissions; and EF sense-checks such as $PM_{10} > PM_{2.5}$.
7. **Reporting checks**. Inventory submissions are checked to ensure correct allocation into the NFR 2014-2 and CRF categories. Emission totals at national and sub-category level are checked against the "master" dataset derived from the UK inventory database outputs, to minimise risks of data transcription errors into reporting templates.

Figure 1-10 Quality checks throughout the UK inventory 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 (the "contacts database")**</u> 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. **Individual data processing tools** are used to prepare the majority of source data into suitable activity data and emission factors for UK emissions 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 emission factor checks for country specific emission factors, and implied emission factor 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. **A core database (NAEI database) of Activity Data and Emission Factors** 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 data source of emission/removal estimates used for reporting (including Common Reporting Format (CRF) 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 Emission Factor components for each estimate are held within the central database and include all sources, activities, gases/pollutants (AQPI and GHGI) and years. The majority of data in the database are imported directly from the individual data processing tools/spreadsheets (described above). ***Data 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/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***[18] are embedded within the database that support the annual QA activities defined in the QA/QC Plan and include:
   a. Checks with previous submissions for changes due to recalculations or errors at a detailed level, (A designated auditor identifies sources where there have been significant 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.
   c. Mass balance checks 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;
   d. Other activity data checks (e.g. production and consumption with official national statistics).
   e. Implied Emission Factor checks (assessing trends in IEF and comparison with previous submissions).
   f. A consistency check between NFR 2014-2 output and IPCC CRF formatted output.

[18] A full list is included in the QA/QC plan.

4. **Data extraction checking routines and procedures:** Data exported from the NAEI database and entered into reporting tools (e.g. the CRF Reporter tool and for Air Quality reporting into the UNECE reporting templates) are finally 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 significant 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 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, on line 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. An annual report outlining the methodology of the inventory and data sources is produced. 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.
    - The agriculture inventory (compiled by Rothamsted Research, North Wyke) is backed up on a daily basis on their network storage system. This system is mirrored with the Rothamsted Research Harpenden site, comprising an offsite backup.
    - At CEH, all data and information relating to the LULUCF inventory is stored on a networked drive (accessible only by the project team) which is backed up daily by CEH computer support. There is a separate folder for each inventory year and at the end of an inventory cycle the final versions of all datasets remain unchanged for back reference if required. In addition to this the model code used within CEH for inventory compilation is stored in a subversion repository to ensure a clear record of all amendments and iterations.

1.6.5 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 UK inventory 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.

1.6.5.1 External Peer Review

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, AQ modelling and research communities who use inventory data as part of their wider studies. 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 UK Government and Devolved Administrations' 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 is able to give feedback comments, advice and any issues associated with the use of AQPI data to the inventory team.

1.6.5.2 Bilateral reviews

The UK also undertakes bilateral and external peer reviews that are managed as part of the UK inventory improvement programme. Bilateral reviews are initiated with other countries as a means to learn from good practice of other countries as well as to provide independent expertise to review estimates. The UK has participated in a number of bilateral exchanges and the current contract makes allowances for biennial bilateral reviews (see Table 1-10).

Table 1-10 Summary of Recent Inventory Reviews

Review description	Summary
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, and review findings are considered for action within the UK inventory improvement programme.
2017: National Emission Ceilings Directive (NECD) review	In-depth review of the UK AQPI inventory under the EU NECD conducted by an expert team on behalf of the European Commission, focussing on SO_x, NO_x, NMVOC, NH_3 and $PM_{2.5}$ for the years 2005, 2010 and 2015 Recommendations made in this recent review will be considered in future in the UK inventory improvement programme.
2016: Stage 3 UNECE Review	In depth review of the UK AQPI inventory submitted under the UNECE LTRAP Convention and EU National Emissions Ceilings Directive. The review was coordinated by the EMEP emission centre CEIP acting as review secretariat. This review has concentrated on SO_2, NO_x, NMVOC, NH_3 plus PM_{10} and $PM_{2.5}$ for the time series years 1990-2014 reflecting current priorities from the EMEP Steering Body and the Task Force on Emission Inventories and Projections (TFEIP). Heavy metals and POPs have been reviewed to the extent possible. Recommendations made in the Stage 3 review were considered in the UK inventory 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 have fed into the UK inventory improvement programme.

Review description	Summary
2015: Multi-lateral review on QAQC.	Hosted by Germany and including QA experts from UK, Denmark, France and the Netherlands, the review compared Member State approaches to QAQC, 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 GLs 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. Reviews highlight reporting issues of transparency, completeness, consistency, comparability or accuracy that need to be resolved by the UK. *These reviews are focussed on the GHG inventory rather than the AQPI inventory, but nevertheless identify areas for improvement that apply across all of the UK inventory 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 fed into the UK inventory 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 over estimate. 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.

1.6.5.3 Stakeholder Consultation and User Feedback

The Inventory Agency consults with a wide range of stakeholders in order to ensure that the UK inventory 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 Business, Energy & Industrial Strategy (BEIS)

- The Inventory Agency met with the BEIS energy statistics team that produces the Digest of UK Energy Statistics to discuss what changes (to both activity and methodology) were expected in the 2017 publication of the statistics, and to clarify some outstanding queries. Subsequently, improvements to the inventory activity data were identified and implemented for the 2018 submission, including:
  - Derivation of a consistent time series of activity data for wood use in the residential and industrial sectors; the BEIS team made minor revisions to the assumed calorific values for wood used as a fuel in different sectors of the UK economy which led to minor modifications to the reported mass-based time series used in the inventory. This follows on from a major update to this data set made by BEIS in 2016 and reported in the IIR for the 2017 submission;
  - Improved understanding of the scope of reported data within the UK energy statistics on renewables, biomass/biofuels and fossil and bio-carbon sources in waste-derived fuels. This has led to several revisions in the assumptions applied to generate emission estimates, including to improve the activity data used in the inventory for waste-derived fuels in the generation of heat;
  - Improved understanding of the data sources and uncertainties associated with the DUKES data for shipping and bunker fuels, leading to the use of new "bottom-up" analysis to inform fuel use and emission estimates from national navigation, and retention of the DUKES data for international bunker fuels.
- Consultation with the BEIS Offshore Inspectorate to request clarifications on the scope and completeness of EEMS reported data for several individual installations, to ensure correct interpretation of the available data. The Inventory Agency met with BEIS O-I in 2017 also to revisit whether there may be a scope to generate estimates of fugitive emissions from oil and gas well blow-outs that are not currently included in inventory estimates; there are still no data available to generate any such estimates, however.

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 emission factor 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, notably for NMVOCs and methane from onshore oil and gas installations where consultation has identified incorrect data reported by plant operators, leading to improvements in the inventory time series
- As in previous years, we have contacted environmental regulators to clarify discrepancies between data reported in the Pollution Inventory (PI), EU ETS and other data sources, including working through PI/SPRI data clarifications for this submission. Through consultation with regulators, the Inventory Agency has been able to access supplementary data to provide a more complete understanding of activity data and emissions where operators are allowed by UK regulators to apply the "fall-back" approach to EU ETS reporting.

Other data providers

- Consultation with steelworks operators to check on data reporting discrepancies identified by the Inventory Agency on receipt of new annual data, and to access more detailed data (by sub-source) for integrated steelworks during 2013-2015, leading to improvements in allocation of emissions between sub-sources in integrated steelworks across 1A1c, 1B1b, 1A2a and 2C1.
- Consultation with UKPIA, the refinery operators' trade association, to clarify the scope and basis of the refinery sector emissions. Also, to seek better understanding of the refinery and fuel supply infrastructure and market as part of research to assess options for a potential UK sampling strategy to gather new data to update estimates of carbon content of refined petroleum fuels.

- Consultation with the Coal Merchants Federation and three major UK fuel suppliers: CPL, Celtic Energy and Hargreaves Fuels, to seek any new data on fuel sales, fuel composition and type, and the main sectors into which they sell their products.
- Consultation with a series of trade associations and individual companies in order to seek new data to inform inventory improvements primarily of NMVOC from solvents, including:
  - European Solvents Industry Group (ESIG): provided estimates of solvent use by REACH category, used to update UK estimates within 2D3a, 2D3e, 2D3g & 2D3i;
  - British Coatings Federation (BCF): provided sales data and estimates of coating consumption and solvent use emissions (and projections) for 2015 and 2020;
  - Cosmetics, Toiletries and Perfumery Association (CTPA): provided new data on UK consumption of non-aerosol consumer products;
  - Society of Motor Manufacturers & Traders (SMMT): confirmed that several sources (e.g. emissions from vehicle dewaxing and underseal treatment) do not occur in UK;
  - British Adhesives & Sealants Association (BASA): published sales statistics were provided to underpin UK estimates, but further work is needed to obtain more detailed data and insights into sector trends;
  - British Aerosol Manufacturers Association (BAMA): through consultation the Inventory Agency understands that new data collection is ongoing and may lead to an improvement in data for future inventory submissions. In this submission, several inventory method assumptions were confirmed or revised, leading to minor changes in UK emission estimates;
  - Numerous other individual companies were also approached for new data, including: Unilever, SC Johnson, Proctor and Gamble, Halfords, Eurobitume. However, no new data were forthcoming from these organisations in time for this inventory submission.

1.6.5.4 Verification

Defra has an ongoing air pollution mapping and dispersion modelling programme which compares emissions inventory data with ambient concentrations measured at an extensive network of air pollution sites. These activities compare emissions with ambient concentrations and deposition estimates and provide some independent verification activities for air quality pollutants. The UK's inventory programme has included 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. In recent years, the focus has been on road transport emissions where time-series trends in emissions or pollutant ratios have been compared with trends and ratios in roadside concentrations. These were used to highlight discrepancies in the trends for NO_x (as NO_2) emissions from road transport, suggesting problems with the emission factors used for recent Euro standard diesel cars. More recently, improvements in the emissions inventory for domestic wood burning including the spatial distribution of PM and benzo(a)pyrene emissions from these sources have been verified through Defra's Pollution Climate Mapping programme[19]. Comparisons in modelled concentrations of benzo(a)pyrene in urban areas have significantly improved since the inventory and maps of domestic solid fuel burning emissions were updated. A recent publication on the trends in ethane and propane concentrations in the UK measured from 1993-2012 through the Defra Hydrocarbon Monitoring Network has highlighted possible inconsistencies in the inventory of VOC and methane emissions from natural gas leakage (Derwent et al, 2017).

Further long-term research is carried out by universities funded through UK's research councils. This research also uses inventory information to interpret observations of air pollution concentrations measured at specific locations, sometimes close to sources, or from tall towers where urban flux measurements are made and compared with inventory data. A member of the Inventory Agency is represented on Defra's Air Quality Expert Group (AQEG) where there are opportunities to bring

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[19] https://uk-air.defra.gov.uk/data/modelling-data

important research findings and inventory information together and discussed in relation to important air quality policy issues.

The work of AQEG and other UK researchers (as noted above) helps to highlight important inventory verification issues and enables Defra and the Inventory Agency to identify and prioritise future research on emissions, measurements and inventory improvements.

1.6.5.5 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 BEIS for the GHGI. Improvements on activity data that improve both AQ and GHG emissions are jointly owned but led by one or other 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, EU projects, 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, expert participation in the European Topic Centre on Air and Climate Mitigation).
- 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 a number of specific consultations, bilateral reviews, research projects and analysis to improve the inventory estimates reporting for the NAEI. These include:

- **Shipping Study (2017).** The UK Government funded a major research project to develop a new shipping inventory to cover activity and emissions in UK ports and waters. The study team accessed new shipping movement data from Automatic Identification System (AIS) transponders that send signals from each ship within UK waters to the UK Marine Coastguard Agency. The analysis provided much more detailed, comprehensive information on shipping movements, estimates of utilisation of primary and secondary units on each ship (e.g. engines, boilers) and led to a large recalculation in the estimates of fuel use and emissions for the sector.
- **Solvents Study (2017).** A programme of consultation with a series of trade associations (such as the British Coatings Federation, British Aerosols Manufacturers Association, European Solvents Industry Group, Cosmetics, Toiletries and Perfumery Association, British Adhesives and Sealants Association) has provided new data that enabled the Inventory Agency to update several sector estimates for NMVOC emissions.
- **Biological treatment of waste (2016)**. This work involved a review of ammonia emission factors for anaerobic digestion, as well as a review of activity data for anaerobic digestion and Mechanical Biological Treatment (MBT).

- **Road transport emission factors for NO_x (2016)** were updated with the latest version of factors in the 2016 version of the EMEP/EEA Guidebook (2016) and also in consultation with the COPERT model development team at Emisia.
- **An annual programme of stakeholder consultation** with trade associations, process operators and regulators to resolve specific issues such as verification/updating of individual assumptions used in methodologies, gap filling etc. (see above).
- **Analysis of EU ETS data (every year)** to assess sector-specific fuel use and fuel quality, to compare and challenge the UK energy statistics, identifying potential gaps or inconsistencies in sector allocations, to resolve through dialogue with the BEIS energy statistics team.
- **Iron and Steel sector estimates (2014-15)**. Consultation with BEIS DUKES, ISSB and Tata Steel led to improved data access for detailed activity and emissions data from integrated steelworks and improved reconciliation of industry energy data against the UK energy balance in DUKES. The research has led to a number of activity data corrections and re-allocations, where the industry information helped to identify mis-allocations or gaps in the DUKES data. The research also enabled greater resolution of data reported through EU ETS, leading to improved understanding of fuel use and emissions within the individual sources across the integrated works. This has led to a number of minor revisions to source estimates alongside a large improvement in data quality through improved completeness, accuracy, time-series consistency and transparency.
- **NO_x and PM_{10} emissions from small regulated industrial processes and commercial plant (2015)**: Improvement of the methodology for PM_{10} and NO_x emissions from small-scale combustion processes including those in the commercial sectors, to use the EMEP-EEA Guidebook factors.
- **Review of emission factors for small combustion plant**, particularly for pollutants such as NO_x as NO_2, CO, PM_{10} & POPs.
- **NMVOC emissions from adhesives use and cleaning solvents (2015, ongoing):** Improvement of the methodology for estimation of NMVOC emissions from adhesives use and cleaning solvents, paying particular attention to improving the estimation of solvent abatement and providing more detailed sectoral breakdowns.
- **Feedstock vs combustion of Other Petroleum Gas (OPG) (2013, 2014, 2015):** The Inventory Agency consulted with the BEIS DUKES team, EU ETS regulators, site-specific regulatory contacts (Site Inspectors, Process Engineers), and directly with plant operators to assess the source and scale of the emissions. Through this research, new activity data for chemical and petrochemical industry use of OPG was estimated across the time series (reported under 1A2c). As in previous years, data discrepancies between DUKES and EU ETS for the refinery sector were noted and resolved through consultation with the BEIS DUKES team, EU ETS regulators and checked against data provided by the refinery sector trade association, UKPIA;
- **Coke oven coke, shipping fuel use and bunker definitions (2014):** Additional consultation with the BEIS DUKES team clarified data management within the UK energy statistics compilation system for coke oven coke, shipping fuel use and bunker definitions, to ensure correct use of DUKES data within the NAEI;
- **Onshore oil and gas terminals and offshore installations (2014, 2015):** Consultation with the BEIS Offshore Inspectorate, oil and gas sector contractors and individual site operators resolved data gaps and inconsistencies within reported emissions data for onshore oil and gas terminals and offshore installations. These resolved differences including discrepancies from the EU ETS and EEMS emission reporting systems;
- **Road traffic data (2014, 2015):** Specific consultation with the Department for Transport Traffic Statistics team has secured the provision of anonymised Automatic Number Plate Recognition data to compliment vehicle counts and potential new data on vehicle speeds;
- **Rail (2014)**: Consultation with the Department for Transport has secured improved data from their new Rail Emissions Model for updating the rail emissions inventory.
- **Wastewater treatment and sewage sludge treatment and disposal (2014, 2015):** Consultation with Defra and the water industry regulator (OFWAT), the Environment Agency and water and sewerage companies in the UK has led to improvements in activity data and emissions data provision for waste water treatment and sewage sludge treatment and disposal. The

Inventory Agency periodically meets with Carbon Managers from most of the UK water companies via the UK Water Industry Research forum and has procured activity and emissions data from more water companies to improve the completeness of estimates in the latest inventory.

- **Incineration and Landfill (2014, 2015):** Research with the EA and Defra has progressed our understanding of the data availability for landfill methane flaring and use in gas engines. Several research tasks in recent years have led to significant improvement in the UK data for landfill gas capture and utilisation from a wide range of landfill sites.
- **Natural gas distribution (2014, 2015):** Consultation with natural gas distribution network operating companies, BEIS and Energy UK to: (i) obtain new data on the estimated gas leakage from the transmission system to improve inventory transparency, (ii) a review of the time series of gas leakage through the distribution network, and (iii) to obtain data on actual (rather than weather-corrected) annual gas demand through all of the regional distribution networks, in order to improve the accuracy of the aggregated UK estimates for natural gas composition;
- **Limestone and dolomite use (2014):** Consultation with the Mineral Products Association, British Glass and the British Geological Survey to review data inconsistencies on national activity data for limestone and dolomite use, access sector-specific production statistics and therefore to derive improved activity data for several industry sectors;
- **Renewable energy consumption (including biomass) (2014, 2015):** Consultation with the team that compiles the RESTATS database, which informs the DUKES renewable energy statistics for the UK, to compare the scope and data sources that underpin the national statistics on biomass and biofuels against data provided directly by industry-specific publications and datasets.
- **Coal Mine Methane (2014):** Consultation with colliery operators and UK Coal, combined with review of annual reports on coal mine methane use in the UK have led to a small revision in the estimates of methane recovery and emissions in recent years. Previously the inventory estimates were based on data from mines that accounted for around 80% of UK production, and this consultation enabled a more complete, representative UK dataset to be used in the inventory;
- **Devolved Government solid and liquid fuels (2013, 2015):** A review of energy data reporting from across the UK sought new data sources for solid and liquid fuel use, aiming to identify information that are resolved geographically and/or by sector, in order to help inform improvements to the UK sector allocations and also the Devolved Government inventory totals. This research was revisited in 2015 and included consultation and review of reports published by Her Majesty's Revenue and Customs, and in the 2013 research also wider consultation with oil brokers, local councils, the Climate Change Agreements (a national policy reporting mechanism operated by BEIS), the National Housing Model, Welsh Government research into gas network expansion and fuel poverty;
- **Off-road machinery activities (2014):** A review was undertaken with stakeholders to get a better understanding of the population, usage and engine size for certain types of machinery used in construction which led to a revision in the amount of fuel consumption by these sources.

1.6.5.6 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 AQ Inventory.

1. Knowledge sharing on emissions inventory compilation methods with Moscow State Government officials.
2. Study tour by representatives of the Israeli Ministry of Environmental Protection and Central Bureau of Statistics, who compile the GHG inventory for Israel.
3. Knowledge sharing with Chinese energy statisticians on GHG emissions trading and statistics.
4. Capacity building activities in South Africa in the agricultural sector.

5. Knowledge sharing with the Romanian GHG inventory team during December 2011 to support the improvement of energy sector reporting.
6. 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.
7. Capacity building in Spain – invited presentation of the UK agricultural inventory improvements and further conversations with Spanish government representatives.
8. Knowledge sharing with Russian and French inventory teams.
9. CEH participation in twice yearly knowledge sharing with European LULUCF inventory compilers at EU Joint Research Council LULUCF meetings.
10. Knowledge sharing with and technical assistance to the Vietnam inventory team to help develop the national inventory system.
11. Capacity building workshop with Balkan EU accession countries on National System development.
12. Study visit by delegation from the Chinese National Center 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.

1.6.6 Treatment of Confidentiality

Much of the data necessary to compile the UK inventory are publicly available. However, some industrial production data are commercially sensitive, such as cement production and adipic acid production. For these sectors, whilst emissions data are reported openly, the activity data are not reported in the NFR14 templates.

Detailed EU ETS data are also supplied by the regulators to the Inventory Agency, which allows further analysis of the data to develop new emission factors or to cross check fuel use data with other sources. This detailed data set is not publicly available, and therefore information obtained from the analysis of this data is suitably aggregated before it can be explicitly reported in the NFR 2014-2 templates or within the IIR.

The Inventory Agency manages confidential data on a password-protected secure server that has limited access rights, to limit access to the inventory compilers and checkers that are required to use the data, and the confidential data are not permitted for use on any research or reporting output for non-national-inventory work programme purposes. Access to the raw data, e.g. from regulators of EUETS data, is managed via BEIS and using encrypted files and separate email communication of passwords.

The UK Informative Inventory Reports from the 2008 IIR onwards[20], and estimates of emissions of air quality pollutants, are all publicly available on the web; see http://naei.defra.gov.uk/

1.6.7 Uncertainty Assessments

An uncertainty analysis for national estimates of NAEI pollutants has been undertaken using both the Tier 1 uncertainty aggregation method, and a more complex and comprehensive Monte-Carlo analysis, as described in chapter 5 of the EMEP/EEA 2016 Guidebook.

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 NECD 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 Chapter 1.7. These results are used to plan the programme of inventory improvement.

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

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 2016 guidebook requires Member States 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 1.6.7. Uncertainty estimates are shown in Table 1-11. 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 (given in Ammonia emission estimates are more uncertain than those for SOx (as SO2), NOx (as NO2) and NMVOC and 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 things such as animal stocking densities, daily weather, soil type and conditions, etc. These are therefore reflected in the uncertainties associated with individual emission factors. Further work to characterise the uncertainties in emission estimates using the revised UK inventory model are ongoing and will be fully reported in the next submission. Table 1 13 to Table 1 20).

Note that, due to time constraints, the uncertainty analysis has not been updated to fully reflect the differences to uncertainty due to the adoption of new methods and data for estimating emissions from agriculture this year. These parameters will be reviewed and incorporated for the next inventory cycle. It is likely uncertainties will be lower than the current assessment, as the new methodology makes use of data and methodologies which we have higher confidence in than previously, but would be of a similar order of magnitude. These updates are likely to be particularly significant for Ammonia, due to the relative significance of agriculture emissions to this pollutant.

Table 1-11 Uncertainty of the Emission Inventories for a sample of key air quality pollutants

Pollutant	Emissions[a]			Estimated Uncertainty[b]		
	2005	2016	Trend	2005	2016	Trend[c]
PM_{10}	190	161	-15%	26%	39%	17%
$PM_{2.5}$	120	94.9	-21%	29%	54%	25%
SO_x (as SO_2)	773	179	-77%	6.6%	14%	2.8%
NO_x (as NO_2)	1719	891	-48%	6.2%	7.8%	3.4%
NMVOC	1117	770	-31%	12%	18%	11%
NH_3	163	176	7.6%	27%	31%	14%
Pb	0.12	0.06	-48%	52%	47%	9.3%
B[a]p[e]	5840	7569	30%	310%	390%	140%

[a] 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%.
[d] B[a]p is benzo(a)pyrene

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 1-12 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 1-12 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 1-12 are presented to indicate the relative uncertainty of pollutant inventories i.e. 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 (as SO_2) was +/- 4%, NMVOC was +/- 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.

Whilst the Tier 1 method has generated significantly different estimates of uncertainty for some pollutants (SO_x (as SO_2), NMVOC, B[a]P in particular), the ranking of pollutants is generally similar to that obtained previously.

Table 1-12 Uncertainty of the Emission Inventories determined previously 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 Hydrogen fluoride[a]	-30 to +>50 -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 more uncertain than those for SOx (as SO_2), NOx (as NO_2) and NMVOC and 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 things such as animal stocking densities, daily weather, soil type and conditions, etc. These are therefore reflected in the uncertainties associated with individual emission factors. Further work to characterise the uncertainties in emission estimates using the revised UK inventory model are ongoing and will be fully reported in the next submission.

Table 1-13 Assessment of Ammonia uncertainty

NFR14 Code	2005			2016			
	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	17.7	99%	11%	8.92	59%	3.0%	9.4%
1B	0.36	38%	0.1%	0.20	45%	0.1%	0.0%
2A	0.51	31%	0.1%	0.35	31%	0.1%	0.0%
2B	4.03	24%	0.6%	1.59	26%	0.2%	0.4%
2C	0.00	91%	0.0%	0.00	91%	0.0%	0.0%
2D	1.21	140%	1.1%	1.21	160%	1.1%	0.8%
2G	0.17	77%	0.1%	0.12	77%	0.1%	0.0%
2H	0.87	130%	0.7%	0.57	130%	0.4%	0.3%
3B	74.3	16%	7.2%	73.8	16%	6.6%	5.5%
3D	46.9	82%	23%	70.5	74%	30%	8.3%
5A	5.03	62%	1.9%	1.29	62%	0.5%	1.5%
5C	0.03	66%	0.0%	0.02	78%	0.0%	0.0%
5B	3.45	35%	0.7%	7.36	23%	0.9%	0.9%
5D	1.74	95%	1.0%	1.46	92%	0.8%	0.3%
6A	7.10	58%	2.5%	8.34	60%	2.8%	2.8%
Total	**163**	**27%**	**27%**	**176**	**31%**	**31%**	**14%**

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 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 boiler. 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 (as NO_2) and SO_X (as SO_2) which are also emitted mainly from major combustion processes. Unlike the case of NO_X (as NO_2) and NMVOC, a few sources dominate the inventory and there is limited potential for error compensation.

1.7.3 Nitrogen oxides

Uncertainty of NO_x (as NO_2) 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: contributes about 1/3 of national NO_X (as NO_2) emissions in both 2005 and the most recent year. 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 widely 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, there is no reliable source of data for the activity for this source, and the uncertainty in the activity data is considered to be significant.

The estimates for large stationary combustion plant are assumed to be significantly 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 1-14 Assessment of Nitrogen Oxides uncertainty

NFR14 Code	2005			2016			
	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	1706	6.3%	6.2%	881	7.9%	7.8%	3.4%
1B	3.15	35%	0.1%	2.04	39%	0.1%	0.0%
2B	1.08	21%	0.0%	0.54	45%	0.0%	0.0%
2C	1.57	21%	0.0%	0.71	27%	0.0%	0.0%
2G	0.08	68%	0.0%	0.05	69%	0.0%	0.0%
3B	0.45	31%	0.0%	0.40	32%	0.0%	0.0%
3D	4.73	44%	0.1%	4.68	43%	0.2%	0.1%
5C	1.57	29%	0.0%	1.27	30%	0.0%	0.0%
5E	0.32	89%	0.0%	0.13	85%	0.0%	0.0%
Total	**1719**	**6.2%**	**6.2%**	**891**	**7.8%**	**7.8%**	**3.4%**

1.7.4 Non-Methane Volatile Organic Compounds

The NMVOC inventory is more uncertain than those for SO_X (as SO_2) and NO_X (as NO_2). 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 (as NO_2), 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, and this reflects the fact that the NMVOC inventory was subject to significant investment in improvement work in the 1990s and early 2000s, resulting in the acquisition of much data. Much less data has been obtained since, leading to an increase in emission uncertainty.

Table 1-15 Assessment of NMVOC uncertainty

NFR14 Code	2005			2016			
	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	285	18%	4.6%	119	32%	5.0%	3.4%
1B	266	19%	4.6%	129	17%	2.8%	2.0%
2A	1.98	37%	0.1%	1.09	35%	0.0%	0.0%
2B	40.6	59%	2.1%	14.4	82%	1.5%	0.8%
2C	1.63	83%	0.1%	0.95	85%	0.1%	0.0%
2D	354	14%	4.5%	328	27%	11%	9.2%
2G	0.20	140%	0.0%	0.14	140%	0.0%	0.0%
2H	77.7	73%	5.1%	97.7	73%	9.3%	3.0%
2I	0.23	120%	0.0%	0.24	120%	0.0%	0.0%
3B	78.1	100%	7.0%	72.6	99%	9.4%	1.8%
5A	6.30	34%	0.2%	1.99	34%	0.1%	0.1%
5C	3.67	280%	0.9%	3.61	280%	1.3%	0.3%
5D	0.25	440%	0.1%	0.26	440%	0.1%	0.1%
5E	1.59	89%	0.1%	0.64	86%	0.1%	0.0%
Total	**1117**	**12%**	**12%**	**770**	**18%**	**18%**	**11%**

1.7.5 Particulate Matter Estimates

The emission inventory for PM_{10} is subject to high uncertainty. This stems from uncertainties in the emission factors themselves, and the activity data with which they are combined to quantify the emissions. 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 significantly improved before the overall uncertainty in PM could be reduced to the levels seen for SO_X (as SO_2), NO_X (as NO_2) or NMVOC.

Table 1-16 Assessment of PM_{10} uncertainty

NFR14 Code	2005			2016			
	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	113	29%	17%	94.2	55%	32%	16%
1B	2.99	120%	1.8%	1.91	80%	0.9%	1.1%
2A	41.9	64%	14%	35.7	72%	16%	3.2%
2B	0.74	47%	0.2%	0.17	45%	0.0%	0.1%
2C	6.58	110%	3.8%	4.94	86%	2.6%	1.2%
2D	6.01	87%	2.7%	8.18	88%	4.5%	2.8%
2G	3.06	318%	5.1%	1.83	288%	3.3%	1.6%
2H	1.86	500%	4.8%	1.31	500%	4.0%	0.7%
2I	1.17	140%	0.9%	1.09	140%	1.0%	0.4%
3B	3.61	220%	4.1%	3.36	210%	4.5%	0.4%
3D	4.45	290%	6.8%	4.74	290%	8.6%	1.5%
5A	0.02	62%	0.0%	0.01	62%	0.0%	0.0%
5C	1.91	390%	3.9%	1.91	400%	4.8%	1.2%
5E	2.80	290%	4.2%	2.06	350%	4.4%	1.0%
Total	**190**	**26%**	**26%**	**161**	**39%**	**39%**	**17%**

Table 1-17 Assessment of $PM_{2.5}$ uncertainty

NFR14 Code	2005			2016			
	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	95.1	33%	26%	74.0	67%	52%	25%
1B	0.83	76%	0.5%	0.53	74%	0.4%	0.2%
2A	6.65	110%	6.2%	4.81	120%	5.8%	0.8%
2B	0.50	45%	0.2%	0.11	42%	0.1%	0.1%
2C	3.97	140%	4.5%	3.17	110%	3.7%	1.5%
2D	2.44	110%	2.2%	3.19	120%	4.1%	2.1%
2G	2.12	239%	4.2%	1.32	208%	2.9%	1.1%
2H	0.56	500%	2.3%	0.39	500%	2.0%	0.2%
2I	0.93	250%	1.9%	0.87	250%	2.2%	0.6%
3B	2.39	220%	4.3%	2.22	220%	5.0%	0.6%
3D	0.60	500%	2.5%	0.64	500%	3.3%	0.7%
5A	0.00	62%	0.0%	0.00	62%	0.0%	0.0%
5C	1.71	410%	5.7%	1.72	410%	7.5%	2.0%
5E	2.60	290%	6.2%	1.91	350%	7.0%	1.6%
Total	**120**	**29%**	**29%**	**94.9**	**54%**	**54%**	**25%**

1.7.7 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 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, however, that the uncertainty in emissions for the most recent year is significantly higher than the uncertainty in 2005 emissions. Over the last 20 years, regulations have been tightened to control the sulphur content of various fuels and SO_x (as SO_2) emissions also have 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 over time. 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.

Table 1-18 Assessment of SO_x (as SO_2) uncertainty

NFR14 Code	2005			2016			
	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	732	6.9%	6.6%	167	15%	14%	2.7%
1B	8.33	10%	0.1%	2.46	11%	0.1%	0.0%
2A	17.3	14%	0.3%	5.52	14%	0.4%	0.1%
2B	7.25	23%	0.2%	1.26	50%	0.4%	0.1%
2C	7.44	13%	0.1%	1.76	24%	0.2%	0.0%
2G	0.06	99%	0.0%	0.03	99%	0.0%	0.0%
5C	0.88	110%	0.1%	0.67	130%	0.5%	0.1%
Total	**773**	**6.6%**	**6.6%**	**179**	**14%**	**14%**	**2.8%**

1.7.8 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 metals 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 do 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 1-19 Assessment of lead uncertainty

NFR14 Code	2005			2016			
	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	36.8	33%	9.8%	23.1	35%	13%	5.8%
1B	2.40	100%	2.0%	1.02	130%	2.0%	0.3%
2A	0.69	68%	0.4%	0.16	91%	0.2%	0.2%
2B	13.6	52%	5.7%	4.66	50%	3.6%	3.1%
2C	51.7	110%	46%	24.0	100%	37%	4.9%
2G	15.4	180%	23%	8.31	180%	24%	4.0%
2I	2.54	90%	1.9%	3.02	90%	4.2%	2.0%
5C	0.17	65%	0.1%	0.10	86%	0.1%	0.0%
Total	**123**	**52%**	**52%**	**64.4**	**47%**	**47%**	**9.3%**

1.7.9 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 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; independent PCDD/PCDF uncertainties will be prioritised in future work.

Table 1-20 Assessment of Benzo[a]pyrene uncertainty

NFR14 Code	2005			2016			
	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	4572	380%	300%	7067	420%	390%	120%
1B	77.6	90%	1.2%	100	90%	1.2%	0.1%
2B	17.9	92%	0.3%	8.42	120%	0.1%	0.2%
2C	161	150%	4.1%	80.6	170%	1.9%	3.0%
2D	10.5	130%	0.2%	7.87	130%	0.1%	0.1%
2G	4.55	135%	0.1%	3.17	135%	0.1%	0.1%
2I	15.4	140%	0.4%	12.6	140%	0.2%	0.2%
5C	644	490%	55%	29.2	370%	1.4%	68%
5E	338	330%	19%	260	400%	14%	8.7%
Total	**5840**	**310%**	**310%**	**7569**	**390%**	**390%**	**140%**

1.8 Assessment of Completeness

The NAEI uses a range of internationally agreed notation keys to indicate where there are methodological or data gaps in the inventories of pollutants, and where emissions are estimated but included elsewhere in the inventory instead of under the expected source category. The correct use of these notation keys ensures the NAEI is reported in a transparent manner, and facilitates the assessment of the completeness of the NAEI.

1.8.1 Not Estimated

Emissions of sources that are not estimated in the UK inventory are reported as NE and are listed in Table 1-21

Table 1-21 Explanation to the Notation key NE

NFR14 code	Substance(s)	Further details
1A2a to 1A2e	NH_3	The UK does not have NH_3 emissions reported by operators, and no other reliable UK-specific data, and since there are no default emission factors in the EMEP/EEA 2016 Guidebook for the coal, oil or gas used in these source categories, the UK does not estimate NH_3 emissions for these fuels in the UK inventory.
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 emission factors available in the 2016 Guidebook; the notation key 'NE' ('not estimated') is recommended for use in the 2016 Guidebook.
2C7d	Metals	No emission factors available in the 2016 Guidebook
2D3c	NMVOC	Activity data are not available for this source category but they are expected to be minor activities and emissions are small as a result.
3F	SO_2, NO_x, NH_3, NMVOC, $PM_{2.5}$	Emissions are reported as 'NE' from 1994 onwards as legislation within the EU has largely outlawed the practice of field burning agricultural wastes. 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. While Tier 2 emission factors (EFs) are available in chapter 3F of the EEA/EMEP Guidebook for wheat and barley residues (Tables 3-3 to 3-6) there is no EF for linseed, therefore the Tier 1 EF would need to be used. There may be some emissions arising from field burning but activity data are not available to estimate emissions for this source. As there are very small amounts of residues that are likely to be burned, any emissions will be extremely small and hence 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 NFR14 disaggregation for a specific sector are reported as IE. Table 1-22 lists all sources included in these categories.

Table 1-22 Explanation to the Notation key IE

NFR14 code	Substance(s)	Included in NFR14 code	Further details
1A1b	NH_3	1B2aiv	For 1A1b, emissions of ammonia from UK refineries are reported in 1B2aiv, with these estimates being 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 1B2aiv.
1A1c	NH_3	1B1b	For 1A1c, 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 al emissions are reported in 1B1b.
1A3ei	All	1A1c	
1A4aii	All	1A2gvii	UK energy statistics do not provide separate figures for gas oil burnt in stationary sources and mobile sources. Instead, the UK Inventory Agency generates independent estimates of gas oil use for off-road vehicles and mobile machinery from estimates of the numbers of each type of vehicle/machinery in use, and their fuel consumption characteristics. These estimates are for all use of gas oil in off-road vehicles and mobile machinery, and no data are available that would allow the gas oil consumption data to be further divided into consumption by economic sector. All emissions are currently reported in 1A2gvii.
1A5a	All	1A4ai	Emissions from 1A5a (stationary combustion for military purposes) is not reported separately in the UK energy statistics and are included under 1A4ai (Commercial/institutional: Stationary)
1B1c	All	1B1b	
1B2aiv	SO_x (as SO_2)	1B2ai	
1B2av	SO_x (as SO_2)	1B2ai	
2A5c	PM	2A5a & 2H3	
2B1	NOx	1A2c	
2B1	NH3, NMVOC	2B10a	
2B2	NH3, NMVOC	2B10a	
2B10b	All (except NMVOCs)	2B10a	
2C2	All	1A2a, 2C1 and 2A3	
2C7d	PM	2C1	

NFR14 code	Substance(s)	Included in NFR14 code	Further details
3B4f	NOx, NMVOC, PM and NH_3	3B4e	
5C1bi	All	5C1a	
1A2gvii, 1A3c, 1A4bii, 1A4cii 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.
1A4ai	Activity data: Biomass	1A2gviii	UK energy statistics only include data for overall usage of waste wood and other biomass by non-residential 'final users' and it is possible that as well as industrial users, these final users could include some in the commercial and public sectors. As only the total use of fuel is available, emissions are reported in a single category – 1A2gviii – but the fuel is also likely to be used in other sectors of 1A2 and also in 1A4ai as well. Currently there is no data available to make a reliable split of fuel use between the various sub-categories of 1A2 and 1A4ai, although it is suspect that most of the fuel is used in industrial plant.

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 trends observable across the main source sectors. The pollutants considered are the NECD pollutants (SO_x as SO_2, NO_x as NO_2, NMVOC, NH_3 and $PM_{2.5}$), the priority metals (lead, cadmium and mercury), Dioxins & Furans (PCDD/PCDF) and Benzo[a]pyrene as an indicator for PAHs.

The geographical coverage of the emissions reported to the CLRTAP 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 power stations
- **1A2 Manufacturing Industries and Construction**
- **1A3a,c,d,e Non-road Transport** - aviation, national shipping, rail and off-road transport
- **1A3b Road Transport**
- **1A4 Small Stationary Combustion and Non-road mobile sources and machinery** – primarily residential combustion and non-road mobile machinery
- **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**
- **3 Agriculture**
- **5 Waste**
- **6 Other** – other sources that are included within the national total.

Chapter 2.2 considers each of the pollutants in turn, and explains the main features of the emissions time series. The text highlights where there have been significant changes in emissions between 1990 and the latest reported inventory year. A wide range of legislation and activities have affected emissions of these pollutants, and these are listed and discussed. The chapter starts with a general discussion of the trends in emissions of NECD 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 are available on the NAEI website (http://naei.defra.gov.uk/). The website also provides access to more detailed NAEI data, including emission factors and emission maps for key pollutants.

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

Chapter 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 Chapter 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 (as NO_2)

Figure 2-1 shows the time series of UK emissions of NO_x (as NO_2). Emissions have declined substantially since 1990.

Figure 2-1 Total UK emissions of NO_x (as NO_2) for 1990 – 2016

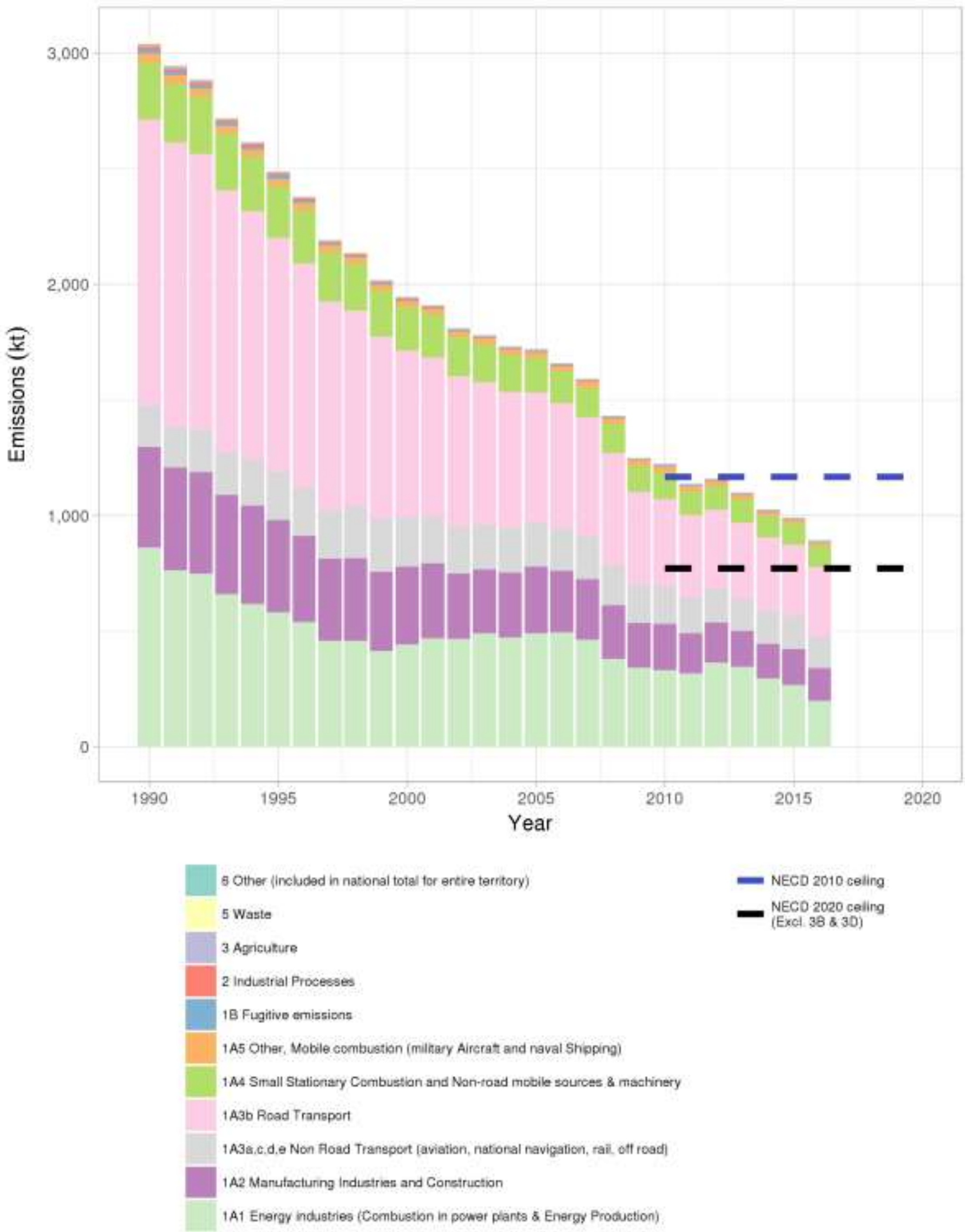


Table 2-3 shows the percentage changes in the emissions of NMVOC since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.
Table 2-3 Table 2-3 shows the percentage changes in the emissions of NO_x since 1990, and summarises the key factors and legislation 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): 3046 ktonnes Total emission (2016): 893 ktonnes Emission reduction 1990-2016: 71%	Largest source category (1990): Road Transport (41%) Largest source category (2016): Road Transport (34%) Emissions reduction 1990-2016, Road Transport: 76%
Key factors and legislation driving the decline in emissions	
• 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 • LRTAP convention which includes measures to combat the effects of NO_x as NO_2 • 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 emissions total are the energy industries (primarily power stations) and road transport (see Figure 2-1). Road transport has accounted for approximately a third of UK NO_x emissions in recent years.

As well as being a pollutant regulated under the Gothenburg Protocol and the NECD, 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 Industrial Emissions Directive, IED, related to 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 significantly 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.

In addition, significant 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 timeseries, 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.

2.2.2 Trends in Emissions of SOx (as SO_2)

Figure 2-1 shows the time series of UK emissions of, SO_x as SO_2. Emissions have declined substantially since 1990.

Figure 2-2 Total UK emissions of SO_x (as SO_2) for 1990 – 2016

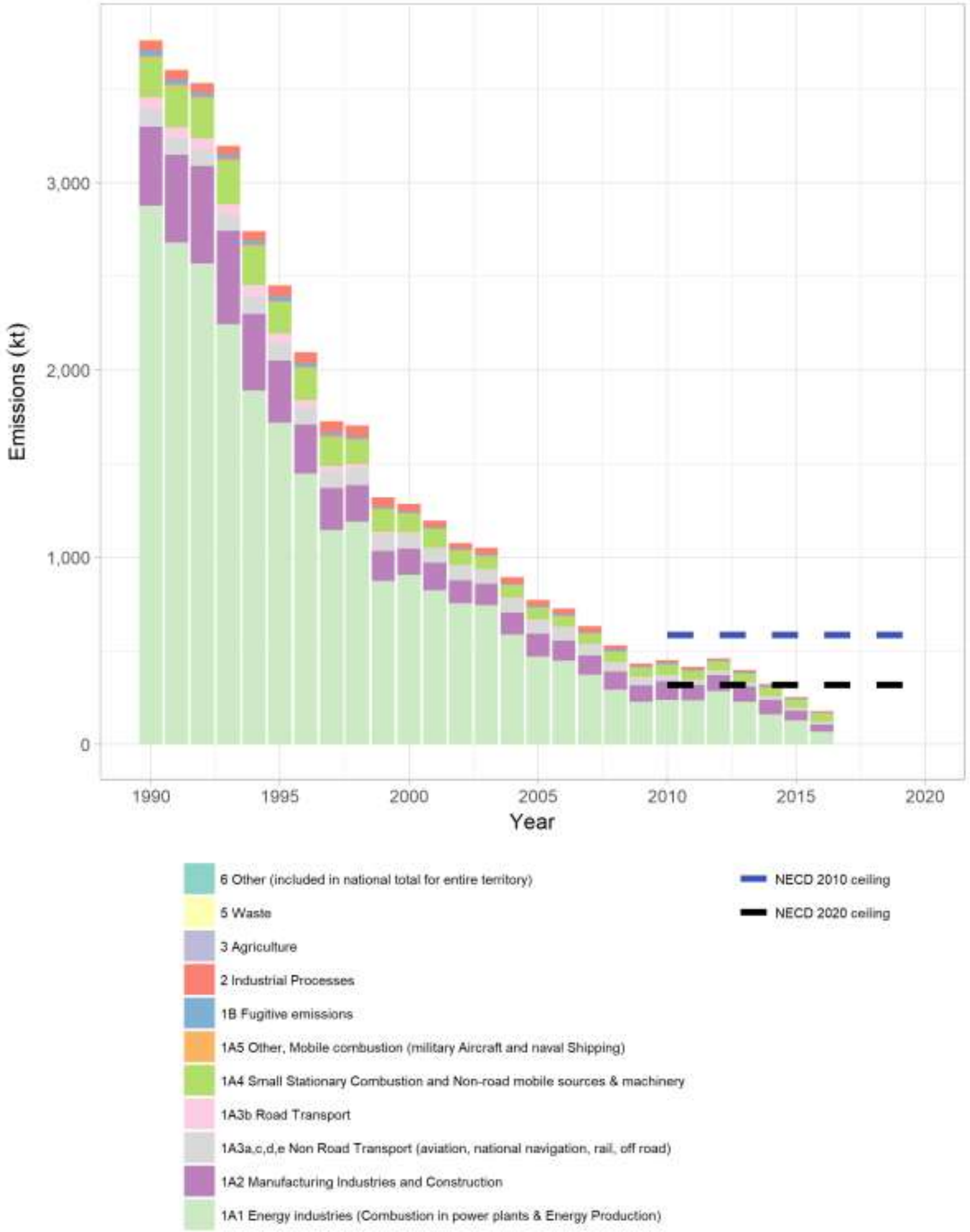


Table 2-2 shows the percentage changes in the emissions of SO_x since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-2 Changes in emissions of SO_x since 1990

Key data relating to the emissions trend	
Total emission (1990): 3767 ktonnes Total emission (2016): 179 ktonnes Emission reduction 1990-2016: 95%	Largest source category (1990): Energy Industries (79%) Largest source category (2016): Energy Industries (37%) Emissions reduction 1990-2016, Energy Industries: 98%
Key factors and legislation driving the decline in emissions	
• 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 the sulphur contents of certain liquid fuels (Directive 1999/32/EC) • LRTAP convention which 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, the energy industries (primarily power stations) contribute most to the emissions total, contributing approximately a third of the total emission in 2016, but much more in earlier years. Combustion in manufacturing industries accounts for approximately a quarter of the total emission in 2016, as does small combustion (such as residential).

Of all the air quality pollutants controlled under the NECD and Gothenburg Protocol, SO_2 emissions show the most marked decrease over time: since 1990, emissions have declined by more than 90%. 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. Approximately 108 million tonnes of coal were used in the UK in 1990, falling to just under 18 million tonnes in 2016. 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 high levels of sulphur, has also fallen – from 14 million tonnes in 1990 to 1 million tonnes in 2016. 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_2 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 NMVOC

Figure 2-3 shows the time series of UK emissions of NMVOC. Emissions have declined substantially since 1990.

Figure 2-3 Total UK emissions of NMVOC for 1990 – 2016

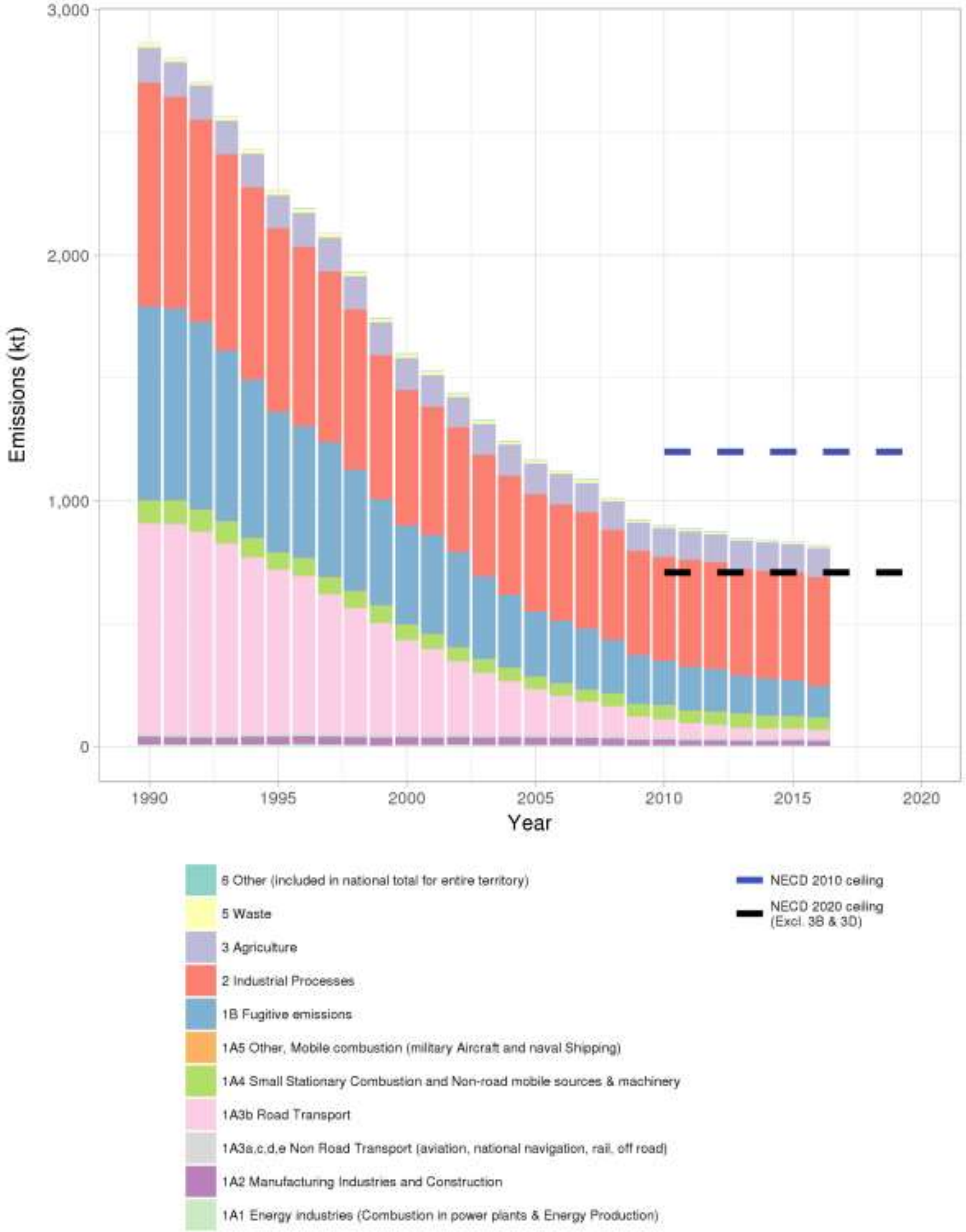


Table 2-3 shows the percentage changes in the emissions of NMVOC since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-3 Changes in emissions of NMVOC since 1990

Key data relating to the emissions trend	
Total emission (1990): 2863 ktonnes Total emission (2016): 819 ktonnes Emission reduction 1990-2016: 71%	Largest source category (1990): Industrial Processes (32%) Largest source category (2016): Industrial Processes (54%) Emissions reduction 1990-2016, Industrial Processes: 51%

Key factors and legislation driving the decline in emissions

- 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
- LRTAP convention which includes measures to combat the effects of NMVOCs

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

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 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, and alcoholic drinks. 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. This category is dominated by extraction, refining and distribution of oil and gas, which contributed 72% of the category emissions in 1990 but 99% in 2016. 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 timeseries. Coal mining was an important source in 1990, but emissions have decreased by 97% since then, as the deep mining of coal has practically ceased in the UK.

2.2.4 Trends in Emissions of NH_3

Figure 2-4 shows the time series of UK emissions of NH_3. Emissions have declined since 1990, but in recent years, emissions have been increasing.

Figure 2-4 Total UK emissions of NH_3 for 1990 – 2016

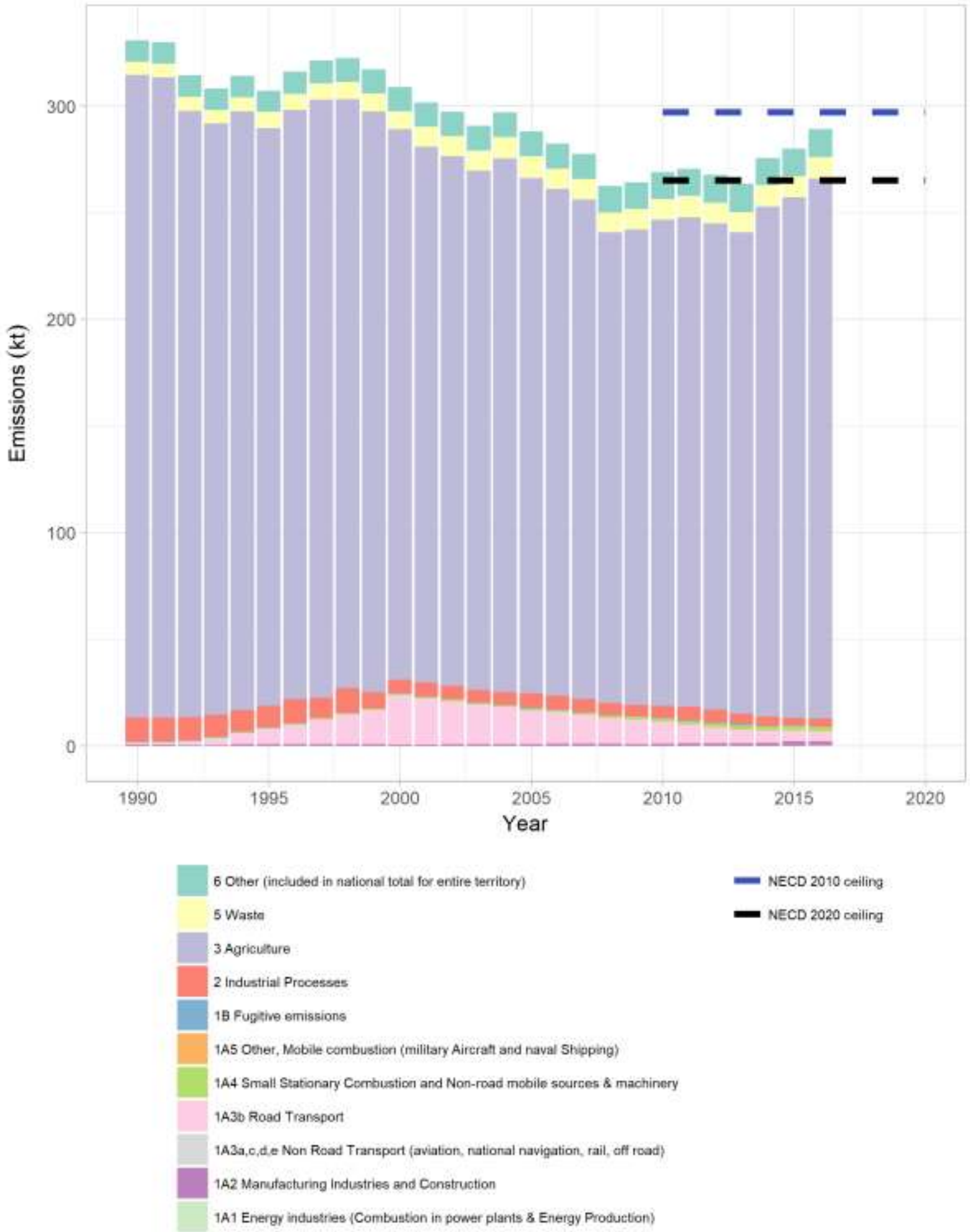


Table 2-4 shows the percentage changes in the emissions of NH_3 since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.

Table 2-4 Changes in emissions of NH_3 since 1990

Key data relating to the emissions trend	
Total emission (1990): 331 ktonnes Total emission (2016): 289 ktonnes Emission reduction 1990-2016: 13%	Largest source category (1990): Agriculture (91%) Largest source category (2016): Agriculture (88%) Emissions reduction 1990-2016, Agriculture: 16%
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) • LRTAP convention which 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 (e.g. livestock), 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 Chapter 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 inorganic (manufactured) fertiliser, especially urea-based fertilisers.

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 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 mostly increased each year, largely due to slight increases in numbers of dairy cattle, but particularly 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. Emissions from chemical fertiliser use have increased by 41% since 2013. As a result, UK emissions of NH_3 in 2016 were 10% above the historical low point achieved in 2008.

A relatively recent development has been the use on agricultural land of digestates from anaerobic digestion of non-agricultural wastes. This emission source was trivial before the mid-2000s but contributed 3% of emissions in 2016. The application of sewage sludges to agricultural land has also grown, particularly in the early 2000s.

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 anaerobic digestion 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 approximately 3-5% 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 approximately halved since 1990.

Figure 2-5 Total UK emissions of $PM_{2.5}$ for 1990 – 2016

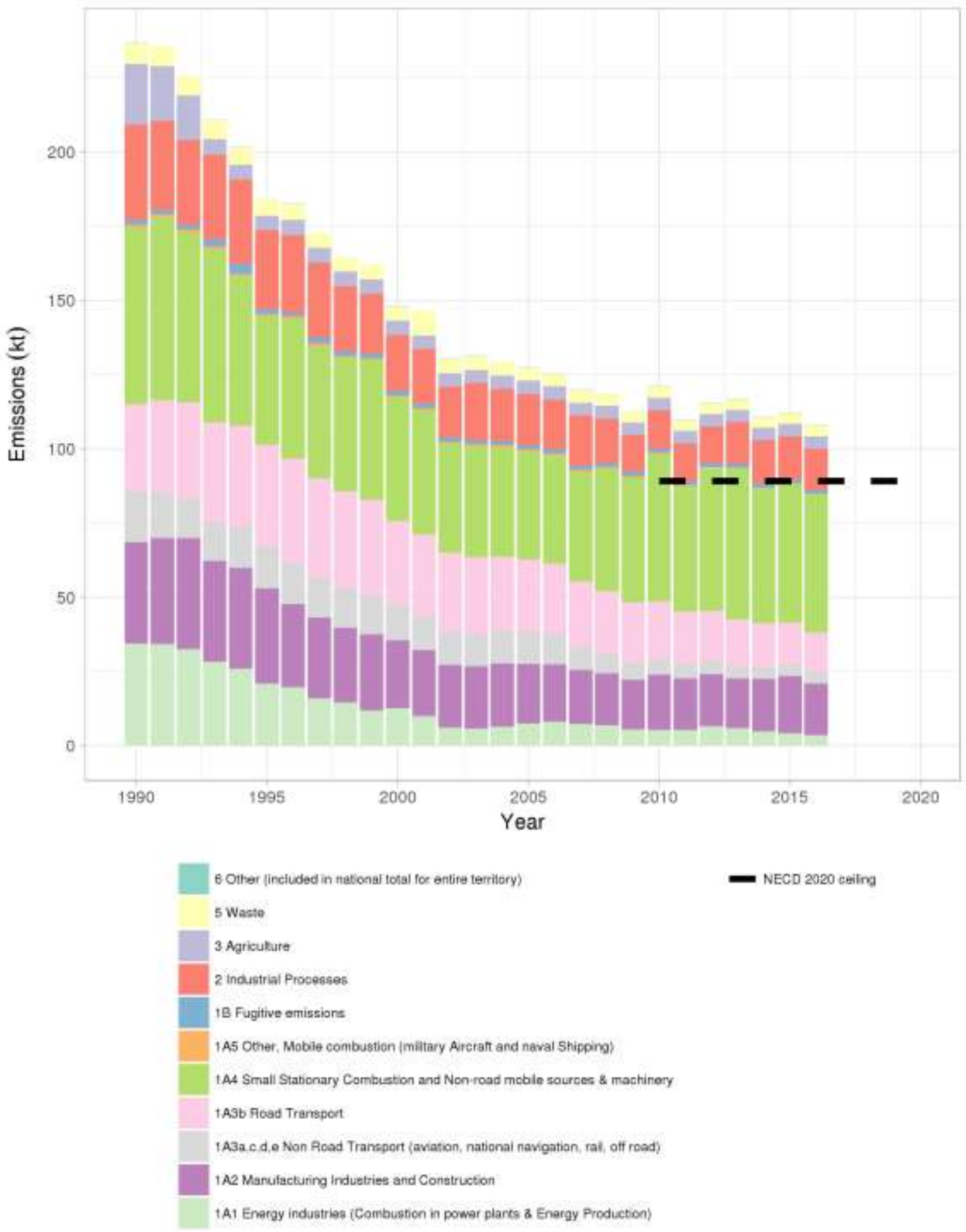


Table 2-5 shows the percentage changes in the emissions of PM2.5 since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.

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

Key data relating to the emissions trend	
Total emission (1990): 237 ktonnes Total emission (2016): 108 ktonnes Emission reduction 1990-2016: 54%	Largest source category (1990): Small combustion (25%) Largest source category (2016): Small combustion (43%) Emissions reduction 1990-2016, Small combustion: 22%
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) • LRTAP convention which 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 significantly since about 2002. This is partly because once important sources such as coal use were reduced to such a degree by that point, further significant reductions have not occurred since. In addition, emissions from residential wood combustion have increased due to growth in the amount of wood burning within this category.

The emissions from Small Stationary Combustion represent the largest source. 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-2000's, there has been an increase in emissions, caused by the increased burning of wood in domestic appliances. This emission source alone contributed 30% of UK emissions in 2016.

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 1990's. Emissions from power stations follow a similar trend to that observed for SO_2, 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 impact the emissions trend for the Manufacturing Industries and Construction source category.

2.2.6 Trends in Emissions of Lead, Cadmium, and Mercury

Lead

Figure 2-6 shows the time series of UK emissions of Lead. Emissions have declined dramatically since 1990.

Figure 2-6 Total UK emissions of Lead for 1990 – 2016

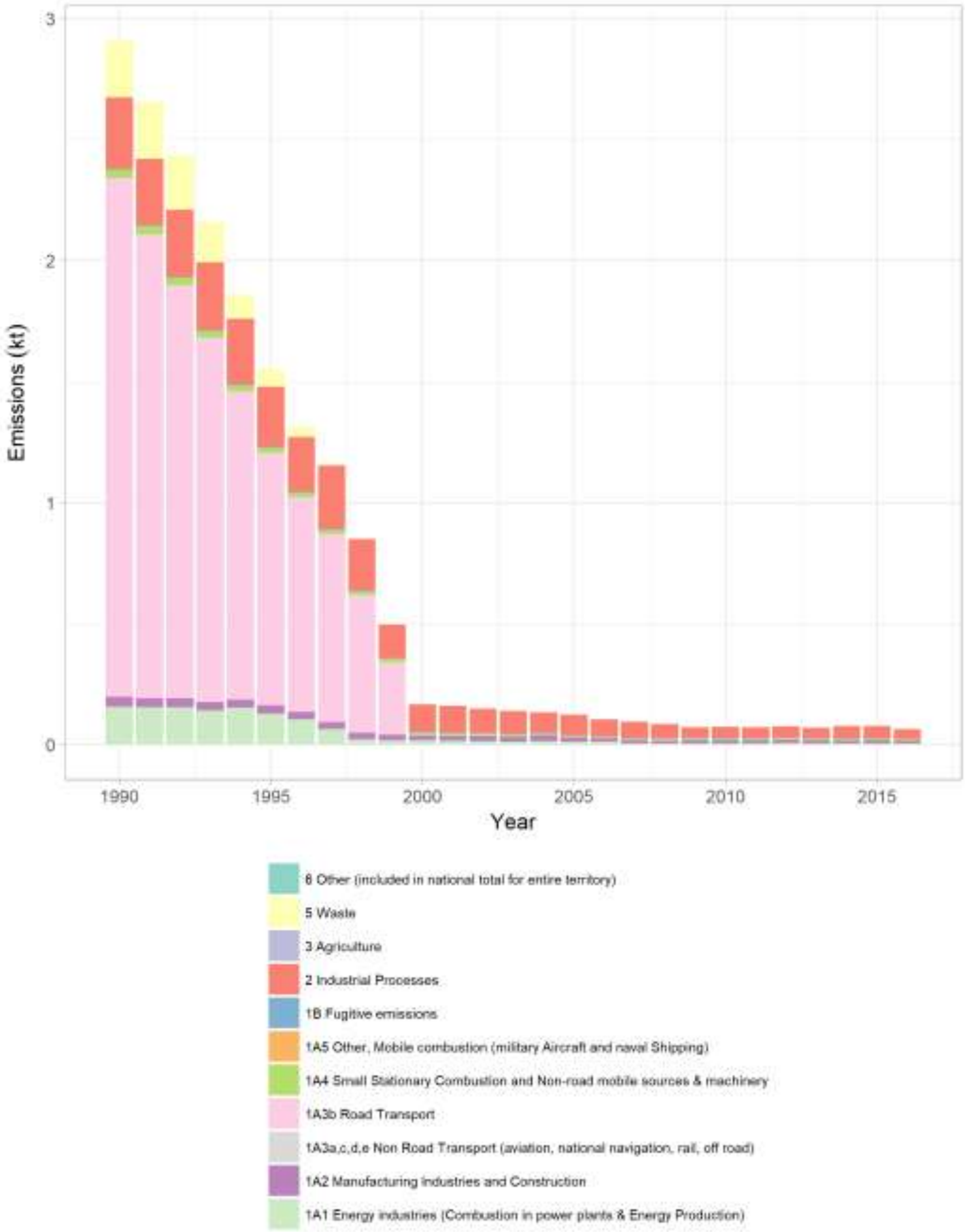


Table 2-6 Changes in emissions of Lead since 1990

Key data relating to the emissions trend	
Total emission (1990): 2909 tonnes Total emission (2016): 64 tonnes Emission reduction 1990-2016: 98%	Largest source category (1990): Road Transport (74%) Largest source category (2016): Industrial Processes (62%)

Road Transport was the largest source sector of lead emissions until 1999. 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 reductions observable in Figure 2-6.

Industrial processes 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 due to the closure of some sites and reductions in emissions at those that remain in recent years.

Emissions from Energy Industries (power stations) declined in the late 1990's. 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.

Cadmium

Figure 2-7 shows the time series of UK emissions of Cadmium. Emissions have declined substantially since 1990.

Figure 2-7 Total UK emissions of Cadmium for 1990 – 2016

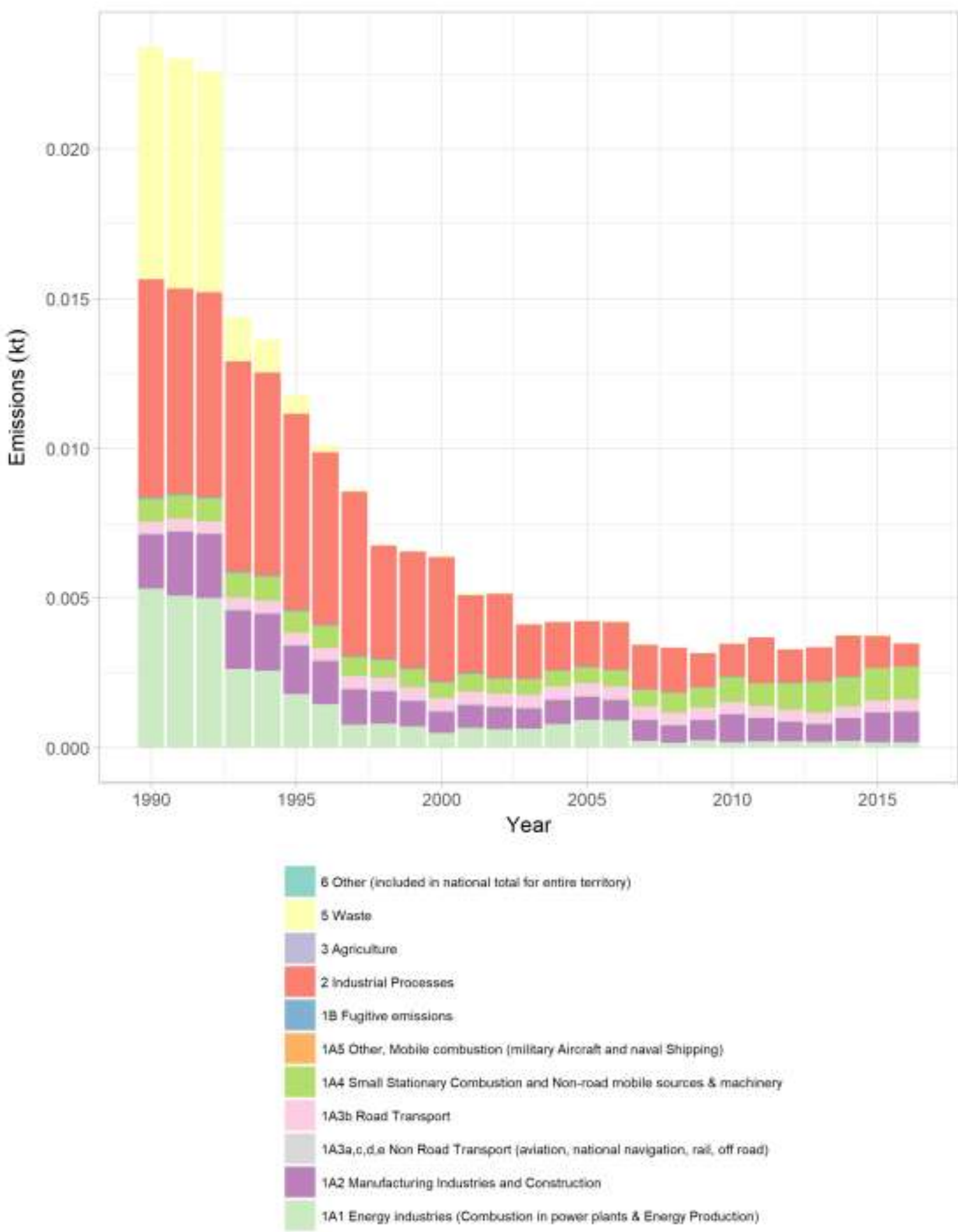


Table 2-3 shows the percentage changes in the emissions of NMVOC since 1990, and summarises the key factors and legislation responsible for the reductions in emissions.
Table 2-3Table 2-7 shows the percentage changes in emissions since 1990.

Table 2-7 Changes in emissions of Cadmium since 1990

Key data relating to the emissions trend	
Total emission (1990): 23 tonnes Total emission (2016): 3 tonnes Emission reduction 1990-2016: 85%	Largest source category (1990): Waste (33%) Largest source category (2016): Small combustion (31%)

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 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 plant. 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 significant reduction in emissions in the Energy Industries sector from 2006 to 2007 is due to reduced emissions from coal combustion.

Emissions from industrial processes decrease 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.

Mercury
Figure 2-8 shows the time series of UK emissions of Mercury. Emissions have declined dramatically since 1990.

Figure 2-8 Total UK emissions of Mercury for 1990 – 2016

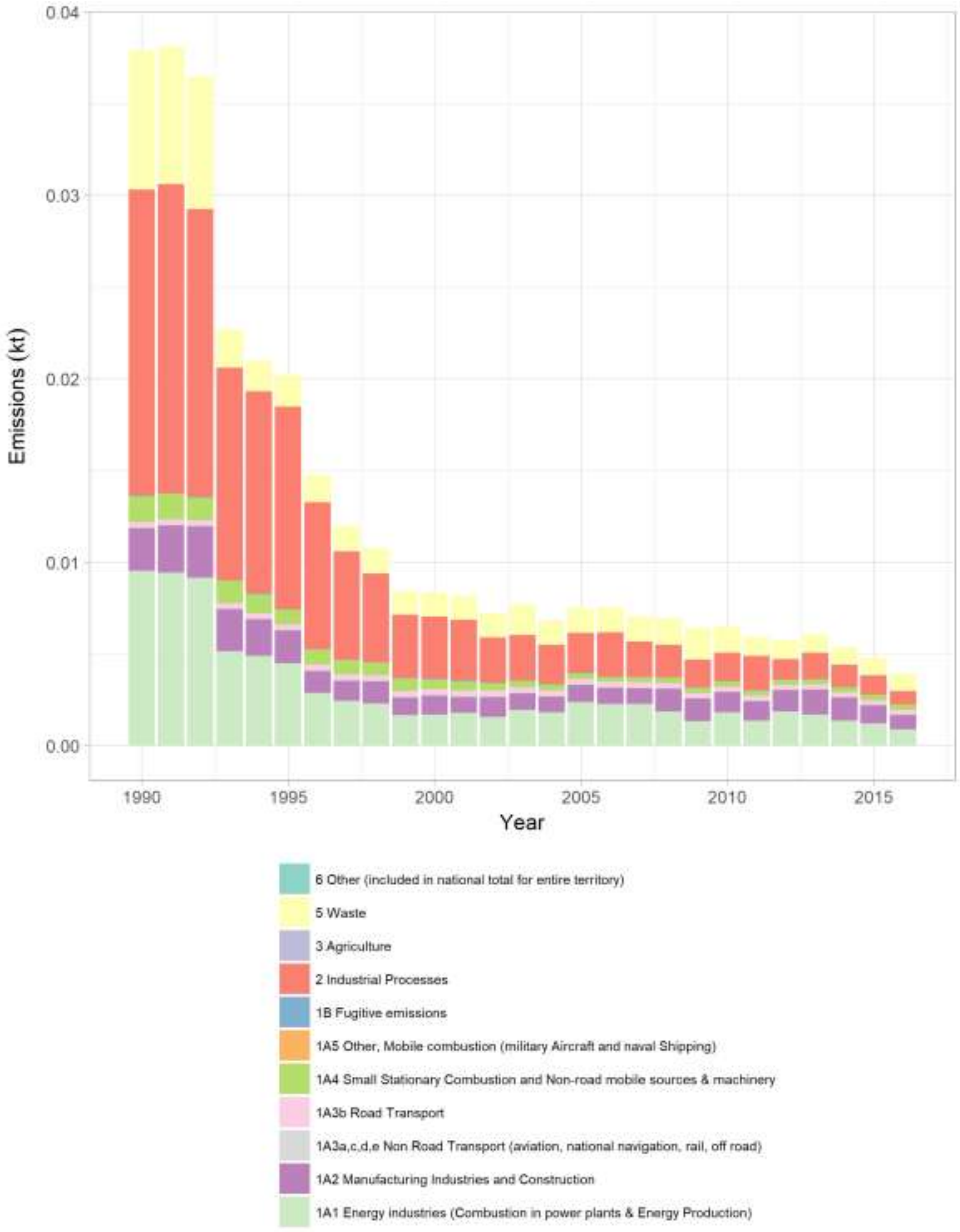


Table 2-8 shows the percentage changes in emissions since 1990.

Table 2-8 Changes in emissions of Mercury since 1990

Key data relating to the emissions trend	
Total emission (1990): 38 tonnes Total emission (2016): 4 tonnes Emission reduction 1990-2016: 90%	Largest source category (1990): Industrial Processes (44%) Largest source category (2016): Waste (25%)

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 in 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 decrease 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. 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.

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

Dioxin and Furans

Figure 2-9 shows the time series of UK emissions of Dioxins and Furans. Emissions have declined significantly since 1990.

Figure 2-9 Total UK emissions of Dioxins and Furans for 1990 – 2016

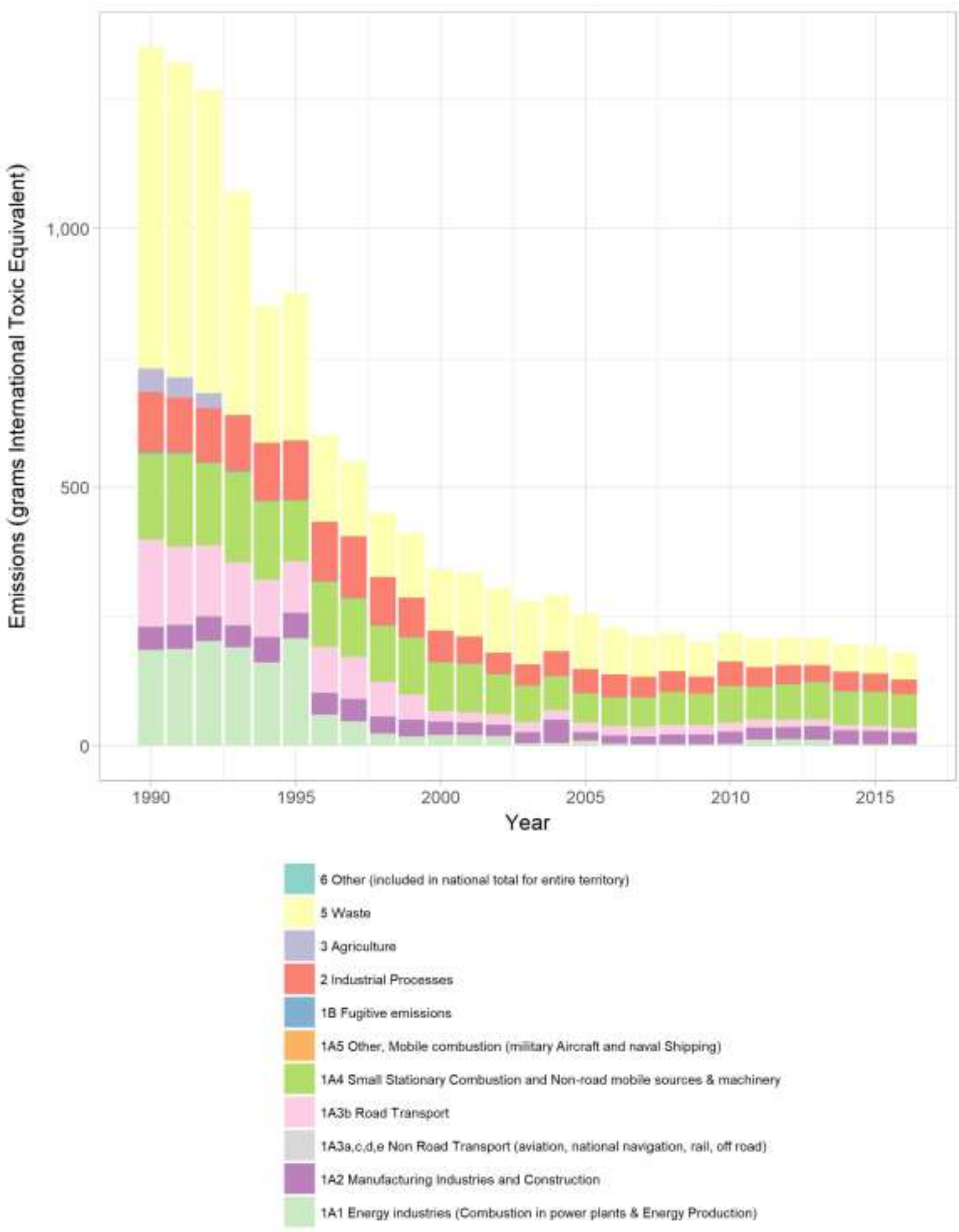


Table 2-9 shows the percentage changes in emissions since 1990.

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

Key data relating to the emissions trend	
Total emission (1990): 1352 g- ITEQ Total emission (2016): 180 g-ITEQ Emission reduction 1990-2016: 87%	Largest source category (1990): Waste (46%) Largest source category (2016): Small combustion (36%)

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 significantly lower 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 significant 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 Small Stationary 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.

Benzo[a]pyrene

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

Figure 2-10 Total UK emissions of Benzo[a]pyrene for 1990 – 2016

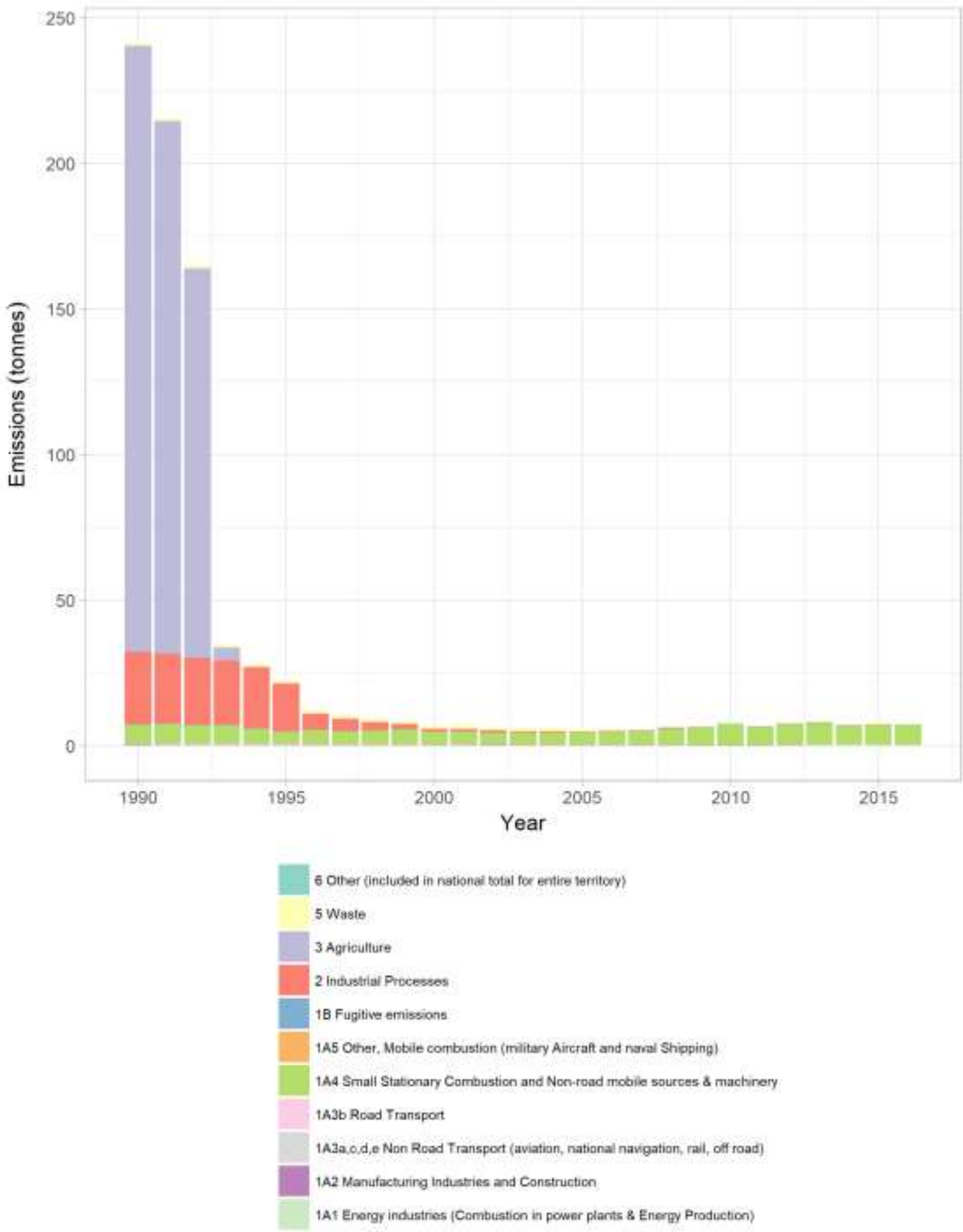


Table 2-10 Changes in emissions of Benzo[a]pyrene since 1990

Key data relating to the emissions trend	
Total emission (1990): 241 tonnes Total emission (2016): 8 tonnes Emission reduction 1990-2016: 97%	Largest source category (1990): Agriculture (86%) Largest source category (2016): Small Combustion (89%)

The large emissions of B[a]P from the agriculture sector in the first few years of the time series are due to field burning. Following a ban on the practice of field burning in agriculture, emissions fall to zero by 1994.

Emissions from the Industrial Processes 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-1990's, and anode baking no longer takes place in the UK, as a result of plant closures.

As other sources have declined, the emissions from the Small Stationary Combustion source sector have become increasingly important, and this source now dominates the total emission of B[a]P. 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 significant trends at a sectoral level.

2.3.1 Power Generation

Power generation (NFR14 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 2016.

Table 2-11 Power Stations: Sector share of UK emissions total in 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
CO	1A1a	3%	-62%
NO_x (as NO_2)	1A1a	14%	-84%
PM_{10}	1A1a	2%	-95%
$PM_{2.5}$	1A1a	3%	-91%
Hg	1A1a	22%	-91%
Cd	1A1a	5%	-97%
SO_x (as SO_2)	1A1a	20%	-99%
HCB	1A1a	68%	1389%

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 (as NO_2) emissions from the sector. Since 1990, the increased use of nuclear generation 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 (as SO_2) emissions; this has accelerated the decline of SO_x (as SO_2) emissions. The reduction of particulate emissions is also due to this switch from coal to natural gas and nuclear power for electricity generation, as well as improvement in the performance of particulate abatement plants at coal-fired power stations. The installation of flue gas desulphurisation at eight power stations has reduced SO_x (as SO_2) 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 emission from power stations is from the burning of municipal solid waste, and emissions have grown significantly 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 about 60% lower in 2016, due to plant closure and low utilization rates at some of the remaining stations.

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 Chapter 3.1.

2.3.2 Industrial Combustion

This category covers the use of fuels in combustion in crude oil refineries and other processes that manufacture or process fuels (NFR14 codes 1A1b & 1A1c) and combustion in industry (NFR14 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 2015 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
SO_x (as SO_2)	1A1b Petroleum refining	15%	-81%
NO_x (as NO_2)	1A1c Manufacture of solid fuels and other energy industries	7%	29%
CO	1A2a Stationary combustion in manufacturing industries and construction: Iron and steel	7%	-69%
SO_x (as SO_2)	1A2a Stationary combustion in manufacturing industries and construction: Iron and steel	5%	-67%
Hg	1A2f Stationary combustion in manufacturing industries and construction: Non-metallic minerals	4%	-12%
CO	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	15%	11%
NO_x (as NO_2)	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	3%	-74%
NMVOC	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	2%	-40%
PM_{10}	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	2%	-74%
$PM_{2.5}$	1A2gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	3%	-74%

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
CO	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	4%	1%
NO_x (as NO_2)	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	7%	-42%
TSP	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	4%	25%
PM_{10}	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	8%	24%
$PM_{2.5}$	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	12%	26%
Hg	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	10%	-49%
Cd	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	26%	16%
Pb	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	15%	-38%
PCDD/PCDF	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	11%	-2%
SO_x (as SO_2)	1A2gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	10%	-86%

The industrial combustion category covers both stationary plant and off-road vehicles and mobile machinery and these combustion processes burn a wide range of fuels in a wide range of combustion devices. In general, the trends since 1990 have been decreasing use of solid and liquid fossil fuels, fairly constant use of natural gas, and increasing use of waste-derived fuels, and biofuels such as biogas and biomass. 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, which have substantially increased across the timeseries.

Figure 2-1 to Figure 2-10 above show the trends with time in the emissions from industrial sources across the timeseries. The changes in fuel consumption are a major factor driving reductions in emissions of many pollutants. Coal and fuel oil contain significant levels of sulphur and metals and so their use can result in emissions of SO_2 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_2 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 significantly. 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 EU Non-Road Mobile Machinery (NRMM) emission Directive.

Emissions of NMVOC 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 NMVOC, and industrial combustion of biomass fuels is the main source of particulate matter. Emissions of NMVOC 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 EU Non-Road Mobile Machinery (NRMM) emission Directive. Emission rates for NMVOC have decreased over time in the case of larger plant burning gas oil and diesel oil, resulting in the decrease for NMVOC. Industrial use of biomass fuels is increasing, resulting in an increase over the time series in particulate matter from the industrial combustion sector.

Further detail in the estimation of emissions from this source sector are included in Chapter 3.2.

2.3.3 Residential, Public and Commercial Sectors

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. However, unlike other pollutants, emissions of PM and PAHs have remained largely unchanged or increased, reflecting the different contributions that coal and wood make to emissions of each pollutant.

The use of coal and other solid mineral fuels as domestic fuels has decreased significantly since 1990, whereas the consumption of wood has increased significantly. Emissions of Cd, PM and PAHs are particularly significant from wood combustion and so, for the residential sector as a whole, emissions of these pollutants have not reduced in the way that has happened for many other pollutants (see Figure Figure 2-5 and Figure 2-10). Table 2-13 summarises key sources and trends.

Table 2-13 Residential: Sector share of UK emissions total in 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
CO	1A4bi Residential: Stationary	27%	-55%
NO_x (as NO_2)	1A4bi Residential: Stationary	4%	-63%
NMVOC	1A4bi Residential: Stationary	5%	-31%
TSP	1A4bi Residential: Stationary	12%	-2%
PM_{10}	1A4bi Residential: Stationary	26%	1%
$PM_{2.5}$	1A4bi Residential: Stationary	40%	0%
Hg	1A4bi Residential: Stationary	5%	-73%
Cd	1A4bi Residential: Stationary	29%	199%
Pb	1A4bi Residential: Stationary	7%	-75%
PCDD/PCDF	1A4bi Residential: Stationary	34%	-60%
SO_x (as SO_2)	1A4bi Residential: Stationary	22%	-64%
PAHs	1A4bi Residential: Stationary	86%	39%
CO	1A4bii Residential: Household and gardening (mobile)	5%	0%
$PM_{2.5}$	1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	2%	-80%

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 EU Non-Road Mobile Machinery (NRMM) emission Directive. A reduction in the maximum permitted sulphur content of gas oil fuels used by these machinery since 2011 has also reduced SO_2 emissions.

Further detail in the estimation of emissions from this source sector are included in Chapter 3.4.

2.3.4 Industrial Processes

Table 2-14 summarises key sources and emission trends for the industrial process sector.

Quarrying and construction are important sources of particulate matter, but emissions have fallen approximately by half since 1990 due to decreased activity in these sectors. Both sectors emit relatively coarse particulate matter and so their significance is much greater for total particulate matter than for $PM_{2.5}$. For example, the construction sector is estimated to have emitted almost half of UK particulate matter in 2016, but only 2% of $PM_{2.5}$.

The chemical industry is a key source category for lead, with 7% of UK emissions in 2016, but also contributes 3% of UK mercury emissions. 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. Lead emissions arise mainly from the production of alkyl-lead fuel additives, but the banning of the use of these additives in most countries in recent decades has very significantly reduced demand for them, and emissions from their production have fallen. Mercury emissions 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 almost a third of UK emissions in 2016, in the case of Pb. Emissions of all of these pollutants have decreased since 1990, most significantly 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 tended to decrease again in 2008-2011, due to a sharp fall in demand in steel which led to decreased production and the mothballing of one large works. 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 sector 2D3) is a key source for NMVOC, contributing 40% of UK emissions of NMVOC in 2016, 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, 10% of UK emission in 2016) and printing inks (2D3h, 1% of UK emissions in 2016) 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 significantly 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 2016. 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 are now 18% of UK NMVOC emissions. Emissions from ‘other solvent use’ (2D3i) contributed 8% of the UK total for NMVOC in 2016, 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 1% of the UK emission of NMVOC in 2016.

The food and drink industry (2H2) is a key source category for NMVOC emissions, contributing 12% of UK emissions in 2016. The largest source is whisky maturation, which accounts for 65% of the food and drink sector emissions, although animal feed manufacture (13% of 2H2), barley malting (7%), fat and oil processing (6%), and baking (4%) are also important. The emission trends with time are primarily driven by production in these sectors, with significant 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 2-14 Industrial Processes: Sector share of UK emissions total in 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
TSP	2A5a Quarrying and mining of minerals other than coal	5%	-43%
PM_{10}	2A5a Quarrying and mining of minerals other than coal	6%	-43%
TSP	2A5b Construction and demolition	47%	-16%
PM_{10}	2A5b Construction and demolition	14%	-46%
$PM_{2.5}$	2A5b Construction and demolition	2%	-46%
SO_x (as SO_2)	2A6 Other mineral products (please specify in the IIR)	3%	29%
Pb	2B10a Chemical industry: Other (please specify in the IIR)	7%	-95%
CO	2C1 Iron and steel production	5%	-41%
TSP	2C1 Iron and steel production	2%	-45%
PM_{10}	2C1 Iron and steel production	3%	-51%
$PM_{2.5}$	2C1 Iron and steel production	3%	-50%
Hg	2C1 Iron and steel production	9%	-34%
Cd	2C1 Iron and steel production	12%	-70%
Pb	2C1 Iron and steel production	31%	-67%
PCDD/PCDF	2C1 Iron and steel production	13%	-64%

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
Hg	2C7c Other metal production (please specify in the IIR)	5%	-96%
Pb	2C7c Other metal production (please specify in the IIR)	5%	-96%
NMVOC	2D3a Domestic solvent use including fungicides	18%	12%
NMVOC	2D3d Coating applications	10%	-68%
TSP	2D3d Coating applications	2%	-8%
PM_{10}	2D3d Coating applications	4%	-8%
$PM_{2.5}$	2D3d Coating applications	3%	-6%
NMVOC	2D3i Other solvent use (please specify in the IIR)	8%	-15%
NMVOC	2H2 Food and beverages industry	12%	34%
Pb	2I Wood processing	5%	-27%

2.3.5 Transport

The transport sector is a key source for many pollutants. Table 2-15 summarises key sources and emission trends for the transport sources.

Table 2-16 Transport: Sector share of UK emissions total in 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
CO	1A3bi Road transport: Passenger cars	14%	-95%
NO_x (as NO_2)	1A3bi Road transport: Passenger cars	16%	-83%
PM_{10}	1A3bi Road transport: Passenger cars	2%	-49%
$PM_{2.5}$	1A3bi Road transport: Passenger cars	3%	-49%
Hg	1A3bi Road transport: Passenger cars	4%	-19%
Cd	1A3bi Road transport: Passenger cars	6%	-10%
NO_x (as NO_2)	1A3bii Road transport: Light duty vehicles	11%	-8%
NO_x (as NO_2)	1A3biii Road transport: Heavy duty vehicles and buses	6%	-80%
NMVOC	1A3bv Road transport: Gasoline evaporation	2%	-95%

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
TSP	1A3bvi Road transport: Automobile tyre and brake wear	3%	24%
PM_{10}	1A3bvi Road transport: Automobile tyre and brake wear	6%	22%
$PM_{2.5}$	1A3bvi Road transport: Automobile tyre and brake wear	5%	24%
TSP	1A3bvii Road transport: Automobile road abrasion	3%	23%
PM_{10}	1A3bvii Road transport: Automobile road abrasion	3%	23%
$PM_{2.5}$	1A3bvii Road transport: Automobile road abrasion	3%	23%
NO_x (as NO_2)	1A3c Railways	4%	57%
CO	1A3dii National navigation (shipping)	3%	120%
NO_x (as NO_2)	1A3dii National navigation (shipping)	10%	-39%
PM_{10}	1A3dii National navigation (shipping)	1%	-85%
$PM_{2.5}$	1A3dii National navigation (shipping)	2%	-85%
SO_x (as SO_2)	1A3dii National navigation (shipping)	7%	-87%

Road transport is a key source for a number of pollutants. 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 (as NO_2), CO, and NMVOC. 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 (as NO_2) emissions. Recent evidence has shown however that Euro 4 and 5 diesel cars and LGVs exceed their type approval limit for NO_x (as NO_2) in real-world operation by significant amounts meaning that there has been little change in emission factors across the range of Euro standards for diesel cars and LGVs. This has been reflected in the emissions factors provided in the recent European COPERT 5 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. More significant reductions in NO_x emissions have occurred for 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 been increasing over the time series with growth in traffic and are now becoming a more important source of traffic-related PM emissions compared with exhaust emissions.

Road transport is a relatively minor source of NH_3 emissions, however NH_3 emissions had 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.

Road transport is the dominant source of emissions compared with other modes of transport in the UK. However, a recent improvement in the method used for estimating emissions from UK domestic shipping (1A3dii) has led to an increase in emissions of all pollutants over the timeseries compared with previous inventory submissions. Domestic shipping is a key category for CO, NO_x, SO_x, PM_{10} and $PM_{2.5}$. Although emissions are higher than previously estimated, emissions of SO_2 and PM are still showing a significant 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 off-shore 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.

The railways sector (1A3c) is a key category for NO_x. Emissions have increased since 1990 due to increased diesel train activities (train kilometres)

Further detailed information on Transport is provided in Chapter 3.3.

2.3.6 Agriculture

The agriculture sector is a key source for NH_3, NMVOC, PM_{10}, and TSP. 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 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
NMVOC	3B1a Manure management - Dairy cattle	3%	-33%
NH_3	3B1a Manure management - Dairy cattle	12%	11%
NMVOC	3B1b Manure management - Non-dairy cattle	6%	-14%
NH_3	3B1b Manure management - Non-dairy cattle	13%	-15%
NH_3	3B3 Manure management - Swine	5%	-56%
PM_{10}	3B4gii Manure management - Broilers	1%	50%
PM_{10}	3B4giv Manure management - Other poultry	1%	80%
NH_3	3Da1 Inorganic N-fertilizers (includes also urea application)	19%	-11%
NH_3	3Da2a Animal manure applied to soils	21%	-21%
NH_3	3Da3 Urine and dung deposited by grazing animals	6%	-18%
TSP	3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products	2%	-12%
PM_{10}	3Dc Farm-level agricultural operations including storage, handling and transport of agricultural products	3%	-12%

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
HCB	3Df Use of pesticides	29%	-92%

Agricultural emissions from livestock and their wastes (NFR14 3B) and emissions from agricultural soils due to use of chemical- and manure-fertilisers and sewage and other sludges (3D) are the major source 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 (NFR14 3Da1) mostly fell between 1990 and 2001, before fluctuating over the following 12 years and then increasing markedly in the period 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 sludges from anaerobic digestion of non-agricultural and sewage sludges.

Emission estimates for NMVOC, PM_{10}, and TSP are calculated using simple approaches and mostly assume 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. The main exception is broilers, where numbers in 2016 were 50% higher than in 1990.

Further detail in the estimation of emissions from this source sector are included in Chapter 5.

2.3.7 Waste

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

Table 2-18 Waste: Sector share of UK emissions total in 2016 and Trends from 1990 to 2016

Pollutant	NFR14 Code and Name	% of total emissions for the given pollutant in 2016	% change in emissions between 1990 and 2016
Hg	5A Biological treatment of waste - Solid waste disposal on land	9%	-44%
Hg	5C1bv Cremation	15%	18%
PCDD/PCDF	5C1bv Cremation	6%	-37%
PCDD/PCDF	5C2 Open burning of waste	8%	-78%
$PM_{2.5}$	5E Other waste (please specify in IIR)	2%	-36%
PCDD/PCDF	5E Other waste (please specify in IIR)	13%	-65%

Emissions from cremations (5C1bv) are a key sector for Hg, 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. People were slightly more likely to still have their own teeth (complete with any mercury fillings) at the time of death in 2016 than was the case in 1990 and so the mercury emission factor is therefore higher in recent years compared to 1990.

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 PCDD/PCDF, and emissions have been influenced by the decline in the use of coal as a domestic fuel (since we assume that some domestic waste is burnt on domestic open fires). However, we also estimate that there has been an increase in the level of outdoor burning of garden and household waste, in line with growth in the number of households. The net effect is a reduction in the estimated overall quantity of waste burnt since 1990% of total emissions for the given pollutant in 2016% change in emissions between 1990 and 2016, although little change in this quantity since 2005. It is possible that rates of open burning could actually have fallen, due to the growth in collection of garden waste in recent decades, but a lack of data means that emission estimates assume no change in the level of bonfires per households. Emission factors for PCDD/PCDF have progressively reduced since 1990, as the make-up of waste materials burnt has evolved.

Further detail in the estimation of emissions from this source sector are included in Chapter 6.

3 NFR14 1: Energy

3.1 NFR14 1A1: Combustion in the Energy Industries

Table 3-1 Mapping of NFR14 Source Categories to NAEI Source Categories: Combustion in the Energy Industries

NFR14 Category	Pollutant coverage	NAEI Source category
1 A 1 a Public Electricity and Heat Production	All CLRTAP pollutants	Power stations
		Public sector combustion (sewage gas)[11]
		Autogenerators (biogas only)[21]
		Miscellaneous industrial/commercial combustion (landfill gas, MSW only)[11]
1 A 1 b Petroleum refining	All CLRTAP pollutants *(except NH_3, HCB and PCBs) add text from email*	Refineries – fuel combustion
1 A 1 c Manufacture of Solid Fuels and Other Energy Industries	All CLRTAP pollutants *(except HCB)*	Coke production
		Collieries – fuel combustion
		Gas production (downstream gas)[22]
		Gas separation plant
		Upstream gas production
		Nuclear fuel production
		Upstream oil production
		Solid smokeless fuel production
		Town gas manufacture

Table 3-2 Summary of Emission Estimation Methods for NAEI Source Categories in NFR14 Category 1A1

NAEI Source Category	Method	Activity Data	Emission Factors
Power stations	UK model	BEIS energy statistics, EU ETS, operators	Major fuels: Operator-reported emissions data under IED/E-PRTR. Minor fuels: default factors (USEPA, EMEP-EEA, UK-specific research)
Miscellaneous industrial/commercial combustion	AD x EF	BEIS energy statistics, EU ETS	MSW: Operator-reported emissions data under IED/E-PRTR. LFG: default factors (USEPA, EMEP-EEA, UK-specific research)
Public sector combustion	AD x EF	BEIS energy statistics	Sewage gas: default factors (USEPA, EMEP-EEA, UK-specific research)

[21] All use of MSW and biogases (landfill gas, sewage gas, biogas from anaerobic digestion of other wastes) to generate electricity and heat is reported in 1A1a, even though at some sites, this might be more accurately described as autogeneration. Use of fossil fuels for autogeneration is reported in 1A2.

[22] 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 NFR14 category, rather than any emissions allocated to 1A3e Pipeline Compressors.

NAEI Source Category	Method	Activity Data	Emission Factors
Autogenerators (biogas)	AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research)
Refineries	AD x EF	BEIS energy statistics, EU ETS	Operator-reported emissions data under IED/E-PRTR, UKPIA; default factors (USEPA, EMEP-EEA, UK-specific research)
Coke production	UK model	BEIS energy statistics, EU ETS, ISSB	Major fuels: Operator-reported emissions data under IED/E-PRTR, Tata Steel, SSI Steel Minor fuels: default factors (USEPA, EMEP-EEA, UK-specific research)
Collieries – fuel combustion	AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research)
Gas production (downstream gas)	AD x EF	BEIS energy statistics, EU ETS	Default factors (USEPA, EMEP-EEA, UK-specific research)
Gas separation plant	AD x EF	BEIS energy statistics, EEMS, EU ETS	EEMS and IED/E-PRTR annual reporting by operators, UKOOA research, EMEP-EEA
Upstream gas production	AD x EF	BEIS energy statistics, EEMS, EU ETS	EEMS and IED/E-PRTR annual reporting by operators, UKOOA / other UK-specific research, USEPA, EMEP-EEA
Nuclear fuel production	AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research)
Upstream oil production	AD x EF	BEIS energy statistics, EEMS, EU ETS	EEMS and IED/E-PRTR annual reporting by operators, UKOOA / other UK-specific research, USEPA, EMEP-EEA
Solid smokeless fuel production	AD x EF	BEIS energy statistics, EU ETS	Default factors (USEPA, EMEP-EEA, UK-specific research)
Town gas manufacture	AD x EF	BEIS energy statistics	Default factors (USEPA, 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 (BEIS, 2017), 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 NFR14 source categories. In most cases, it is possible to obtain a precise mapping of an NAEI source category to a NFR14 source category; however, there are some instances where the scope of NAEI and NFR14 categories are different, as discussed below. Emission estimation calculations are performed for individual NAEI source categories and then aggregated to match the NFR14 reporting system for the CLRTAP submission.

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 3-3 Fuel types used in the NAEI

Fuel type	Fuel name	Comments
Crude-oil based fuels	Aviation Spirit	
	Aviation Turbine Fuel (ATF)	Includes fuel that is correctly termed jet gasoline. Also known as kerosene
	Burning Oil	
	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.
	Petrol	
	Petroleum Coke	Covers 'green' coke used as a fuel and catalyst coke.
	Refinery Miscellaneous	
	Vaporising oil	Not used as a fuel 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 gas used by offshore installations and one power station. Not included separately in DUKES.
	Colliery Methane	
	Town Gas	Not used as a fuel since 1988
Biomass	Wood	Covers all wood burnt by power stations and the residential sector but only waste wood in the case of industry.
	Straw	
	Poultry Litter	Includes meat & bone meal.
	Landfill Gas	
	Sewage Gas	
	Liquid bio-fuels	Liquid bio-fuels used at power stations
	Biogas	Methane generated via anaerobic digestion other than from landfill or sewage plants.
	Biomass	Solid biomass other than waste wood, used as a fuel by industry
Wastes	Municipal Solid Waste	
	Scrap Tyres	Not identified separately in DUKES.
	Waste Oil/ Lubricants	Not identified separately in DUKES.
	Waste Solvents	

Almost all of the NFR14 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 NFR14 sector.

3.1.2 General approach for 1A1

The methodology for NFR14 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)[23] for upstream oil and gas installations situated offshore.

The PI data are available from www.environment-agency.gov.uk,

SPRI data can be viewed at:
http://www.sepa.org.uk/air/process_industry_regulation/pollutant_release_inventory.aspx,

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. The EEMS dataset is supplied to the UK Inventory Agency by the Department of Business, Energy & Industrial Strategy Offshore Inspectorate, which is the regulatory authority for upstream oil and gas installations.

The emissions reported in the PI, WEI, SPRI and NIPI are available as total emissions of each relevant pollutant for each permitted process, rather than being split down by source type or fuel used. 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 & steel production, power plants, 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 site. For example, emissions data for each integrated steelworks are now given as a single figure, and single permits cover all plant utilities and numerous different chemical production units at each chemical works.; Emissions at an installation are therefore not reported split, either by fuel or by process source. This does have some implications for the inventory – these data reported by operators are considered to be the most reliable basis for inventory estimates, but there is uncertainty over the exact scope of estimates for some sites, and so there is the potential that some emissions are not allocated in an ideal way (e.g. for integrated steelworks, emissions of NMVOC, NOx, PM_{10} etc, could arise from a multitude of fuels as well as being from process units). The EEMS dataset does provide some breakdown of emissions by source for the upstream oil and gas sector, with separate emission estimates presented by pollutant, by installation and by source, including: fuel combustion, flaring, venting, process emissions, fugitive releases and oil loading / unloading activities.

To derive UK source emission estimates based on the use of these regulatory pollution inventories, it is therefore sometimes necessary to split the reported emissions data by fuel and/or sub-source. For 1A1a & 1A1b, we split reported emissions of most pollutants across the different fuels known to be burnt by the reporting processes. Where emissions from high-emitting industries are reported across several NFR14 categories (such as the steelworks example mentioned above, or for refineries) the UK Inventory Agency has developed reporting templates that plant operators or trade association contacts complete in order to provide a more accurate breakdown of emissions by source. For less significant 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 accurate for a specific source. In recent years, energy data for energy-intensive industry sectors from the EU Emissions Trading System (EU ETS) are used to revise energy data for some industry sectors such as refineries. The EU ETS data are provided by process operators and verified by accredited verifiers. The data set covers all UK plant within certain sectors: all refineries, major power producers, steelworks, and cement & lime kilns are included, for example. EU ETS-based energy data are therefore considered to be very accurate, and are used for source sectors where the coverage of EU ETS is complete for all UK installations in that sector (e.g. all cement kilns). 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 EU ETS data are believed to be accurate the differences are therefore 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.

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

Emissions of some pollutants are estimated using literature emission factors and activity data from DUKES, rather than from operator-reported data (i.e. installation-level data in the PI, WEI, SPRI, NIPI, and EEMS data). This is particularly true of pollutants such as NMVOC, benzene, 1,3-butadiene, metals and POPs, where the level of operator reporting to regulatory mechanisms is much lower than is the case for NO_x (as NO_2), for example. Many operators do not have to provide emissions data for these pollutants because these emissions are below minimum thresholds for regulatory compliance reporting. 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

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[24], for the reasons presented in section 1.4.2 National Statistics.

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 Emissions Trading System (EU ETS). In part, this is due to the use of recovered waste oils, which is reported as ‘fuel oil’ in the EU 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. As with fuel oil, a re-allocation of gas oil is made so that the NAEI is consistent with the EU ETS data for power stations, but also consistent with overall demand for gas oil, given in DUKES. The EU 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;

  UK inventory activity data include estimates of petroleum coke burnt by power stations (based on data from industry sources and the EU ETS) which differ slightly from the data given in DUKES. Furthermore, activity data for refinery use of petroleum coke for 2005-2010, 2013, 2015 and 2016 are based on EU ETS data, rather than DUKES, because the ETS figures exceed those given in DUKES, and are regarded as more reliable. 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, because the NAEI values for all sectors are based on more detailed data sources than DUKES. The NAEI figure for total use of petroleum coke (including non-energy uses) is, as a result, higher than the DUKES demand figures for 1990-1991, 1999, 2001, 2005-2007 and 2015-2016.

[24] 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.

- Since 2002, DUKES has not included any energy use of gases derived from natural gas liquids (LPG and OPG) that are burned in plant associated with gas separation processes at oil terminals, as these data are no longer routinely provided to BEIS by oil companies. Through the EU ETS and EEMS, however, the use of OPG (mainly ethane) as a fuel at these sites is reported to the environmental regulatory agencies. The EU ETS provides data for this source-activity from 2005 onwards, whereas the EEMS dataset provides data from 1998 until some of the terminals ceased reporting to EEMS (in 2010). The EEMS data are used therefore to estimate the OPG use in these terminals from 2003 onwards, with EU ETS data used to ensure completeness from 2010 onwards.

- The activity data for gas use in the upstream oil and gas sector are under-reported in DUKES prior to 2001. From 2001 onwards, a new reporting system, 'Petroleum Production Reporting System' (PPRS), was used to compile the DUKES data on gas use from upstream exploration and production. The long-term trends Table 4.2 in DUKES shows that "own gas use" by the industry increased by 20% between 2000 and 2001, but this step change is not a real reflection of increased activity but rather in the gap in DUKES gas statistics prior to PPRS, which is mainly due to non-reporting of gas use by gas terminals. The EEMS data provides activity data and emissions from own gas use at 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. These EEMS and UK Oil and Gas activity data are used in preference to the DUKES data for up to 2001, impacting on emission estimates in 1A1c.

- DUKES data for refinery use of refinery fuel gas (referred to as "OPG" in DUKES) are lower than those reported within the EU ETS for most years of the recent time series. Analysis of the total reported emissions data from EU ETS (from 2005 onwards) from the activity data reported in DUKES and from the installation operators directly to the UK Petroleum Industries Association indicates that the gap in UK energy balance data is evident in most years from 2004 onwards. Therefore, in deriving estimates for the UK inventories, the refinery fuel gas activity is aligned with the data from the trade association (UKPIA) for 2004 and from EU ETS in all years where EU ETS data are higher than DUKES data, i.e. 2006-2011, and 2013-2016.

- In the UK energy commodity balance tables presented in DUKES 2014 onwards, the BEIS 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 BEIS 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.

- A new shipping sector research project, finalised in 2017, has developed a new time series of gas oil and fuel oil data for the shipping sector which indicates fuel use significantly higher than reported in DUKES. See section 3.3.5 for further details.

3.1.4 Methodology for power stations (NFR14 1A1a)

NFR14 Sector 1A1a is a key source for NO_x (as NO_2), SO_x (as SO_2), CO, PM_{10}, $PM_{2.5}$, Cd, Hg and HCB.

The electricity generation sector is characterised by a relatively small number of industrial sites. The main fossil fuels used are bituminous coal and natural gas. Approximately 12 Mt of coal were burnt at 12 power stations during 2016 (down by approximately 60% from the previous year), while approximately 9,300 Mtherms of natural gas were consumed at 37 large power stations and 20 small (<50MWth) regional stations (almost all gas plants are Combined-Cycle Gas Turbines, CCGTs). Gas oil or burning oil was used as the primary fuel by four large and nine small power stations; in most cases of gas oil and burning oil use, however, it is used primarily as a start-up or support fuel, for coal-fired or gas-fired power stations. Heavy fuel oil was not used as the primary fuel at any station in 2016, although it too is used as a start-up 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 recent past. In the past, UK power stations have also burnt scrap tyres, Orimulsion, and coal slurry, but none of these fuels has been used in the UK in recent years.

Biofuels are burnt as the primary fuel at an increasing number of power generation sites to help electricity generators meet Government targets for renewable energy production. Four established sites use poultry litter as the main fuel, four more burn straw, and another eight sites burn wood or other biomass. Many coal-fired power stations have increased the use of biofuels such as short-rotation coppice and biomass-based liquid fuels to supplement the use of fossil fuels.

Electricity and/or heat is also generated at 51 Energy from Waste (EfW) plants in the UK. 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 NFR14 5C1a. The waste incinerator on the Scilly Isles may not recover heat or generate electricity, but it is very small, and separate activity data are not available so it is reported under 1A1 together with all other UK incinerators, 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 the E-PRTR. These data are used as the basis of UK inventory emission estimates for the sector. The guidance published for EfW/incineration processes in England and Wales (in 2012) states explicitly that the approach for generating annual emissions data is to "*Calculate release based on daily CEMs average and daily average flow, integrated over year. (Note: based on raw/as measured data without subtraction of confidence intervals)".* This is consistent with other installation reporting to UK regulator inventories for PRTR; the protocol for operator reporting to regulators and PRTR, and subsequently used to derive UK inventory estimates does not include any subtraction of confidence intervals. The UK Inventory Agency has sought further clarifications from UK regulatory agencies, in response to NECD review questions; in response, 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 and so we are confident that the UK estimates are complete, with no under-reports.

Landfill gas and sewage gas are burnt to generate electricity. At the end of 2016, there were 642 sites utilising landfill gas or sewage gas to generate electricity. The UK also had 366 sites where biogas from anaerobic digestion (AD) of wastes from farming, food production or other industries is used to generate electricity. These biogas sites were originally labelled in the UK inventory as autogenerators, but are now treated as power stations, with emissions reported in 1A1a. It is possible that some of the sites burning sewage gas, landfill gas, and other biogas could be more accurately described as autogenerators, however we do not have information for the 1000 or so sites and so report all three in the same way, in 1A1a.

Nearly all 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 only exceptions are a number of very small power stations, typically providing electricity to island communities, which burn burning oil or diesel oil. Emissions from these non-reporting sites are relatively insignificant in the UK context, and emissions are estimated based on activity data from EU ETS or based on plant capacity information. Emission estimates for the sector are therefore largely based on the emission data reported for individual sites:

UK emission = Σ Reported Site Emissions

There are a few instances of sites not reporting emissions of some pollutants, generally because those emissions are trivial, 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 significantly to emission totals, as the non-reporting sites are usually smaller, lower-emitting sites. For example, in the case of NO_x as NO_2 in 2016, reported emissions make up 99.5% of the total UK estimate, whilst the remaining 0.5% is estimated for sites where no reported data are available.

The methodology is complicated by stations burning more than one fuel; as far as possible the UK inventory 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 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 persistent organic pollutants (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 NMVOC 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 NMVOC 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 significant 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 plants and MSW incinerators are also based on operator-reported data within the PI, WEI and SPRI: there are currently no sites in Northern Ireland. 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 (as NO_2) and SO_x as SO_2 from major fossil-fuel powered stations. For NO_x (as NO_2), emission factors from Stewart & Walker (1997) are used for the years prior to 1989, while in the case of SO_x as SO_2, factors for 1970-1987 are based on information provided by coal suppliers. The emission factors for NO_x (as NO_2) & SO_x (as SO_2) 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 (as NO_2) and SO_x (as SO_2), 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 emissions 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 as NO_2 and SO_x as SO_2 from landfill gas engines and NO_x as NO_2 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 EMEP-EEA 2016 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 (as NO_2) emission factor for engines burning landfill gas and sewage gas is based on engines being typically 3MW and complying with the regulatory emission limit values appropriate for this size of plant. The SO_x as SO_2 emission factor for landfill gas engines is based on monitoring results for seven landfill gas engines (reported in Gregory, 2002).

The table below illustrates the methodology by pollutant. To clarify the reporting scope, the metals reported within the UK inventory for sector 1A1a where operator-reported data are primarily used to inform inventory estimates, includes: 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 (as NO_2)	1990- latest year: O 1989: O/M 1970-1988: L
	SO_x as SO_2	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, NMVOC, 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 (as NO_2), SO_x as SO_2	1992- latest year: O 1970-1991: not occurring
	CO	1997- latest year: O 1992-1996: L 1970-1991: not occurring
	VOC, 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 (as NO_2), SO_x as SO_2	1994- latest year: O 1970-1993: not estimated separately, included with estimates for coal
	CO, NMVOC, 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 (as NO_2)	1997- latest year: O 1992-1996: O/M 1970-1991: E
	SO_x as SO_2	1997- latest year: O 1993-1996: O/M 1970-1992: not estimated
	CO	1997- latest year: O 1993-1996: O/M 1970-1992: E
	NMVOC, Hg, PM_{10}	1997- latest year: O 1996: O/M 1970-1995: E
	Dioxins, PAH	1970- latest year: L
Gas oil	NO_x (as NO_2)	1997- latest year: O 1994-1996: O/M 1970-1993: L

Fuels	Pollutant	Methodology
	SO_x as SO_2	1997- latest year: O 1994-1996: O/M 1970-1993: F
	CO	1997- latest year: O 1996: O/M 1970-1995: L
	NMVOC, 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 2016 Guidebook

3.1.5 Methodology for Refineries (NFR14 1A1b)

NFR14 Sector 1A1b is a key source for SO_x as (SO_2).

The UK had eight oil refineries at the start of 2016, 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. Additional data for CO, NO_x (as NO_2), SO_x as SO_2, and PM_{10} are supplied annually by process operators via the United Kingdom Petroleum Industry Association (UKPIA, 2017). These data split the emissions[25] for the complex refineries into those from large combustion plants (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 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:

UK Emission = Σ Reported Site Emissions

The UKPIA 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 1998-2016. Data for Scotland's refineries are reported in the SPRI for the years 2002 and 2004-2016. Emissions data for NO_x (as NO_2) and SO_x as SO_2 from the large 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 (as NO_2) and SO_x (as SO_2), and back to 1998 for other pollutants. While emission factors for earlier years are generated by extrapolation from 1990 data for NO_x (as NO_2) and SO_x as SO_2, and 1998 data for other pollutants.

[25] 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.

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 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 BEIS energy statistics team to reconcile the EU 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 trivial or because a site has closed down partway through a year and therefore does not submit an emissions report. 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 significantly 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 UK inventory 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, but the NAEI needs to record 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 (as NO_2), SO_x (as SO_2), and PM_{10} from catalyst regeneration involving the burning of petroleum coke are calculated directly from the data provided by UKPIA. The UK inventory 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 emissions of persistent organic pollutants, reporting of emissions in the PI 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 UK energy statistics (BEIS, 2017); however, the EU ETS data on energy use and emissions indicate an under-report in refinery fuel gas use at UK refineries within the energy statistics, and there is close consistency between EU ETS and UKPIA emissions totals for carbon dioxide. Therefore, the EU ETS activity data for refinery fuel gas are used in preference to DUKES, with amendments to the DUKES statistics back to 2004 inclusive in all years where EU ETS data are higher than DUKES. (See also Section 3.1.3 above for further information.)

3.1.6 Methodology for other energy industries (NFR14 1A1c)

NFR14 Sector 1A1c is a key source for NO_x (as NO_2). The sector covers emissions from production of manufactured fuels (coke, other solid smokeless fuels (SSF), town gas), coal extraction, oil and gas exploration and production, and gas distribution.

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 2016, there were just three coke ovens at steelworks in the UK, following the closure of two other coke ovens associated with the Teesside steelworks in 2015 and closure of the last independent coke oven in late 2014. Solid smokeless fuels (SSF) can be manufactured in various ways but only those processes regulated under IED/E-PRTR are included in the inventory since only these give rise to significant emissions. 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 plants in the UK in 1987.

Table 3-5 UK Coke Ovens and SSF Manufacturing Plant in Operation, 1970-2016

Process type	Period	No of plant
Coke ovens	2015-2016	3
	2004-2014	6
	2003	7
	1993-2002	9
	1991-1992	10
	1970-1990	Insufficient data
Solid smokeless fuel manufacture	2006-2015	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:

UK Emission = Σ 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 significantly 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, emissions from process sources can also be very significant, and the approach taken to allocate reported emissions to fuels varies from pollutant to pollutant.

The first approach is used for NO_x (as NO_2), 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 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 emissions from the coke oven gas.

Emissions of other pollutants will either be significant both from combustion and process-related sources, or will predominantly occur from process sources. In the case of SO_x as SO_2, emissions data are split between coke oven gas combustion and process sources using a ratio based on actual emissions data for these sources for the mid-1990s. For CO, NMVOC, 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 types of emissions. These emissions are reported under NFR14 Sector 1B1b. The UK inventory 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 2001a) or from USEPA 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 so reporting of emissions is very limited in the Pollution Inventory due to reporting thresholds, with only CO, NO_x and PM_{10} reported 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 (EMEP, 2016) or earlier versions of the (EMEP-CORINAIR) guidebook, and several UK research reference sources from the early 1990s. These emissions are reported under NFR14 Sector 1B1b.

Gas Production (Downstream Gas)
Emissions from fuel use in the downstream gas production industry are primarily from 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. For most years, the activity data for this source are taken directly from DUKES; however, the EU ETS reporting system also provides activity data for gas use in compressor stations since 2005, and in some years the EU ETS data exceeds the gas allocation in DUKES. Therefore, in the UK inventory we use the DUKES data unless EU ETS data are higher; where we use the higher EU 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 applied, taken primarily from USEPA AP-42, the EMEP-EEA 2016 Guidebook and from UK industry research where it is available.

Upstream Oil and Gas Exploration and Production (E&P) Sources
The UK inventory includes emissions from all of the upstream oil and gas E&P sources, with emissions allocated to NFR14 source category 1A1c from all fuel combustion-related activities at offshore and onshore oil and gas platforms and floating production and storage vessels, as well as from combustion sources at onshore terminals.

Offshore oil and gas facilities are regulated by the BEIS Offshore Inspectorate, whilst onshore facilities are regulated under the IED/EPR by the Environment Agency, NRW, and SEPA.

Annual emission estimates from all such facilities are reported via the Environmental Emissions Monitoring System (EEMS) from 1998 to 2010; offshore facilities still report to EEMS, whilst for onshore terminals this reporting is now voluntary, as it is regarded as duplication of mandatory reporting under the IED/EPR. For combustion of gas, gas oil and fuel oil, the EEMS dataset includes activity data and emission estimates for NO_x (as NO_2), SO_x (as SO_2), CO, NMVOC 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 EU 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 IED EPR operator reported data, with data for prior to 1998 based on periodic studies by the trade association, UK Oil and Gas including a revision of time series estimates provided in December 2005. Emission estimates of PM_{10} from use of gas oil and natural gas by oil & gas production facilities are derived using default factors from USEPA AP-42, while PM_{10} factors for process gas used as fuels at terminals are taken from the EMEP-EEA 2016 Guidebook.

Other 1A1c Sources
Other emission sources reported under 1A1c include fuels used at collieries and fuels used at sites processing nuclear fuels. Emissions from these sources are relatively low in the UK inventory context. The emission estimation methodology in all cases uses the UK energy statistics activity data and applies default emission factors from USEPA AP-42, the EMEP-EEA 2016 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 BEIS 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 Environment Agency, 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 & verified locally by their main regulatory contact (Site Inspector), and then passed to a central Pollution

Inventory 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 UK inventory team in order to identify any major outliers. The PI, WEI, SPRI & NIPI contain well in excess of 100,000 individual emissions data points covering thousands of sites, and at many sites emissions show significant year on year changes. Such variations can 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 or failure of those systems, etc. Finally, operators may change the basis on which they 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 we have assumed that most year-on-year variations in emissions data are a reflection of real changes in emissions, and only reject emissions data in a small number of cases where the reliability of the data seems to be particularly in doubt. Conclusions from our reviews are periodically fed back to the regulators. Specific data inconsistencies are sometimes queried directly with the PI, WEI, SPRI & NIPI teams, Site Inspectors or other technical experts within the regulatory agencies, to seek to resolve data-reporting errors and to ensure the use of appropriate data within UK inventory outputs.

3.1.8 Recalculations in NFR14 1A1

There have been no particularly significant recalculations since the 2017 submission in NFR14 1A1. The most notable of the recalculations are:

- Emissions from the consumption of biogas in autogeneration have been re-allocated from 1A2g to 1A1a in the latest submission, which increases emissions in 1A1a, most significantly in recent years as the UK has seen a notable increase in use of anaerobic digestion to generate biogas that is subsequently used to generate electricity.
- The activity data for gas oil use in 1A1 and also for waste-derived fuels have been revised in the latest submission, which also lead to small increases in emissions in 1A1 in the latest submission; these are due to recalculations in the national energy statistics and also improved resolution of waste-derived fuel activity data in DUKES.
- Minor revisions to operator-reported data in the refinery sector have led to minor recalculations of emissions of pollutants such as NOx in 2015.
- The provision of improved estimates for the source-specific splits of emissions across integrated steelworks has also led to recalculations in 1A1 that are merely re-allocations within the UK inventory totals. New data from Tata steel provides revised estimates of emissions for coke oven plant, combustion plant and sinter plant for UK steelworks in 2013-2015, leading to slightly lower emissions in coke ovens (1A1c) and higher emissions for other sources.
- Emissions of dioxins and PAH in 1A1 have been revised through a review of the available literature factors and operator-reported data across the time series. In 1A1a, dioxin estimates have been increased for several years of the time series due to new operator-reported emissions data for the Lancing power station. Emission estimates for B[a]P are significantly higher due to inclusion of estimates for all stations using biofuels and for gas-fired plant. In 1A1b, the use of EMEP-EEA default factors has led to notably lower dioxin & B[a]P emissions than previous submissions, especially due to lower literature factors for emissions from petroleum coke and heavy fuel oil (in case of dioxins only).

3.1.9 Planned Improvements in NFR14 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. We do not have any details of how these operators derive their estimates, so it is impossible to be sure how reliable the figures are, however as described elsewhere, the data in the regulators' inventories is subject to thorough QA/QC, and the level of reporting is very high with all significant sites within 1A1 reporting data. We therefore regard the emission estimates for 1A1 to be generally of high quality. Note, however, that this relates to the emission totals only – the operators do not provide emissions data split by fuel or process, so all disaggregation by fuel etc. is based on assumption, and therefore much more uncertain. The presumption of a high level of overall quality in the emission estimates for 1A1 mean that this category is not regarded as a high priority for any major improvements.

Some sub-sectors within 1A1 consist mostly of a handful of smaller sites (for example power stations using gas oil or biomass as the primary fuel are almost all very small). Because of their small size, most of these sites do not emit sufficiently large quantities of air pollutants to require emission reporting. Therefore, for these smaller sites, we have to make assumptions and extrapolate data, in order to derive emission estimates. The resulting emission estimates are therefore more uncertain, and tend to vary significantly from year to year due to the limited and variable input data. It should be stressed though that these more uncertain sub-sectors are, since they consist of a small number of small sites, insignificant emission sources compared with the UK as a whole, and so are not a priority for improvement.

3.2 NFR14 1A2: Manufacturing Industries and Construction

Table 3-6 Mapping of NFR14 Source Categories to NAEI Source Categories: Stationary Combustion

NFR14 Category (1A2)	Pollutant coverage	NAEI Source category
1 A 2 a Iron and Steel	All CLRTAP pollutants (except HCB)	Blast furnaces
		Sinter plant use of coke
		Iron and steel - combustion plant
1 A 2 b Non-ferrous metals	All CLRTAP pollutants	Non-ferrous metal (combustion)
		Autogenerators (coal)
1 A 2 c Chemicals	All CLRTAP pollutants	Ammonia production - combustion
		Methanol production - combustion
		Chemicals (combustion)
1 A 2 d Pulp, Paper and Print	All CLRTAP pollutants	Pulp, paper & print (combustion)
1 A 2 e Food processing, beverages and tobacco	All CLRTAP pollutants	Food & drink, tobacco (combustion)
1 A 2 f Stationary combustion in manufacturing industries and construction: Other	All CLRTAP pollutants	Cement - non-decarbonising
		Cement production - combustion
		Lime production - non decarbonising
		Other industrial combustion
1 A 2 gvii Mobile Combustion in manufacturing industries and construction: (please specify in the IIR)	All CLRTAP pollutants	Industrial off-road mobile machinery
1 A 2 gviii Stationary combustion in manufacturing industries and construction: Other (please specify in the IIR)	All CLRTAP pollutants	Autogenerators
		Other industrial combustion

Table 3-7 Summary of Emission Estimation Methods for NAEI Source Categories in NFR14 Category 1A2

NAEI Source Category	Method	Activity Data	Emission Factors
Blast furnaces	UK model for integrated works	BEIS energy statistics, EU ETS, ISSB	Operator-reported emissions data under IED/E-PRTR, plant-specific data from Tata Steel. Default factors (EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Iron and steel - combustion plant	UK model for integrated works; AD x EF	BEIS energy statistics, EU ETS, ISSB	Operator-reported emissions data under IED/E-PRTR, plant-specific data from Tata Steel. Default factors (EMEP-EEA, USEPA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.

NAEI Source Category	Method	Activity Data	Emission Factors
Non-ferrous metal (combustion)	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Ammonia production - combustion	AD x EF	BEIS energy statistics, operator data on natural gas use for feedstock and combustion.	Operator data on annual NO_x emissions from combustion sources, Default factors (USEPA) for other pollutants.
Chemicals (combustion)	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics, EU ETS	Default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Pulp, paper & print (combustion)	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Food & drink, tobacco (combustion)	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Autogenerators	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Operator-reported emissions data under IED/E-PRTR. Default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Cement - non-decarbonising	AD x EF	Mineral Products Association clinker production data, EU ETS	IED/E-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).
Cement production - combustion	AD x EF	Mineral Products Association fuel use data, EU ETS	IED/E-PRTR annual reporting by operators, default factors (USEPA, EMEP-EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Lime production - non decarbonising	AD x EF	EU ETS data, with extrapolation across time-series using IED/E-PRTR emissions data and production estimates from British Geological Survey.	IED/E-PRTR annual reporting by operators, default factors (USEPA, EMEP-EEA, UK-specific research).
Other industrial combustion	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics (modified to accommodate other data sources such as MPA, EU ETS). EU ETS data (OPG).	Default factors (USEPA, EMEP-EEA, HMIP, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Industrial off-road mobile machinery	AD x EF	Inventory agency estimate of fuel use by different mobile units	Default factors (EMEP-EEA, USEPA, UK-specific research)

3.2.1 Classification of activities and sources

As with NFR14 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 NFR14 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 NFR14 system being used instead for submission under the CLRTAP. All of the subsectors of 1A2 consist of a mixture of large and small plant, but the precise number of industrial combustion processes is not known.

In most cases it is possible to obtain a precise mapping of an NAEI source category to a NFR14 source category. However, there are a few instances where the scope of NAEI and NFR14 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 3.2.4) and so mapping of the NAEI source categories to a single NFR14 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 significant 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 is 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 ETS and other site-specific data, while data for 1A2g are taken from DUKES. Details of the methods used to disaggregate fuel data are given in Section 3.2.3. Autogeneration using coal is reported in 1A2b since most of the coal burnt is 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 NFR14 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 NFR14 sector.

3.2.2 General approach for 1A2

NFR14 Sector 1A2a (iron and steel combustion) is a key source for CO and SO_x (as SO_2); sector 1A2f (mineral products – combustion) is a key source for metal emissions, including Hg; sector 1A2gvii (industrial off-road mobile machinery) is a key source for CO, NO_x (as NO_2), NMVOC, PM_{10} and $PM_{2.5}$; sector 1A2gviii (other industrial combustion) is a key source for SO_x (as SO_2), NO_x (as NO_2), CO, TSP, $PM_{2.5}$ and PM_{10}, metal emissions including Cd, Pb, Hg and also for PCDD/PCDFs.

The inventory estimates for the chemicals sector are prepared at a greater level of resolution, with emissions estimated separately for 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.

For many sources and pollutants, the UK inventory estimates are based on operator-reported emissions data, including:

- 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 UK inventory estimates are derived from the aggregate of reported emissions, with some gap-filling assumptions applied for installations where the reported emissions fall below the threshold for regulatory reporting (under IED/PRTR);
- Similarly, emissions from burning of gases to heat blast furnaces are also calculated from reported data for SO_2 and NO_x (as NO_2), with operators providing the estimates for individual

plant across integrated steelworks. For other pollutant emissions there is less detailed and complete operator data, and therefore an approach based on use of literature factors is used.

- Emissions of CO and NO_x (as NO_2) 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, whilst SO2 estimates are based on compositional analysis from coal suppliers.

Other NAEI source categories are a mixture of large and small plants and a bottom-up approach utilizing reported emissions is not possible. In these cases, therefore, literature emission factors, taken mainly from the 2016 EMEP/EEA Emission Inventory Guidebook, are used together with activity data from DUKES.

The UK submission reports biomass activity data (AD) and emissions for all industrial combustion sub-sectors (1A2b,c,d,e) all aggregated within 1A2g, as this reflects the resolution of data available from UK energy statistics. As the UK does not have any AD by sub-sector for biomass, there is no improvement in UK inventory accuracy to be gained by seeking to make separate sector estimates. Therefore, the UK does not propose to generate sector-specific biomass emission estimates unless new data become available to enable that disaggregation of the 1A2g estimates to be performed.

3.2.3 Fuel consumption data

Fuel consumption data are predominantly taken from DUKES. 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 1.3.2 National Statistics.
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 specific fuel use data for those sectors, which are therefore split-out from the wider industrial fuel use data. Fuel use data for cement kilns are provided by the Mineral Products Association (MPA, 2017), and are also available from the EU ETS. The EU ETS data provides the basis for the Inventory Agency annual estimates of fuel used at lime kilns.
2) 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 industry. The inventory, however, must include emissions from these off-road vehicles and mobile machinery as separate categories to the use of gas oil in stationary combustion equipment. The Inventory Agency therefore generates independent estimates of gas oil use for off-road vehicles and mobile machinery from estimates of the numbers of each type of vehicle/machinery in use, and their fuel consumption characteristics. Emission estimates are also made independent of DUKES for other sectors including power stations, railways, and agricultural machinery. Estimates are then made of gas oil use in stationary combustion plant using EU ETS data. Since the EU ETS only covers larger sites, the consumption of gas oil given in the EU ETS is factored up to account for all stationary plant, by assuming a similar split between EU ETS and non-ETS usage as is the case for natural gas. This approach was adopted since gas oil is mostly used as a secondary fuel at sites burning natural gas as the primary fuel. Finally, overall consistency with UK consumption of gas oil, as given in DUKES, is maintained by summing the NAEI estimates of gas oil usage, comparing with the DUKES totals, and then adjusting the NAEI estimates for gas oil used for off-road vehicles as necessary to ensure that the NAEI total matches that given in 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 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 fuels is not reported within DUKES, as the feedstock provided to the installations are reported as “non- energy use”. Therefore, in the UK inventories emission estimates are based on reported EU ETS activity data for these installations (for 2005 to 2016), 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 NFR14 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 considered more reliable.

5) In the UK energy commodity balance tables presented in DUKES 2014, the BEIS 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 BEIS 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 and natural gas. Full details of the methods used to generate the activity data are given below.

3.2.3.1 Coal

Fuel use in NFR14 sector 1A2f only covers the consumption in cement kilns and lime kilns, for which the Inventory Agency make estimates based on data from the MPA and EU 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 1990-2016, 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 sites construction, site capacity, the choices of fuel available to the cement industry and IPC 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, therefore, 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.

3.2.3.2 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 NFR14 1A1c for gas compressors in the downstream gas distribution network is estimated based on data reported by operators under EU ETS. The data from EU 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 for 1A1c.

3.2.3.3 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 3.3.5).

3.2.3.4 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 is unable to 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.

3.2.4 Methodology for cement & lime kilns

The UK had 11 sites producing cement clinker during 2016. 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. Lime was produced at 12 UK sites during 2016, however two of these sites produce lime for use on-site in the manufacture of soda ash via the Solvay process, so emissions from those two plant are reported under 2B7. Four of the remaining 12 sites produce lime for use on-site in sugar manufacturing, and one other sites produces dolomitic limes. 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:

UK Emission = Σ Reported Site Emissions

There are instances of sites not reporting emissions of some pollutants, generally because those emissions are trivial, 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 significantly 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 (as NO_2) 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.

3.2.5 Methodology for blast furnaces

Emissions data for the period 2000-2016 are supplied by the process operators (Tata Steel, 2017; SSI, 2015). In the case of NO_x (as NO_2), 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 NFR14 category 2C1.

Due to economic difficulties in the iron and steel industry in recent years, at the time of the compilation of the 2016 submission, we had been unable to collect the data that we normally would from operators. In the absence of this data, PI data for 2013-2015 emissions was used, in conjunction with the previously reported detailed data from operators for the years up to 2012. These data for 2013-2015 have now been over-written by updated operator data from Tata Steel (Tata Steel, 2017) that provides more accurate resolution of emissions from coke ovens, combustion plant, fugitives and sinter plant. Tata Steel also provided data for their one remaining site in 2016, however the Scunthorpe works has now been sold and we have been unable so far to obtain detailed emissions data from the new owner for the year 2016. For this works therefore we have had to use the site emissions data reported in the PI and assume the same split between different sources as indicated in the data received from Tata for 2015, when they still owned the plant.

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 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 significantly 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.

3.2.6 Methodology for industrial combustion

As previously described, consumption of coal, fuel oil, gas oil and natural gas is estimated separately for 1A2a through to 1A2g. With a few exceptions such as blast furnaces and cement kilns discussed above, the emission factors used are the same for the different sub-categories of industrial fuel. In the case of other fuels such as coke oven coke, LPG, and burning oil, all industrial fuel use is reported in 1A2g, so there is no need to even consider using different factors for different industrial sub-sectors. The 1A2g sector is also sub-divided into combustion in stationary plant (1A2gviii) and combustion in off-road vehicles and mobile machinery (1A2gvii), although the methodology for the latter sector is described with other transport-related sources, in section 3.3.7.

Emission estimates for CO, NO_x (as NO_2) and PM_{10} from the combustion of coal, coke oven coke, fuel oil, gas oil, burning oil and natural gas are largely based on the use of Tier 1 EMEP/EEA Emission Inventory 2016 Guidebook default factors. This approach is straightforward and transparent, but is subject to high uncertainty. The Guidebook does provide Tier 2 emission factors for certain combustion processes but these are mainly furnaces and kilns, and in many cases relate to industries that are of minor significance in the UK (for example, primary production of non-ferrous metals). In any case, UK energy data are not available at a sufficiently detailed level to allow the use of any of the Tier 2 factors, except for cement and lime where UK-specific emissions data are available and used instead.

In the case of SO_x (as SO_2), emission factors for coal and oils are derived from data on typical sulphur contents of the fuels, with information being provided by fuel suppliers. The factors for coal have become more uncertain over time, due to a shift away from UK-mined coal (for which it is relatively easy to get data on sulphur contents), to imported coal (for which we cannot get good data).

For other pollutants, the approach has always been to use a single, literature-based emission factor for each fuel. Emission factors are mostly taken from the EMEP/EEA 2016 Guidebook, with the US EPA compilation of emission factors (AP-42) also used extensively.

In the case of coal-fired autogeneration, one plant is responsible for almost all of the fuel used nationally, and so emissions from that sector alone are calculated using emission factors derived from the emissions reported in the PI for that plant, and an estimate of coal consumption at that plant derived from the reported emissions of CO_2.

3.2.7 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, with specific additional QA/QC for 1A2 outlined here.

Allocations of fuel use are primarily derived from BEIS publications that are subject to established QA/QC requirements, as required for all UK National Statistics. For specific industry sectors (iron & steel, cement, lime, autogeneration) the quality of these data are also checked by the Inventory Agency through comparison against operator-supplied activity and emissions information and energy use data obtained from the EU Emissions Trading System. As discussed above, there are instances where such information has led to amendments to the fuel allocations reported by BEIS (through fuel re-allocations between sectors).

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

3.2.7.1 Recalculations in NFR14 1A2

The most significant recalculations since the 2017 submission in NFR14 1A2 are:

- Emissions of many pollutants in 1A2a (iron and steel combustion) have been recalculated for 2013-2015 based on revised data provided by the main operator of integrated steelworks in the UK (Tata Steel) to provide updated emission totals by sub-unit, which has led to revisions in the allocations of emissions across 1A1c, 1A2a and 2C1. Emissions of NO_x and SO_2 are now reported as slightly higher in 1A2a, compared to the 2017 submission, whilst there is little change in emission estimates of other pollutants such as PM_{10}.
- Dioxin emissions for most of the 1A2 sectors have been recalculated with increases generally across the time series due mainly to applying the latest EMEP/EEA 2016 guidebook default factors for coal use (which is higher than the previous factor used). Other revisions to EFs have also had an effect, as slightly lower (EMEP/EEA) defaults are now applied for gas oil and fuel oil (in 1A2a), which partly offsets the change to the coal EF. A minor impact is the introduction of dioxin estimates from gaseous fuels in 1A2; previously no such estimates were included in the UK inventory but the EMEP/EEA defaults have now been applied, increasing emissions slightly across the time series.
- Emission estimates have also been added for PAH emissions from gaseous and light petroleum fuels, and existing emission factors for some solid and heavy petroleum fuels have been revised, with factors from the EMEP/EEA 2016 Guidebook being generally used. Although these improvements have increased the level of completeness of the UK inventory, they have had only a relatively trivial impact on UK emission totals.

- SO_2 emissions have been estimated for gaseous fuels, following this being identified as a gap during the recent NECD review.
- A new database-based system has been used to generate emission factors for 1A2 (and, to a lesser extent, 1A1 & 1A4) from EMEP/EEA Guidebook defaults. This new system ensures harmonisation of assumptions used to convert the Guidebook factors (on a *net* energy basis) to NAEI units (on a *gross* energy basis for gases and on a mass basis for solid/liquid fuels). Although this is a significant improvement in terms of ensuring the quality of the inventory, it has had only trivial impacts on emission totals.
- There was a systematic re-allocation of natural gas use within the UK energy statistics (BEIS, 2017), which re-allocated gas use from 2008 onwards between commercial (1A4) and industry (1A2). The result of this is a minor overall change to the UK inventory totals, but for the 1A2 sector this leads to notably higher allocations of gas use compared to the previous submission, and therefore higher emissions of pollutants associated with gas combustion, e.g. NOx, CO.
- Revisions to the DUKES total UK consumption of gas oil in 2015 (and minor changes in earlier years) has led to a higher allocation of gas oil to industrial combustion, as the "residual" emission source once all known emission sources are accounted for. There have also been revised data on the UK fleet penetration and emissions performance of several classes of mobile machinery (e.g. stage IIIA forklifts and dumpers), which has led to some redistribution of fuel use estimates across the 1A2gvii mobile machinery fleet and revisions to EFs for specific mobile machinery types, within the UK off-road model. The impacts of these AD revisions and improvements to the UK model are that 1A2gvii emissions of PM_{10} and NO_X are now higher than the previous submission for recent years of the time series, and much higher in 2015 (due to the DUKES AD revision compounding the impacts of EF changes in the model); similarly, emissions of CO are slightly higher for recent years; emissions of pollutants such as SO_2, B[a]P and dioxins are less impacted by the EF and model revisions but are notably higher in 2015, driven by the DUKES AD revision for petroleum fuels.
- The emissions from biogas use in autogeneration have been re-allocated in the UK inventory from 1A2gviii in the previous submission, to 1A1a in the 2018 submission. This is the main reason for recalculations in 1A2gviii, which for many pollutants are now lower in recent years (as the generation of power from biogas is a relatively recent technology in UK). For SO_2, however, the recalculations are dominated by revisions in the allocations of coal and petcoke, the most notable of which is an increased allocation in 2013, which is the result of a reallocation of coal use from the residential sector to unclassified industry; petcoke activity data has been recalculated and is slightly higher now for recent years (~2-3% higher since 2010).

3.2.8 Planned Improvements in NFR14 1A2

With a few 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 2016 Guidebook defaults, based on inventory good practice. However, this approach cannot take into account 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. As a result, emission estimates for 1A2 are relatively uncertain. Ideally, emission estimates should be able to accurately reflect the types of combustion appliances in use in the UK and take into account the level of abatement of emissions (and also the changes in these over time). In practice the data do not exist that would allow this to be done. So while emission estimates are highly uncertain, it is currently not possible to identify any options for significantly improving emission estimates.

3.3 NFR14 1A3: Transport

Table 3-8 Mapping of NFR14 Source Categories to NAEI Source Categories: Transport.

NFR14 Category (1A3)	Pollutant coverage	NAEI Source category	Source of Emission Factors
1 A 3 a i(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	
1 A 3 a ii (i) Civil Aviation (Domestic, LTO)		Aircraft - domestic take-off and landing	
		Aircraft between UK and Gibraltar - TOL	
1 A 3 b i 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, UKPIA (2017) or factors from COPERT 5 and EMEP inventory guidebooks
		Diesel cars (cold start, urban, rural and motorway driving)	
		Road vehicle engines (lubricating oil)	
1 A 3 b ii 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)	
1 A 3 b iii Road transport: Heavy duty vehicles		Buses and coaches (urban, rural and motorway driving)	
		HGV articulated (urban, rural and motorway driving)	
		HGV rigid (urban, rural and motorway driving)	
1 A 3 b iv Road transport: Mopeds & motorcycles		Mopeds (<50cc 2st) - urban driving	
		Motorcycle (>50cc 2st) - urban driving	
		Motorcycle (>50cc 4st) – urban, rural and motorway driving	
1 A 3 b v Road transport: Gasoline evaporation	NMVOCs	Petrol cars and LGVs, mopeds and motorcycles (<50cc 2st and >50cc 4st)	
1 A 3 b vi 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)	
1 A 3 b vii 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)	
1 A 3 c Railways	All CLRTAP pollutants including PCDD/PCDFs *(except PAHs, HCB and PCBs)*	Rail - coal	UK factors, UKPIA (2017)
		Railways - freight	
		Railways - intercity	
		Railways - regional	

NFR14 Category (1A3)	Pollutant coverage	NAEI Source category	Source of Emission Factors
1A3dii National navigation (Shipping)	All CLRTAP pollutants *(except PCBs)*	Marine engines	UK factors and EMEP inventory guidebooks
		Shipping – coastal	Scarbrough et al. (2017), EMEP/EEA Guidebook, UKPIA (2017)
		Inland waterways	EMEP inventory 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	UK Literature sources, EMEP Guidebook
1A4bii Non-road mobile sources and machinery	All CLRTAP pollutants *(except NH_3 HCB and PCBs)*	Domestic house and garden mobile machinery	EMEP inventory guidebooks
1A4cii Non-road mobile sources	All CLRTAP pollutants *(except NH_3 HCB and PCBs)*	Agricultural mobile machinery	EMEP inventory guidebooks
1A4ciii Non-road mobile sources	All CLRTAP pollutants *(except PCBs)*	Fishing	UK factors and EMEP inventory guidebooks
1 A 5 b Other, Mobile (Including military)	All CLRTAP pollutants *(except HCB and PCBs)*	Aircraft - military	UK Literature sources, EMEP Guidebook
		Shipping - naval	Scarbrough et al. (2017), EMEP/EEA Guidebook, UKPIA (2017), Entec (2010)

This section and the table immediately above cover NFR14 category 1A3 in full plus other types of mobile machinery and non-road transport included under NFR14 categories 1A2, 1A4 and 1A5.

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 3-8 above according to the NFR14 source categorisation.

Almost all of the NFR14 source categories listed in Table 3-8 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR14 sector.

3.3.2 Aviation

In accordance with the agreed guidelines, the UK inventory 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 are not included in national totals. Emissions from both the landing and take-off (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 UK inventory is a complex UK-specific model that uses detailed flight records and plane-specific, 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 Energy & Environment 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); and
- ✓ the published inventories for Heathrow, Gatwick and Stansted airports, commissioned by the airport operators themselves. Emissions of NO_x (as NO_2) and fuel use from the Heathrow inventory are used to verify the inventory results.

In 2006, the Department for Transport (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 UK inventory method, for all UK flights. Other recommendations that are reflected in the UK inventory 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 UK inventory 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[26]. In addition, flights to and from oilrigs are included in the inventory.

Improvements to the UK aviation method in recent years include:

- The 1990-2012 inventory incorporated data from local London airport inventories (2008 onwards) so that aircraft engine mixes; times in mode and thrust settings are consistent with the latest fleet and performance data. Furthermore, international flights with an intermediate stop at a domestic airport were reclassified as having a domestic leg and an international leg.

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

- The 1990-2013 inventory incorporated revised cruise emissions in line with the updated EMEP-EEA air pollutant emission inventory guidebook. Errors had been corrected in the assumptions regarding climb thrust settings and engine bypass ratios.

- The 1990-2014 inventory incorporated improvements in the assignment of aircraft to EMEP-EEA cruise categories; and updated assumptions regarding the APU types fitted to aircraft.

- The 1990-2015 inventory incorporated minor revisions to the following:
  - assignment of aircraft to EMEP-EEA cruise categories
  - assumptions regarding the APU types fitted to aircraft
  - surrogate aircraft data used in calculation of LTO cycle emissions

- The 1990-2016 inventory incorporates:
  - Further revisions to assignment of aircraft to EMEP-EEA EMEP/EEA (2016) Guidebook cruise categories
  - Further improvements to assumptions regarding the APU types fitted to aircraft
  - Minor revisions to assignment of aircraft to other operational categories
  - Revisions to the fuel consumptions and emission factors assumed for a number of smaller aircraft, particularly for piston aircraft, which consume aviation spirit, based on factors in the EMEP/EEA (2016) Guidebook.

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 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. Domestic movements in 2016 are at similar levels to those seen in 2014.

3.3.2.1 Emission Reporting Categories for Civil Aviation

Table 3-9 below shows the emissions included in the emission totals for the domestic and international civil aviation categories currently under the UNFCCC, the EU NECD and the CLRTAP. Note the reporting requirements to the CLRTAP have altered recently – the table contains the most recent reporting requirements.

Table 3-9 Components of Emissions Included in Reported Emissions from Civil Aviation

	EU NECD	LRTAP Convention	EU-MM/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). 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.

A summary of aircraft movement data is given in

Table 3-10. 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 (BEIS, 2016). 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 (1995) and 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 Ministry of Defence (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 3-10 Aircraft Movement Data

	International LTOs (000s)	Domestic LTOs (000s)	International Aircraft, Gm flown	Domestic Aircraft, Gm flown
1990	460.5	377.0	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	146.4
2011	769.2	381.2	1465.2	141.6
2012	765.7	365.2	1444.6	137.5
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

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 (as SO_2) and metals are derived from the contents of sulphur and metals in aviation fuels (UKPIA, 2017). These contents are reviewed, and revised as necessary, each year. Full details of the emission factors used are given in Watterson *et al*. (2004).

Table 3-11 Sulphur Dioxide Emission Factors for Civil and Military Aviation for 2016 (kg/t)

Fuel	SO_x as SO_2 (kg/t)
Aviation Turbine Fuel	1.6
Aviation Spirit	1.6

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 International Civil Aviation Organization (ICAO) database. The cruise emissions are taken from EMEP/EEA Guidebook data (which are themselves developed from the same original ICAO dataset). Average factors for aviation representative of the fleet in 2016 are shown in Table 3-12.

Table 3-12 Average Emission Factors for Civil and Military Aviation for 2016 (kt/Mt)

	Fuel	NO_x (as NO_2)	CO	NMVOC
Civil aviation				
Domestic LTO	AS	3.99	936.58	18.71
Domestic Cruise	AS	1.58	1228.38	10.22
Domestic LTO	ATF	12.48	9.08	1.74
Domestic Cruise	ATF	15.05	6.47	0.69
International LTO	AS	4.08	925.93	17.85
International Cruise	AS	1.47	1219.75	10.20
International LTO	ATF	13.66	9.23	1.14
International Cruise	ATF	17.09	1.30	0.14
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
Use of all aviation spirit assigned to the LTO cycle
Reasons for the upward revision of CO and NMVOC emission factors for aviation spirit use during the LTO cycle (as compared to the 2017 submission): CO and NMVOC emission factors for piston aircraft (which consume aviation spirit) are very large compared with jet and turboprop aircraft (which consume aviation turbine fuel). As a result, the revisions made to the emission factors assumed for piston aircraft have had a disproportionate impact on Domestic LTO emission factors for NMVOC (and to a lesser extent CO). However, it should be born in mind that compared with aviation turbine fuel the total consumption of aviation spirit is very small.

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 (2016) provides fuel consumption and emissions of non-GHGs (NO_x (as NO_2), 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 Guidebook. Therefore, each specific aircraft type in the CAA data are assigned to a generic type in the 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 as SO_2 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 emission 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 (1997a) and EMEP/ EEA Guidebook (2016) cruise defaults. The EMEP/ EEA (2016) 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 NFR14 category 1A5 Other.

3.3.2.8 Fuel reconciliation

The estimates of aviation fuels consumed in the commodity balance table in the BEIS publication DUKES are the national 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 Road Transport (1A3b)

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 mainly taken from the 2016 EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016), consistent with the speed-emission factor functions given in COPERT 4.11.4 and COPERT 5 (Emisia, 2016).

3.3.3.1.3 Summary of activity data

Traffic activity data in billion vehicle km by vehicle type are provided by the UK Department for Transport (DfT) and total fuel sales for petrol and diesel are provided in the Digest of UK Energy Statistics (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 to the NECD and CLRTAP for tracking compliance with the UK's emissions ceilings 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)[27] and references under the revised NEC Directive (2016/2284/EU)[28] 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 national 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)

[27] http://www.ceip.at/fileadmin/inhalte/emep/2014_Guidelines/ece.eb.air.125_ADVANCE_VERSION_reporting_guidelines_2013.pdf
[28] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC

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 1x1km 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 1990-2016 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 2018, 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 from rows 164 onwards. National Totals for compliance – row 144 are based on the fuel used approach (except for SO_2 and metals as explained above).

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 the Digest of UK Energy Statistics (DUKES) published by BEIS 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 2016, 11.95 Mtonnes of petrol and 24.65 Mtonnes of diesel fuel (DERV) were consumed in the UK. Petrol consumption has decreased while diesel consumption has increased compared with consumption in 2015. It was estimated that of this, 3.4% of petrol was consumed by inland waterways, and off-road vehicles and machinery. Some 0.5% of this was used in the Crown Dependencies, leaving 11.49 Mtonnes of petrol consumed by road vehicles in the UK in 2016. An estimated 1.7% of road diesel was used by inland waterways and off-road vehicles and machinery (the bulk of these use gas oil), and 0.2% used in the Crown Dependencies, leaving 24.18 Mtonnes of diesel consumed by road vehicles in the UK in 2016.

According to figures in DUKES (BEIS, 2017), 0.071 Mtonnes of LPG were used for transport in 2016, a small decrease from 0.082 Mtonnes the previous year.

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 BEIS refer only to mineral-based fuels (fossil fuels). According to statistics in DUKES and from HMRC (2017), 0.60 Mtonnes bioethanol and 0.63 Mtonnes biodiesel were consumed in the UK in 2016. On a volume basis, this represents about 4.4% of all petrol and 2.3% of all diesel sold in the UK, respectively. This is a small decrease in bioethanol consumption compared with 2015, and a small increase in biodiesel consumption compared with 2015. On an energy basis it is estimated that consumption of bioethanol and biodiesel displaced around 0.36 Mtonnes of mineral-based petrol (about 3.0% of total petrol that would have been consumed) and 0.55 Mtonnes of mineral-based diesel (about 2.2% of total diesel that would have been consumed), respectively.

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 EMEP/EEA Emissions Inventory Guidebook (2016). 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 2005-2016. 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 (SMMT, 2017). 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 3-13 for years 1990-2016.

Table 3-13 UK Fleet-averaged fuel consumption factors for road vehicles (in g fuel/km)

g fuel/km	1990	1995	2000	2005	2010	2015	2016
Petrol cars	56.3	55.8	54.8	54.9	54.0	50.4	49.2
Diesel cars	55.0	53.4	53.6	53.6	54.1	50.3	49.6
LGVs	77.9	78.7	77.6	74.9	74.7	72.1	71.4
HGVs	210	205	194	207	211	216	217
Buses and coaches	292	293	268	267	262	255	254
Mopeds and motorcycles	36.2	37.0	38.0	36.9	35.9	34.9	34.8

Fuel reconciliation and normalisation

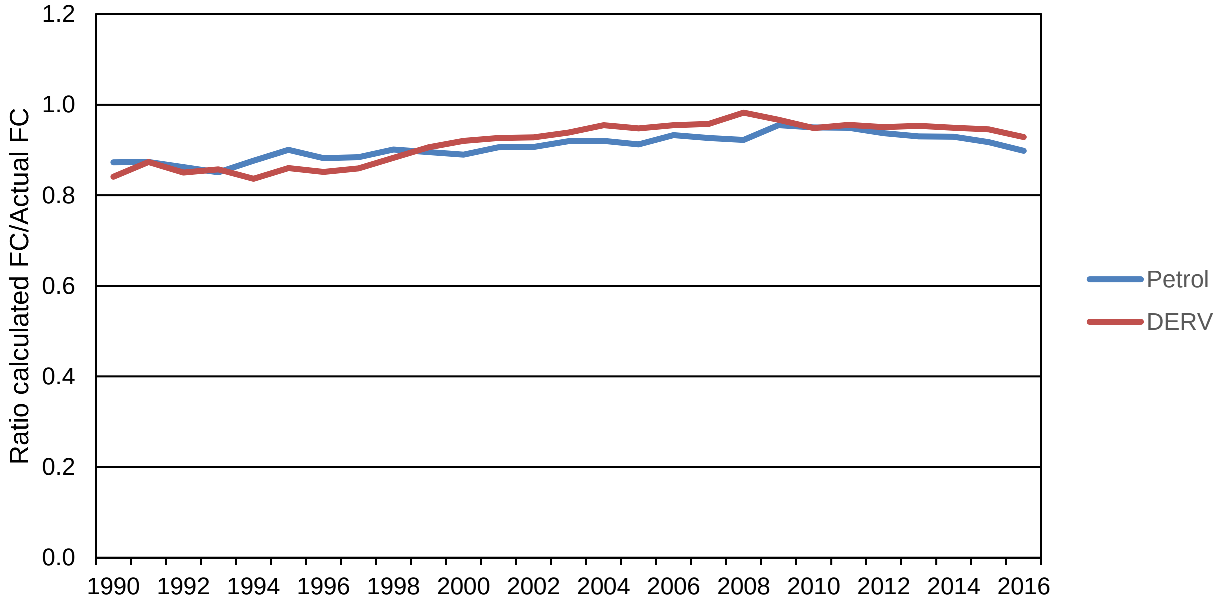
A model is used to calculate total petrol and diesel consumption by combining these factors with relevant traffic data. The "bottom-up" calculated estimates of petrol and diesel consumption are then compared with BEIS figures for total fuel consumption in the UK published in DUKES, adjusted for the small 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 all years, the bottom-up method tends to underestimate fuel consumption. The maximum deviation from DUKES is 16% (for DERV, in 1990) however the ratio tends towards 1 up to 2009, indicating better agreement with fuel sales data in recent years than in the earlier part of the time-series. In 2016, the bottom-up method underestimates petrol and diesel consumption by 10.1% and 7.1% respectively.

In order 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. Passenger cars consume the vast majority of petrol, 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. There are no reliable figures available on the total number of vehicles or types of vehicles running on this fuel. This is unlike vehicles running on petrol and diesel where the DfT has statistics on the numbers and types of vehicles registered as running on these fuels. It is believed that many vehicles running on LPG are cars and vans converted by their owners and that these conversions are not necessarily reported to vehicle licensing agencies. Figures from DUKES suggest that the consumption of LPG was 0.2% of the total amount of petrol and diesel consumed by road transport in 2016, and vehicle licensing data suggest 0.2% of all light duty vehicles ran on LPG in 2016.

Emissions from natural gas consumption

The UK inventory does not currently estimate emissions from vehicles running on natural gas. The number of such vehicles in the UK is extremely small, with most believed to be running in captive fleets on a trial basis in a few areas. Estimates are not made as there are no separate figures from BEIS on the amount of natural gas used by road transport, nor are there useable data on the total numbers and types of vehicles equipped to run on natural gas from vehicle licensing sources. The small amount of gas that is used in the road transport sector would currently be allocated to other sources in DUKES.

Fuel-based emission factors

Emissions of some pollutants such as SO_2 and metals, vary in direct proportion to the amount of fuel consumed and are less influenced by aftertreatment 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_2

Emission factors for SO_2 are based on the sulphur content of the fuel. Values of the fuel-based emission factors for SO_2 vary annually as the sulphur-content of fuels change, and are shown in Table 3-14 for 2016 fuels based on data from UKPIA (2017).

Table 3-14 Fuel-Based SO_2 2016 Emission Factor for Road Transport (kg/tonne fuel)

Fuel	SO_2[a]
Petrol	0.011
Diesel	0.015

a 2016 emission factor calculated from UKPIA (2017) – figures on the weighted average sulphur-content of fuels delivered in the UK in 2016.

Metals

Emission factors for metals are based on the EMEP/EEA emissions inventory guidebook for road transport (EMEP, 2016). The guidebook factors cover the combined effect of the trace amounts of metals in the fuel itself and in lubricating oil and from engine wear. The exception is for lead emissions from petrol where UK-specific factors are used. The factors used are given in Table 3-15.

Table 3-15 Emission factors used in the UK inventory for road transport

Metal	Fuel	Emission Factor (t/Mt)
Cr	DERV	0.03
Cr	Petrol	0.016
As	DERV	0.0001
As	Petrol	0.0003
Cd	DERV	0.0087
Cd	Petrol	0.0108
Cu	DERV	0.0212
Cu	Petrol	0.042
Hg	DERV	0.0053
Hg	Petrol	0.0087
Ni	DERV	0.0088
Ni	Petrol	0.013
Pb	DERV	0.05
Se	DERV	0.0001
Se	Petrol	0.0002
Zn	DERV	1.74
Zn	Petrol	2.16
V	DERV	12.7
Mn	DERV	0.04
Be	DERV	0.144
Sn	DERV	0.304

The Guidebook does not provide factors for the metals V, Mn, Be and Sn, so for these metals UK specific factors are used.

In order 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 factor for unleaded petrol is 54 µg/kg fuel which is higher than the value of 33 µg/kg fuel given by the 2016 EMEP/EEA Guidebook. 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 (as SO_2) and metals are broken down by vehicle type based on estimated fuel consumption factors and traffic data in a manner similar 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 (as NO_2), 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 the Department for Transport. 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 have to 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 TRL on behalf of DfT (Barlow and Boulter, 2009, see TRL Report PPR355 at https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009 . Emission factors for average speeds on the road network are then combined with the national road traffic data.

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; and
- 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) and non-built-up areas (rural) and motorways (DfT, 2017a). DfT provides a consistent time series of vehicle km data by vehicle and road types going back to 1993 for the 2016 inventory, taking into account 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 (DRD), Northern Ireland, Road Services (DRDNI, 2015a). 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 (2013) was used. The data was scaled up or down based on the ratio of the data for 2008 between DRDNI (2015) and DRDNI (2013) for the given vehicle type and road type considered. Data for 2015 and 2016 were not available in time 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 2016 in Great Britain. Motorcycle vehicle km data were not available from the DRDNI and 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. Additional information is provided by DRDNI about the split between cars and LGVs and the petrol/diesel car split for cars and LGVs in the traffic flow based on further interrogation by DRDNI of licensing data (DRDNI, 2015).

The Northern Ireland data have 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 2016. Table 3-16 shows the UK vehicle kilometres data from 1990 to 2010 (at five-year intervals) and for the most recent years (2015, 2016).

Table 3-16 UK vehicle km by road vehicles

Billion vkm		**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**
Petrol cars	urban	142.2	137.9	135.1	119.9	99.4	89.3	88.7
	rural	140.9	133.9	134.1	127.2	109.0	93.5	92.6
	m-way	49.3	48.4	53.0	48.9	41.7	34.3	33.3
Diesel cars	urban	5.8	17.2	26.1	40.8	54.0	65.2	68.6
	rural	6.1	17.9	28.3	47.5	65.8	88.3	93.3
	m-way	2.8	8.5	14.7	25.2	33.6	46.0	48.3
Petrol LGVs	urban	11.1	7.5	4.2	1.9	1.3	1.0	0.9
	rural	11.4	8.3	5.0	2.3	1.6	1.3	1.3
	m-way	3.9	3.2	2.0	0.9	0.6	0.6	0.5
Diesel LGVs	urban	5.8	10.2	15.6	21.2	22.7	25.3	26.1
	rural	6.0	11.4	18.8	25.9	29.5	33.9	36.0
	m-way	2.0	4.3	7.4	10.4	11.4	14.7	15.5
Rigid HGVs	urban	4.5	3.7	3.9	4.0	3.2	2.9	2.7
	rural	7.1	6.8	7.2	7.5	6.6	6.3	6.3
	m-way	3.7	3.7	4.2	4.2	4.1	3.9	3.9
Artic HGVs	urban	1.1	1.1	1.1	1.1	0.8	0.9	0.9
	rural	4.4	4.7	5.2	5.4	5.1	5.3	5.3
	m-way	4.7	6.0	7.4	7.9	7.5	8.4	8.5
Buses	urban	2.4	2.9	3.0	3.2	3.1	2.6	2.4
	Rural	1.7	1.5	1.7	1.5	1.6	1.4	1.3
	m-way	0.6	0.5	0.5	0.5	0.5	0.4	0.4
M/cycle	Urban	3.3	1.9	2.3	2.9	2.5	2.2	2.4
	Rural	2.0	1.6	2.0	2.2	1.8	2.0	1.9
	m-way	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Total		**423.3**	**443.8**	**482.9**	**512.9**	**507.9**	**529.9**	**541.5**

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 speed data for traffic in a number of different areas were taken from the following main sources: Transport Statistics Great Britain (DfT, 2009a) provided averages of speeds in Central, Inner and Outer London surveyed at different times of day during 1990 to 2008. Speeds data from other DfT's publications such as 'Road Statistics 2006: Traffic, Speeds and Congestion' (DfT, 2007a) and 2008 national road traffic and speed forecasts (DfT, 2008a) were used to define speeds in other urban areas, rural roads and motorways. Where new information is not available, previous NAEI assumptions were maintained or road speed limits used for the vehicles expected to observe these on the type of road concerned. Table 3-17 shows the speeds used in the inventory for light duty vehicles, HGVs and buses.

Table 3-17 Average Traffic Speeds in Great Britain

Road Type		Cars & LGV (kph)	HGV (kph)	Buses (kph)
Urban Roads				
Central London	Major principal roads	16	16	16
	Major trunk roads	24	24	16
	Minor roads	16	16	16
Inner London	Major principal roads	21	21	24
	Major trunk roads	32	32	24
	Minor roads	20	20	20
Outer London	Major principal roads	31	31	32
	Major trunk roads	46	46	32
	Minor roads	29	29	29
	Motorways	108	87	87
Conurbation	Major principal roads	31	31	24
	Major trunk roads	38	37	24
	Minor roads	30	30	30
	Motorways	97	82	82
Urban	Major principal roads	36	36	32
	Major trunk roads	53	52	32
	Minor roads	35	34	29
	Motorways	97	82	82
Rural Roads				
Rural single carriageway	Major roads	77	72	71
	Minor roads	61	62	62
Rural dual carriageway		111	90	93
Rural motorway		113	90	95

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 (2016, personal communication) are used to define the UK's vehicle fleet composition on the road. The ANPR data has been collected annually (since 2007) at over 256 sites in the UK on different road types (urban and rural major/minor roads, and motorways) 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 and 2015. 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 (which can be associated with its Euro standard), engine sizes, vehicle weight and road types.

The ANPR data are primarily used to define the fleet composition on different road types for the whole of Great Britain (GB), rather than in specific regions. However, Devolved Administration (DA)-country specific vehicle licensing data (hereafter referred as DVLA data) are used to define the variation in some aspects of the vehicle fleet composition between DA country. The ANPR data are used in two aspects to define:

- Petrol and diesel mix in the car fleet on different road types (urban, rural and motorway).
- Variations in age and Euro standard mix on different road types

As the ANPR data are only available between 2007 and 2011 and for 2013 and 2015, it was necessary to estimate the road-type variations in the fleet for years 2016 and before the ANPR became available otherwise a step-change would be introduced in the emission time-series. For the petrol/diesel mix of the GB car fleet as a whole, 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 preferential use of diesel cars on motorways, as was previously assumed in the inventory, but that preferential 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 only four years of ANPR data (2010, 2011, 2013, and 2015) 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 similar to 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 3-16.

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 and better fuel injection and engine management systems.

Table 3-18 shows the regulations that have come into force up to 2016 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 3-18 Vehicles 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
		EC 715/2007 (Euro 6)	1/4/2015
	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
		EC 715/2007 (Euro 6)	1/4/2015
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 (<1.3t) 1/1/2002 (>1.3t)
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2011
		EC 715/2007 (Euro 6)	1/4/2016
	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 (<1.3t) 1/1/2002 (>1.3t)
		98/69/EC (Euro 4)	1/1/2006
		EC 715/2007 (Euro 5)	1/7/2011

Vehicle Type	Fuel	Regulation	Approx. date into service in UK
		EC 715/2007 (Euro 6)	1/4/2016
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 (2 st, 4st) 97/24/EC: all sizes (Euro 1) 2002/51/EC (Euro 2) 2002/51/EC (Euro 3) Euro 4	 1/1/2000 1/7/2004 1/1/2007 1/7/2016

In previous years, the inventory was developed using licensing data to define the age mix of the national fleet and data from travel surveys that showed how annual mileage changes with vehicle age. This was used to split the vehicle km figures by age and Euro classification. The ANPR data provided direct evidence on the age mix of vehicles on the road and how this varied on different road types and thus obviated the need to rely on licensing data and assumptions about changing mileage with age. The information tended to show that the diesel car, LGV and HGV fleet observed on the road was rather newer than inferred from the licensing records and mileage surveys. However, this information was only available for 2007-2011, 2013, and 2015, so it was important to consider how the trends observed in these limited years of ANPR data availability could be applied to earlier years. This was done by developing a pollutant and vehicle specific scaling factor for each road type reflecting the relative difference in the fleet mix on each road type defined by the ANPR data compared with that obtained from the licensing and older mileage with age data. The fleet-adjustment scaling factors were averaged over the 2007-2011 period and were extrapolated to a value of 1 in 1990 because in this year all vehicles meet pre-Euro 1 standard, and hence differences in the age of the fleet on different road types have no effect on emissions. An overall year-, vehicle-, road- and pollutant-specific factor is then applied to GB average emission factors calculated from the vehicle fleet turnover model across the whole time-series to account for the variations in fleet profiles according to vehicle usage as evidenced from the ANPR data.

As no ANPR data were available for 2012, the average of the fleet-adjustment scaling factors for 2011 and 2013 was applied to the emission factors derived for the fleet in 2012 according to licensing data. As no ANPR data was available for 2014, the average of the fleet-adjustment scaling factors for 2013 and 2015 was applied to the emission factors derived for the fleet in 2014 according to licensing data. As no ANPR data were available for 2016, the fleet-adjustment scaling factors for 2015 were applied to 2016.

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, 2017c). 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, 2017b). The emissions impact of alternative vehicle technologies (e.g. hybrid and electric cars) has been taken into account based on emission factors provided in Murrells and Pang (2013). Uptake rates of these alternative vehicles technologies are based on information provided by DfT (2017e).

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, 2017c), 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, 2017d) provided a time series of vehicle km (2000-2015) 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 17 tonnes across the time-series, while there has been an increase in traffic activity for rigid HGVs over 17 tonnes. Data for 2016 was not available and so the vehicle size mix for 2015 was applied to 2016. 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 <15t and the remaining are 15-18t. For London buses, the split is defined by the fleet composition provided by Transport for London (TfL, 2017).

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. 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, 2009b). 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 HGVs 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 pays particular attention to the unique features of the HGV and bus fleets in London. This is primarily so as to be able to account for measures taken to reduce emissions and improve air quality in London.

The effect of the Low Emission Zone (LEZ) on PM emissions from HGVs and buses from 2008 is taken into account by using a different Euro standard mix for HGVs within the LEZ area. To be compliant, vehicles must meet Euro III standards or above from 2008, but this is only in respect of PM emissions. With respect to other pollutant emissions, the London fleet of HGVs and buses (except TfL's buses) are assumed to be the same as the national fleet.

The specific features of the fleet of buses operated by Transport for London (TfL) were taken into account. Information from TfL on the Euro standard mix of their fleet of buses was used and it is assumed that approximately 78-87% of all bus km in London are done by TfL buses, the remainder being done by non-TfL buses having the composition of the national bus fleet, except from 2008 onwards where the fleet is modified to be compliant with the LEZ.

The inventory takes into account the introduction of the next phase of the London LEZ in January 2012 which requires the minimum of Euro 3 PM standards for larger vans and minibuses.

Information from TfL was also 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. Emission factors for London black cabs were assumed to be the same as a diesel LGVs. The measures introduced by TfL requiring a minimum of Euro 3 PM standards for black cabs in London are included.

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 a number of 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 (UKPIA, 2004). These factors and their effect on emissions were taken into account in the inventory. It is assumed that prior to 2000, only buses had made a significant 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 taken into account 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 included in 1A3b categories rather than 2D3. The measured emission factors which form the basis of the exhaust emission factors in COPERT and the Guidebook include the contribution of lubricants, i.e. it is the combined effect of both fuel and lubricant that is measured. Emissions from the lubricant combustion for 2-stroke and 4-stroke vehicles are therefore included in the 1A3bi-iv sources.

Hot Emission Factors

The emission factors for different pollutants are now taken from COPERT 5 and the EMEP/EEA Emissions Inventory Guidebook (2016 version).

Regulated pollutants NO_x, CO, NMVOCs, $PM_{10/2.5}$

COPERT 5 and the 2016 EMEP/EEA Guidebook provide emission factors as equations relating emission factor in g/km to average speed. NMVOC emissions are calculated from total hydrocarbon (THC) emission factors. THC emissions include CH_4. Therefore, NMVOC emissions are derived by subtracting CH_4 emissions from the THC 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 2016 EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016).

Scaling factors are also provided to take into account 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 NO_x, PM, CO and THC emission factors.

COPERT 5 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 3-19. 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. Tables showing the emission factors calculated for speeds typical of these road types covering each of the main vehicle types, fuel types and Euro standards currently in the fleet are provided in a separate methodology report for the UK road transport sector (Brown et al, 2018).

Various other assumptions and adjustments were applied to the emission factors, as follows.

The emission factors used for NMVOCs, NO_x (as NO_2), 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 (2017) 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 Energy & Environment 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 given by 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 3-19 shows implied emission factors (in g/km) for each main vehicle category and pollutant for the UK fleet from 1990-2016. 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). Because of minor revisions to the mix of Euro classes and technologies in the fleet each year as well as the proportion of kilometres travelled at different speeds, these implied emission factors are slightly different to the previous submission, even where emission factors by Euro class have not changed.

Table 3-19 UK fleet averaged hot exhaust emission factors for road transport

Pollutant	Source	Units	1990	1995	2000	2005	2010	2015	2016
CO	Petrol cars	g/km	7.3	5.7	3.0	1.9	0.92	0.55	0.50
	DERV cars		0.55	0.41	0.26	0.11	0.069	0.047	0.047
	LGVs		11	7.0	3.0	0.99	0.51	0.22	0.18
	HGVs		2.0	1.8	1.5	1.4	1.1	0.68	0.57
	Buses and coaches		3.5	3.3	1.9	1.5	1.3	1.2	1.0
	Mopeds and motorcycles		20	20	19	14	8.9	5.7	5.0
NO_x (as NO_2)	Petrol cars	g/km	2.5	1.8	0.99	0.54	0.21	0.09	0.08
	DERV cars		0.64	0.66	0.68	0.73	0.64	0.59	0.57
	LGVs		2.6	2.1	1.5	1.1	0.87	1.1	1.2
	HGVs		8.7	7.7	6.5	5.7	4.1	1.8	1.4
	Buses and coaches		12	11	9.5	8.3	6.7	4.4	3.7
	Mopeds and motorcycles		0.30	0.32	0.32	0.29	0.24	0.21	0.20
NMVOC	Petrol cars	mg/km	1100	821	405	206	72	31	27
	DERV cars		98	60	40	23	13	8.8	8.3
	LGVs		874	568	269	109	50	31	28
	HGVs		574	458	283	182	93	42	35
	Buses and coaches		1225	1112	596	320	161	83	72
	Mopeds and motorcycles		2514	2267	1948	1354	862	562	506
PM_{10}	Petrol cars	mg/km	5.7	4.2	2.4	1.7	1.3	1.2	1.3
	DERV cars		193	122	68	37	23	11	9
	LGVs		108	142	98	69	45	21	17
	HGVs		337	291	178	121	68	29	23
	Buses and coaches		544	515	261	152	90	52	44
	Mopeds and motorcycles		41	36	30	21	14	9.4	8.6
NH_3	Petrol cars	mg/km	1.7	20.9	66.7	49.4	36.6	17.9	15.4
	DERV cars		0.87	0.87	0.88	0.88	0.94	1.4	1.4
	LGVs		1.4	2.2	5.8	4.3	3.2	2.2	2.1
	HGVs		3.0	3.0	3.0	3.0	4.6	8.3	8.6
	Buses and coaches		3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Mopeds and motorcycles		1.9	1.9	1.9	1.9	2.0	2.0	2.0
B[a]p	Petrol cars	µg/km	0.48	0.43	0.31	0.21	0.16	0.14	0.13
	DERV cars		2.9	1.5	0.82	0.37	0.23	0.16	0.16
	LGVs		1.8	2.1	1.3	0.70	0.41	0.27	0.25
	HGVs		1.5	1.3	0.72	0.45	0.30	0.17	0.14
	Buses and coaches		2.6	2.3	1.3	0.75	0.51	0.33	0.28
	Mopeds and motorcycles		2.8	2.8	2.9	2.9	2.9	2.9	2.9

Note: B[a]p is benzo(a)pyrene

Figure 3-2 UK fleet averaged CO hot exhaust emission factors for road transport

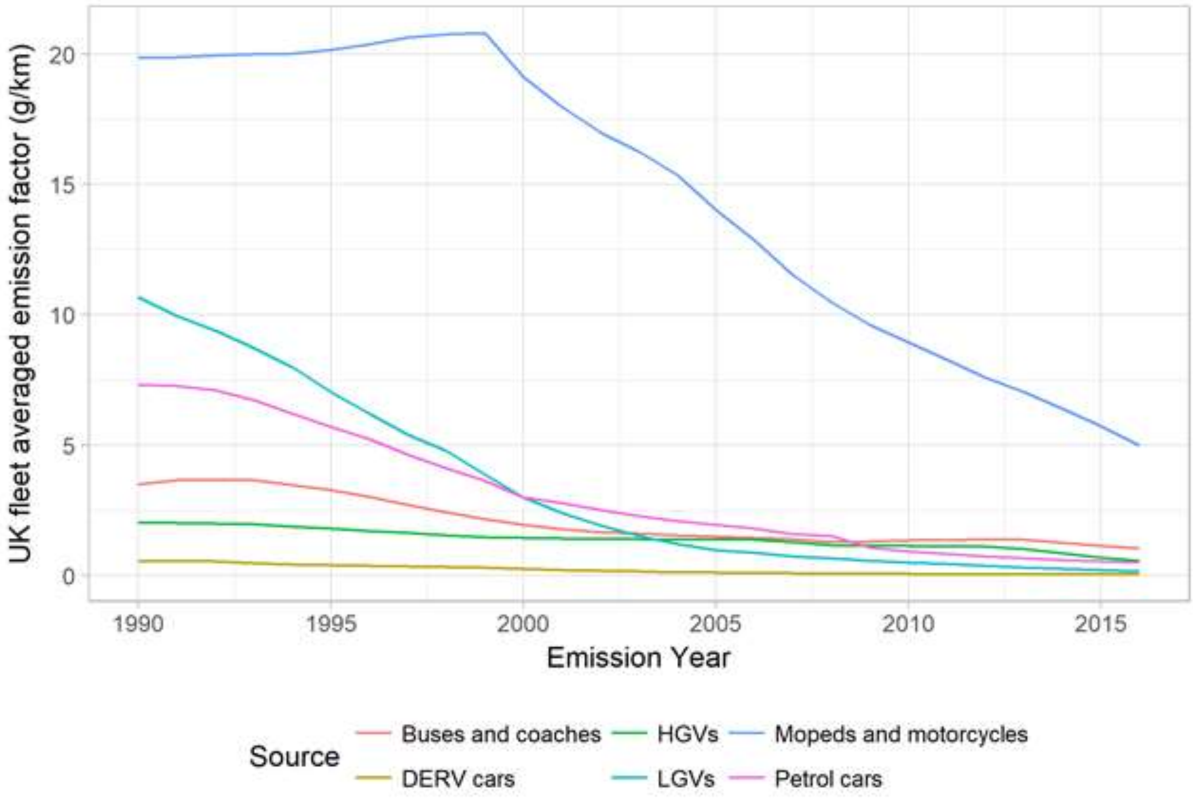


Figure 3-3 UK fleet averaged NO_x (as NO_2) hot exhaust emission factors for road transport

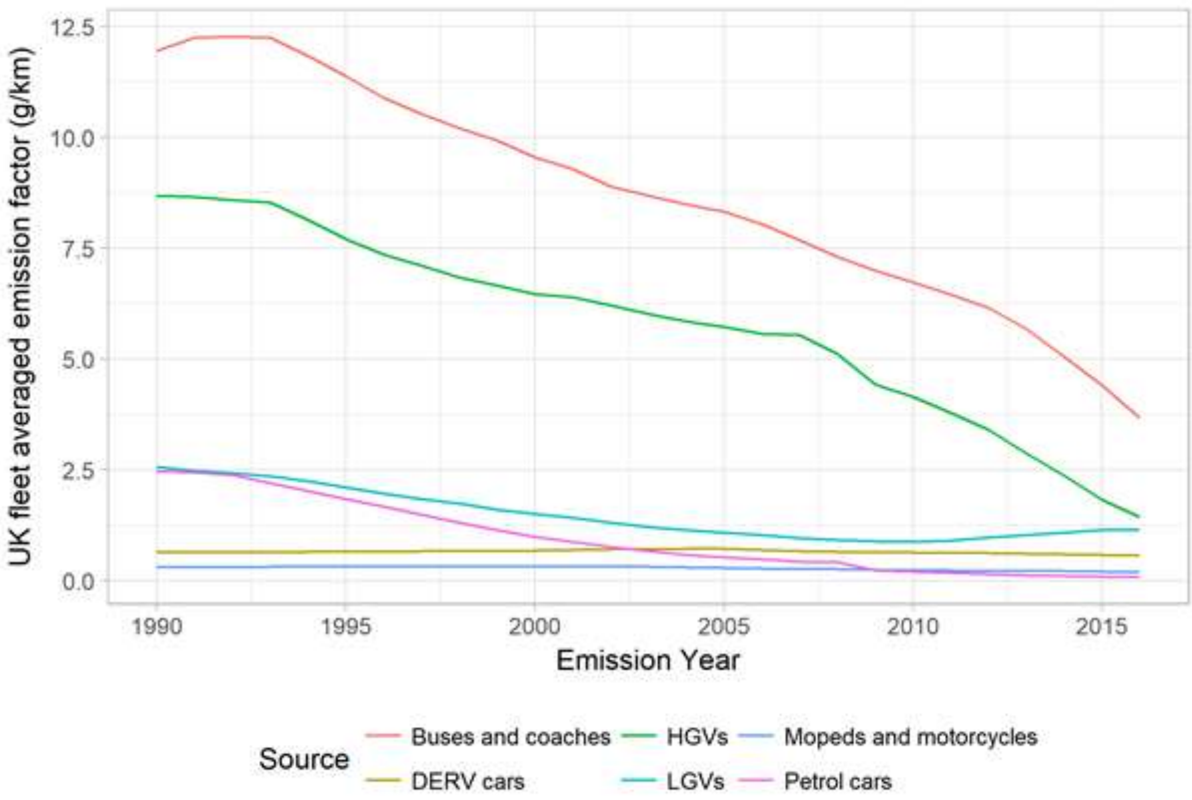


Figure 3-4 UK fleet averaged NMVOC hot exhaust emission factors for road transport

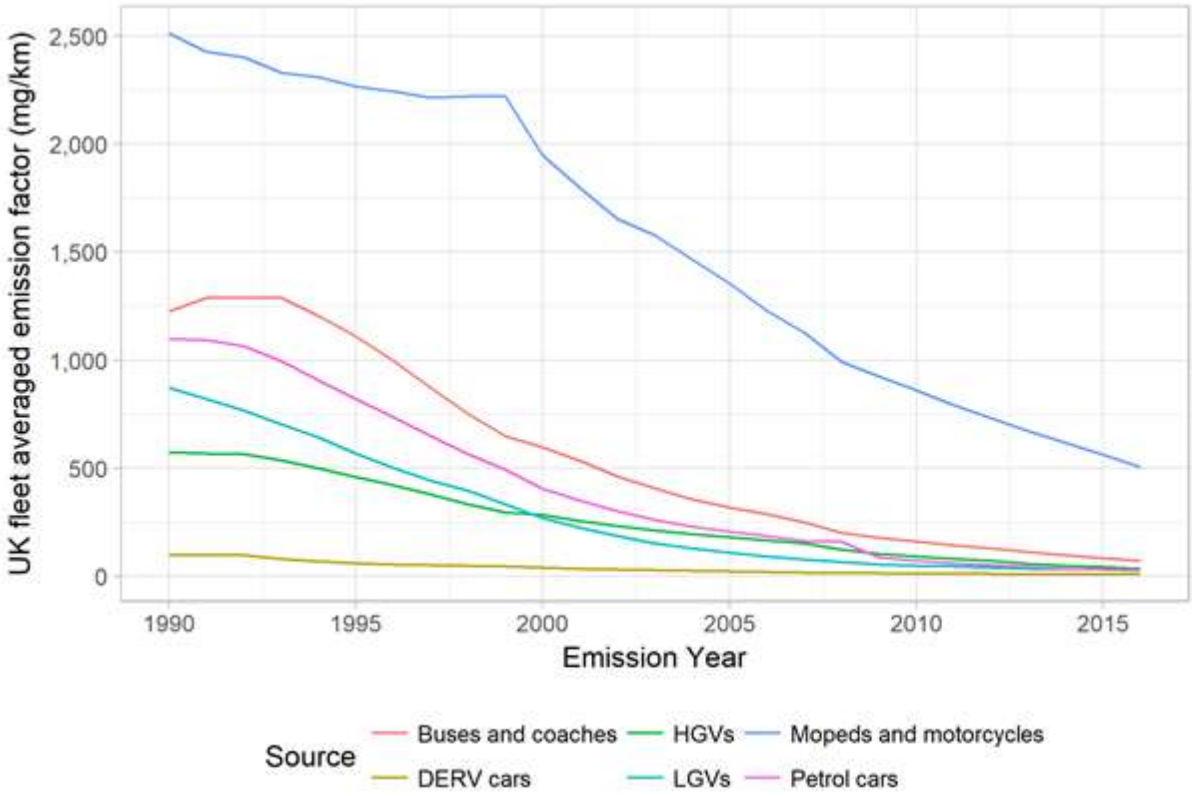


Figure 3-5 UK fleet averaged PM_{10} hot exhaust emission factors for road transport

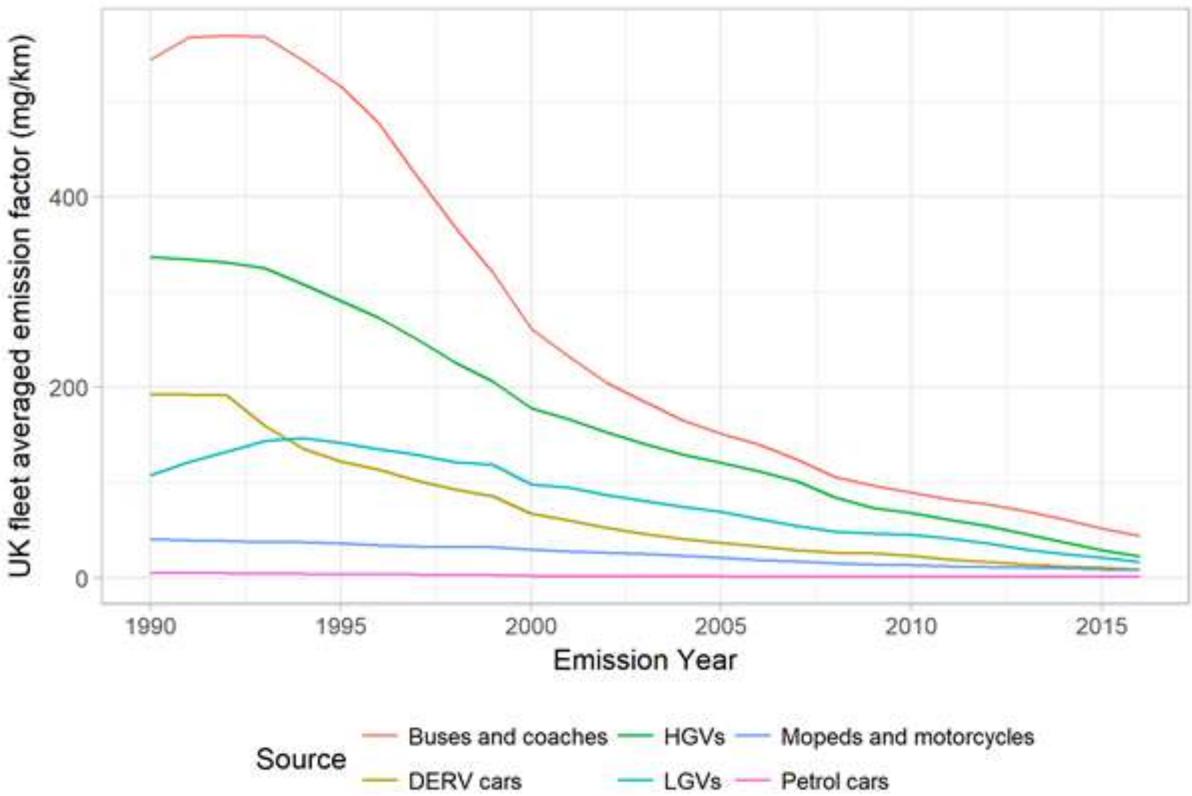


Figure 3-6 UK fleet averaged NH_3 hot exhaust emission factors for road transport

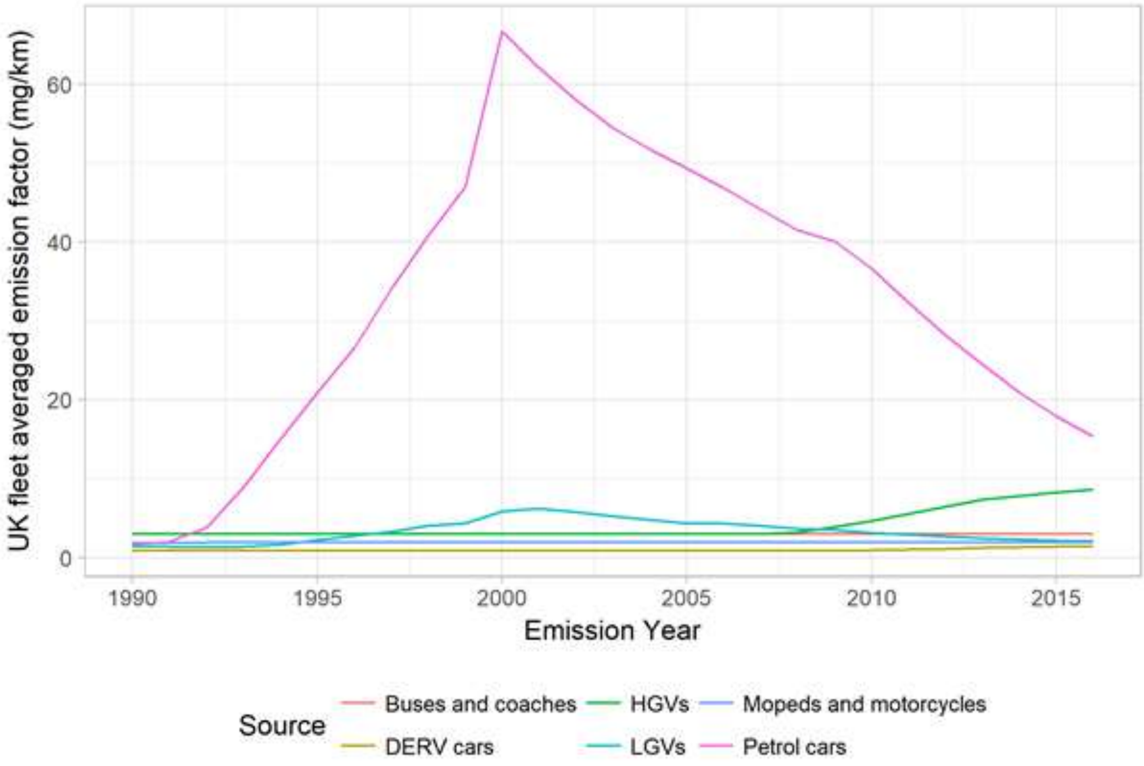
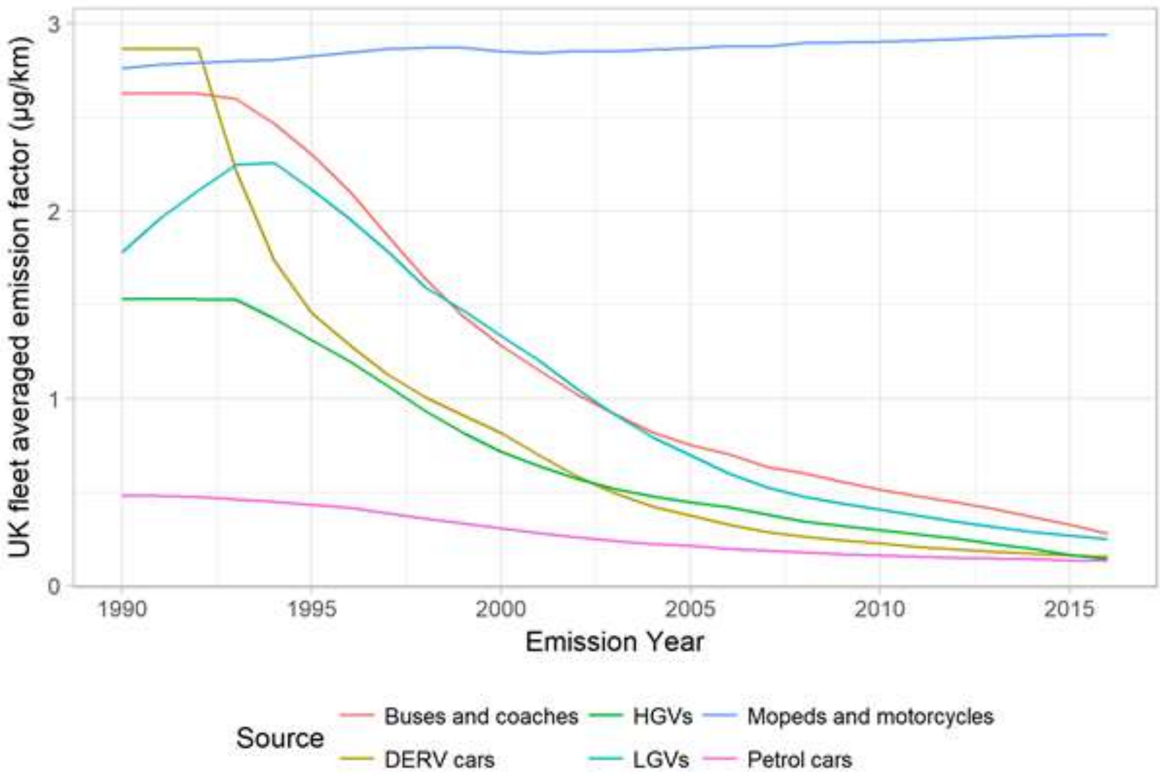


Figure 3-7 UK fleet averaged Benzo(a)pyrene (B[a]p) hot exhaust emission factors for road transport



Non-regulated pollutants: NH_3, PAHs, **PCDD/PCDFs, PCBs, HCB**
Ammonia emissions from combustion sources are usually small, but significant levels can be emitted from road vehicles equipped with catalyst devices to control NO_x emissions. Nitrous 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 Emissions Inventory Guidebook (EMEP, 2016) and the COPERT 5 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 3-19 and Figure 3-6 show the implied emission factors for NH_3 for each main vehicle category in the UK fleet from 1990-2016.

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 USEPA as compounds of interest using a suggested procedure for reporting test measurement results (USEPA, 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, available at https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009, was initially undertaken. Single emission factors were given for a number of PAHs, including the 16 USEPA 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);
- EMEP/EEA emission inventory guidebook 2009, 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 was volatile or condensed phase and either trends in NMVOC 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 3-19 and Figure 3-7 shows the implied emission factors for benzo[a]pyrene for each main vehicle category for the UK fleet from 1990-2016.

Emission factors for PCDD/PCDFs are based on the 2016 EMEP/EEA Emissions Inventory 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 UK inventory and is consistent with information in the European dioxin inventory (http://ec.europa.eu/environment/archives/dioxin/pdf/stage1/road_transport.pdf). The inventory also includes emission factors for PCBs, consistent with those in the 2016 EMEP/EEA Emissions Inventory Guidebook. In the previous 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 is not included in the 2016 EMEP/EEA Emissions Inventory Guidebook and thus HCB emissions are no longer estimated.

Pollutant speciation
A number of 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 UK inventory is required to provide estimates of the fraction emitted as NO_2 for different vehicle categories. Values of f-NO_2 are taken from the EMEP/EEA Emissions Inventory Guidebook (2014) for different vehicle types and Euro standards and recent studies by Carslaw et al (2016). All the factors are taken from the Guidebook, except those for Euro V and VI HGVs and buses which are based on Carslaw et al from measurements of NO_2/NO_x ratios using roadside remote sensing. 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 at http://naei.defra.gov.uk/data/ef-transport. 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 Emissions Inventory Guidebook (2016), the fraction of PM_{10} emitted as $PM_{2.5}$ is assumed to be 1.0 for all vehicle exhaust emissions. This is an update from the value of 0.95 used in previous versions of the inventory and is in response to recommendations from the NECD expert review of the UK inventory in 2017.

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 (2016).

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 are calculated following the recommendations made by TRL in a review of alternative methodologies carried out on behalf of DfT (Boulter and Latham, 2009). The main conclusion was that the inventory approach ought to take into account new data and modelling approaches developed in the ARTEMIS programme and COPERT 4 (EMEP, 2007). However, it was also acknowledged that such an update can only be undertaken once the ARTEMIS model and/or COPERT 4 have been finalised and that at the time of their study it was not possible to give definitive emission factors for all vehicle categories.

Boulter and Latham (2009) also stated that it is possible that the incorporation of emission factors from different sources would increase the overall complexity of the UK inventory model, as each set of emission factors relates to a specific methodology. It was therefore necessary to check on progress made on completing the ARTEMIS and COPERT 4 methodologies and assess their complexities and input data requirements for national scale modelling.

The conclusion from this assessment of alternative methodologies was that neither ARTEMIS nor a new COPERT 4 was sufficiently well-developed for national scale modelling and that COPERT 4 referred to in the EMEP/EEA Emissions Inventory Guidebooks still utilises the approach in COPERT III (EEA, 2000). COPERT III was developed in 2000 and is quite detailed in terms of vehicle classes and uses up-to-date information including scaling factors for more recent Euro standards reflecting the faster warm-up times of catalysts on petrol cars. COPERT III 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 of these are dependent on ambient temperature. Different cold/hot emission factor ratios are used for different vehicle types, Euro standards, technologies and pollutants.

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 COPERT III and were used with monthly average temperatures for central England based on historic trends in UK Met Office data.

The factor β is related to ambient temperature and average trip length by the following equation taken from COPERT III:

$\beta = 0.6474 - 0.02545 \, . \, l_{trip} - (0.00974 - 0.000385 \, . \, l_{trip}) \, . \, t_a$
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, 2007b). 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 EMEP/EEA Emissions Inventory Guidebook (EMEP/EEA, 2016), so this figure was adopted.

The COPERT III method provides pollutant-specific reduction factors for β to take account of the effects of Euro 2 to Euro 4 technologies in reducing cold start emissions relative to Euro 1.

This methodology was used to estimate annual UK cold start emissions of NO_x (as NO_2), PM, CO and NMVOCs from petrol and diesel cars and LGVs. Emissions were calculated separately for each Euro standard of petrol cars. Cold start emissions data are not available for heavy-duty vehicles, but these are thought to be negligible (Boulter, 1996).

Cold start emissions of NH_3 were estimated using a method provided by the COPERT 4 methodology for the EMEP/EEA Emissions Inventory Guidebook (EMEP, 2013). 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 takes into account 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 3-20, calculated for zero cumulative mileage and <30ppm S fuel. There are no cold start factors for HGVs and buses.

Table 3-20 Cold Start Emission Factors for NH_3 (in mg/km)

mg/km	Petrol cars and LGVs
Pre-Euro 1	2.0
Euro 1	38.3
Euro 2	43.5
Euro 3	4.4
Euro 4	4.4
Euro 5	12.7
Euro 6	12.7

All the cold start emissions are assumed to apply to urban driving.

3.3.3.6 Evaporative Emissions (1A3bv)

Evaporative emissions of petrol fuel vapour from the tank and fuel delivery system in vehicles fall under NFR category 1A3bv and constitute a significant fraction of total NMVOC emissions from road transport. The methodology for estimating evaporative emissions was updated to the Tier 2 method approach given in the EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016). This update from an earlier version of the Guidebook was in response to recommendations from the NECD expert review of the UK inventory in 2017. This is the preferred approach to use for national scale modelling of evaporative emissions for the UK inventory, as concluded from a review by Stewart *et al*. (2009) and recommendations of a review carried out by TRL under contract to DfT (Latham and Boulter 2009).

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 2016 is shown for petrol cars and motorcycles in Table 3-21. The units are in g per vehicle per day. These figures are higher than figures implied in last year's inventory as a consequence of updating the methodology to the 2016 version of the EMEP/EEA Guidebook. The updated methodology was used to revise evaporative emission estimates across the whole time-series. For petrol cars, the new method leads to lower estimates of evaporative emissions from 1990-2003 compared with the previous method and higher estimates from 2004-2015. For mopeds and motorcycles, the new method leads to higher estimates across the whole time-series.

Table 3-21 Fleet-average emission factor for evaporative emissions of NMVOCs in 2016

g/vehicle.day	2016
Petrol cars	1.75
Motorcycles	3.75

3.3.3.7 Non-exhaust emissions of PM (1A3bvi and 1A3bvii)

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 Emissions Inventory Guidebook (EMEP, 2016) derived from a review of measurements by the UNECE Task Force on Emissions Inventories (http://vergina.eng.auth.gr/mech0/lat/PM10/). 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 (2005) report on PM.

Table 3-22 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. There are no controls on emissions from tyre and brake wear, so the emission factors are independent of vehicle technology or

Euro standard and are held constant each year. Emissions are calculated by combining emission factors with vehicle km data and are reported under NFR14 code 1A3bvi.

PM emissions from road abrasion are estimated based upon the emission factors and methodology provided by the EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016). 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 3-23. 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 3-22 Emission factors for PM_{10} from tyre and brake wear

mg PM_{10} /km		Tyre	Brake
Cars	Urban	8.7	11.7
	Rural	6.8	5.5
	Motorway	5.8	1.4
LGVs	Urban	13.8	18.2
	Rural	10.7	8.6
	Motorway	9.2	2.1
Rigid HGVs	Urban	20.7	51.0
	Rural	17.4	27.1
	Motorway	14.0	8.4
Artic HGVs	Urban	47.1	51.0
	Rural	38.2	27.1
	Motorway	31.5	8.4
Buses	Urban	21.2	53.6
	Rural	17.4	27.1
	Motorway	14.0	8.4
Motorcycles	Urban	3.7	5.8
	Rural	2.9	2.8
	Motorway	2.5	0.7

Table 3-23 Emission factors for PM_{10} from road abrasion

mg PM_{10}/km	Road abrasion
Cars	7.5
LGVs	7.5
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 Emissions Inventory Guidebook (EMEP, 2016), the fraction of PM_{10} emitted as $PM_{2.5}$ for tyre wear, brake wear and road abrasion is shown in Table 3-24.

Table 3-24 Fraction of PM_{10} emitted as $PM_{2.5}$ for non-exhaust traffic emission sources

	$PM_{2.5}$ /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 components. Based on information on the metal content of tyre material and brake linings, the metal emissions from tyre and brake wear are included in the inventory and calculated from the mass content of each metal component in the PM. Details on the metal emissions inventory are reported elsewhere.

3.3.3.8 Inventory based on fuel sold

In response to the recommendation from the 2017 NECD review, the UK has provided road transport emission estimates based on the fuel sold approach as part of the 2018 submissions under the CLRTAP and NECD. 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[29] 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 actors calculated in step a) to produce emission estimates for each vehicle type based on the fuel sold approach.

Table 3-25 and Table 3-26 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 emissions ceilings. 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. In most cases (except for NO_x in 2005 and 2016), the changes as a percent of national totals (NT) using the fuel sold approach are below the 2% threshold of significance (threshold criteria used for technical correction under the NECD review).

Table 3-25 Road transport emissions (in ktonnes) based on fuel sold vs fuel used approaches

	Approach	2005	2010	2011	2012	2013	2014	2015	2016
NO_x	Fuel used	559.6	375.7	355.1	339.7	328.5	320.1	309.8	299.8
	Fuel sold	601.2	394.3	370.7	357.4	344.4	336.6	327.8	322.6
NMVOCs	Fuel used	181.9	68.6	57.0	49.1	42.1	37.4	34.6	31.8
	Fuel sold	198.9	71.4	59.3	51.5	44.3	39.4	36.8	34.5
NH_3	Fuel used	15.9	10.1	8.7	7.5	6.4	5.6	4.9	4.4
	Fuel sold	17.4	10.5	9.1	7.8	6.7	5.9	5.3	4.8
$PM_{2.5}$	Fuel used	24.3	19.4	17.8	16.8	15.7	14.8	14.2	13.4
	Fuel sold	26.0	20.4	18.5	17.7	16.5	15.6	15.1	14.5

Table 3-26 Differences in national totals (NT) between fuel used and fuel sold approaches

		2005	2010	2011	2012	2013	2014	2015	2016
NOx	Differences in ktonnes	41.6	18.6	15.6	17.7	16.0	16.6	18.0	22.8
	% change as NT	2.4%	1.5%	1.4%	1.5%	1.5%	1.6%	1.8%	2.6%
NMVOCs	Differences in ktonnes	16.9	2.8	2.3	2.4	2.2	2.0	2.2	2.7
	% change as NT	1.4%	0.3%	0.3%	0.3%	0.3%	0.2%	0.3%	0.3%
NH3	Differences in ktonnes	1.5	0.4	0.3	0.4	0.3	0.3	0.3	0.4
	% change as NT	0.5%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%

[29] With the exception to SO_2 and metals emission estimates as they were calculated based on the sulphur or metal content of fuels.

		2005	2010	2011	2012	2013	2014	2015	2016
PM2.5	Differences in ktonnes	1.7	1.0	0.8	0.9	0.8	0.8	0.8	1.1
	% change as NT	1.3%	0.8%	0.7%	0.8%	0.7%	0.7%	0.8%	1.0%

3.3.4 Railways (1A3c)

A Tier 2 methodology is used for calculating emissions from Intercity, regional and freight diesel trains, as well as coal-fired heritage trains.

UK specific emission factors for passenger trains in g/vehicle (train) km are taken from the Department for Transport's Rail Emissions Model (REM) for different rail engine classes based on factors provided by WS Atkins Rail. 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 UKPIA.

Gas oil consumption data was obtained from the Office of Rail and Road for passenger and freight trains for 2005-2015. This was combined with trends in train kilometres to estimate consumption for other years. Train km data from REM are used to provide the breakdown between train classes.

Details of Methodology
The UK inventory reports emissions from both stationary and mobile sources.

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 Section 3.4. These emissions are based on fuel consumption data from BEIS (2017).

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 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 1990-2016 and are believed to be due to consumption by heritage trains. For the air pollutants, 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 NFR14 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 the UK's Department for Transport's Rail Emissions Model for 2009 to 2011 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. Train kilometre data for freight trains are based on an estimate for 2004 combined with the trend in net tonne km of freight moved for other years obtained from the Office of Rail and Road (ORR) National Rail Trends Yearbook (NRTY) and data portal.

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 2011-2015. No data are available for the years 1970-2004 and 2010, therefore fuel consumption for these years was estimated based on the trend in train kilometres. Consumption data is now available for 2016; however, this data was published too late for inclusion in this year's inventory cycle, hence fuel consumption data for this year was also estimated based on the trend in train kilometres.

In recent years passenger train kilometres have steadily increased until a small decline in 2016. This trend is generally reflected in the passenger train fuel consumption data. The amount of freight moved has declined steadily since 2013 as a result of a substantial decline in the amount of coal hauled. The amount of freight moved in 2016 is around 78% of the amount estimated for 2013. However, fuel consumption has not reduced accordingly due to an increase in container traffic. Freight fuel consumption in 2016 is 95% of the 2013 fuel consumption. The large reduction in fuel consumption by freight trains from 2014 to 2015 estimated last year using trends in tonnes of freight moved, which showed a significant decline, has been replaced with a smaller decline based on actual fuel consumption statistics for rail freight in 2015 provided by the ORR which were not available at the time the previous inventory was compiled.

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.

Carbon and sulphur dioxide emissions are calculated using fuel-based emission factors and the total fuel consumed. Emissions of CO, NMVOC, NO_x (as NO_2) 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:
  - Vehicle train kilometres data for different train classes for 2009, 2010 and 2011 are derived from the Department for Transport's Rail Emissions Model. The fleet for other years is estimated based on the year of introduction of new engines and assuming that the new trains introduced since 2012 are compliant with the European Non Road Mobile Machinery Stage IIIB regulations.

- For freight trains:
  - The breakdown by train class was obtained from the Department for Transport's Rail Emissions Model for 2009. The fleet for other years is estimated based on the year of introduction of new engines and assuming that the new freight locomotives introduced since 2012 are compliant with the European Non Road Mobile Machinery Stage IIIB regulations.

The emission factors shown in Table 3-27 are aggregate implied factors for trains running on gas oil in 2016, 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.

Table 3-27 Railway Emission Factors for 2016 (kt/Mt fuel)

	NO_x (as NO_2)	CO	NMVOC	SO_x (as SO_2)	PM_{10}
Freight	86.6	12.6	4.9	0.02	1.2
Intercity	41.6	8.6	3.0	0.02	3.4
Regional	46.6	9.2	2.4	0.02	1.3

An emission factor of 0.01kt/Mt fuel for NH_3 was taken from Tables 3.2-3.4 of the 1.A.3.c Railways chapter of the EMEP Emissions Inventory Guidebook (EMEP (2016)).

3.3.5 Navigation (1A3d, 1A4ciii, 1A5b)

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.

For shipping, a major research project to improve the methodology for estimating emissions from domestic shipping sources has been completed and the results are incorporated into the inventory for the first time in this submission. This impacts emissions from 1A3d, 1A4ciii (fishing), 1A5b (naval shipping) and marine bunkers. A new shipping emissions model has been developed using terrestrial Automatic Identification System (AIS) vessel movement data for 2014 supplied by the UK Maritime and Coastguard Agency. The new methodology meets and exceeds the requirements of a Tier 3 methodology set out in the EMEP EEA Emissions Inventory Guidebook 2016 and the requirements for reporting national greenhouse gas emissions to the UNFCCC under the 2006 IPCC Guidelines. The new 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. This replaces the previous approach of determining emissions based on the total length of a voyage along assumed routes and vessel speeds rather than actual routes and speeds undertaken and also accounts for vessel draught.

The receivers capture a number of smaller vessels and voyages such as movements to and from off-shore oil and gas rigs not captured in the previous approach[30]. It also captures some vessels such as tugs that were previously captured in the methodology used for estimating emissions from inland waterway vessels. As the new approach is considered to capture these vessel movements more accurately than estimated in the inland waterways model, those vessel categories were removed from the inland waterways emission estimation model. The new approach also uses a more detailed set of port statistics for different vessel categories as proxies for estimating activities in years back to 1990 and forward to 2016 from the 2014 base year. Emission factors were updated with detailed values for different main and auxiliary engine types, fuels and vessel movement types, consistent with those used in the IMO global emissions inventory and accounting for current regulations on fuel sulphur content in different sea territories around the UK.

The new shipping model estimates replace the existing NAEI estimates for:

- National Navigation (source category 1A3dii), the main category of domestic voyages for coastwise 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.

Existing approaches from the NAEI were used for:

- Inland waterways (source category 1A3dii) includes sailing boats with auxiliary engines, motorboats / workboats, personal watercraft and inland-goods carrying vessels used on rivers, canals and for recreational use off the UK coast.
- Naval vessels (source category 1A5b).
- Shipping between UK and Gibraltar, Overseas Territories and Bermuda.

Full details on the method used for this model are given in Scarbrough et al. (2017). A brief overview of the method is given in Scarbrough et al. (2017) and immediately below.

3.3.5.1 Overview of methodology

The new NAEI shipping model methodology (Scarbrough et al. (2017)) is similar to the previous NAEI approach in that fuel consumption and emissions are estimated 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 past years and up to the current year. Future shipping fuel consumption and

[30] The inventory based on Entec (2010) was derived from a dataset of vessel movements from the then Lloyd's Marine Intelligence Unit, covering primarily the cargo vessels over 300 gross tonnes with some enhancement of certain passenger vessel movements. Although attempt was made to correct for this, based on estimates of the contribution made by vessels <400 tonnes from other studies on shipping emissions, the previous Entec inventory did not provide comprehensive coverage of vessels categories such as offshore industry service vessels, tugs and service fleets, fishing fleets and to a lesser degree passenger vessels. At the time the Entec inventory was developed, there were no independent sources of data to verify the scaling up of the movement-based inventory to account for small vessels, although some small vessels such as tugs have been captured in the inventory for inland waterways.

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.

The new shipping model emission calculation – of multiplying an emission factor expressed in grams per kWh by estimated engine demand in kWh – is also similar to the previous NAEI estimates that are based on Entec (2010). In this sense, the new model methodology meets the requirements of Tier 3 in EMEP (2016). The new 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, 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 SECA, whether the vessel is at berth, and whether the vessel is a passenger vessel.

A significant 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. The new model methodology separates vessel movements into domestic, international and passing the UK (transit). This new domestic estimate is used for UK reporting of national emission totals in inventory submissions to the UNFCCC, UNECE/CLRTAP and EU NECD.

3.3.5.1.1 Benefits of the new methodology

The new model methodology is more sophisticated than the previous NAEI shipping emissions approach, and goes beyond the Tier 3 methodology described in EMEP (2016). The following improvements are realised:

- **More complete activity dataset.** The switch in choice of activity dataset from a port to port database used in Entec (2010) that focuses on internationally trading vessels to an AIS activity dataset provides improved domestic vessel coverage, particularly of those vessel types with previously poor coverage. This includes, in particular, offshore industry vessels, fishing boats, passenger ferries and service craft.
- **Spatially resolved activity dataset.** The AIS dataset shows the actual locations of vessels, meaning emission estimates can be spatially resolved to a high resolution. This compares with the previous shipping inventory (Entec, 2010) which estimated routings of vessel voyages.
- **Improved emission calculation accuracy of main engines.** The calculation of fuel consumption and emissions of vessels now accounts for the actual speed of the vessel at any given point, rather than assuming that vessels always travel at their designed speed as was assumed in Entec (2010). The emission calculation also now uses the reported draught of the vessel to estimate 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 rather than a single voyage average, which in turn provides a more realistic estimation of the spatial distribution in the emissions.

- **Improved emission calculation accuracy of auxiliary engines.** Auxiliary engine power demand, previously modelled in Entec (2010) with static assumptions, is now varied by vessel category, size and by mode.
- **Now accounts for fuel consumption and emissions from auxiliary boilers.** This emission source, used on board larger vessels for heating and hot water production, was not previously estimated in the Entec (2010) model.
- **More vessel types are distinguished.** Vessel type and size classification have been aligned with the IMO classification. This has 47 categories after splitting by size and type, compared to eight in Entec (2010). Separate assumptions are made for the fuel and emission calculations by category. Several new categories of vessels are now stipulated compared to previously, including in particular offshore industry vessels, subcategories of service vessels and cruise vessels.
- **Improved estimate accuracy for vessels starting and finishing at the same port.** Vessels that start and finish at the same port are treated in the same way as other vessels in this new model. Their emissions are estimated and spatially resolved. The previous shipping model in Entec (2010) was limited to high-level estimates of such voyages, and they were not spatially resolved.
- **Crown dependencies are now specifically included.** Emissions associated with movements among and to/from the three crown dependencies can be distinguished.
- **Updated emission factors.** Emission factors were updated with detailed values for different main and auxiliary engine types, fuels and vessel movement types, consistent with those used in the IMO global emissions inventory
- **More detailed consideration of types of fuels and associated emission factors for movements in different sea territories, SECAs and non-SECAs over the time-series**.
- **More detailed set of UK port statistics used as proxies to develop time-series in vessel activities.** Port statistics specific to 15 different vessel types are used to define trends in activities, whereas previously only 8 were used.

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.

Table 3-28 Sources of activity data and emission factors for navigation

	Source	NFR14	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, UKPIA (2017)
	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, UKPIA (2017)
	Fishing in non-UK sea territories					
	Naval	1A5b	MoD data on fuel consumption by naval vessels			Assumed same as international shipping vessels using gas oil
	Shipping between UK and OTs	1A3dii	DfT Maritime Statistics and OT port authorities: number of sailings between UK and OT	2000-2016	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
	Inland waterways	1A3dii	Based on estimates of vessel population and usage estimates using data from various sources	2008	Statistics on expenditure on recreation (ONS), tourism (Visit England), port freight traffic (DfT), inland waterways goods lifted (DfT) used to scale from 2008	EMEP/EEA Guidebook, UKPIA (2017)

	Source	NFR14	Activity data			Emission factors
			Source	Base year	Time-series	
International		1A3di	Fuel consumption from marine bunkers from DUKES (2017)			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 Coastal shipping (1A3dii)

The new shipping emissions model has been developed using 2014 terrestrial Automatic Identification System (AIS) vessel movement data supplied by the UK Maritime and Coastguard Agency. The new 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. This replaces the previous approach of determining emissions based on the total length of a voyage along assumed routes and vessel speeds rather than actual routes and speeds undertaken and also accounts for vessel draught.

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 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 NFR14 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 remains the same as in the previous NAEI – DfT port statistics are used as proxies for activity levels – but is refined to match the increased number of vessel categories than used previously, for example, the offshore sector. This is detailed further in section 3 of Scarbrough et al. (2017).

The changes that have been made from the previous shipping emission time-series approach are to:

- introduce new specific activity indices for the additional vessel categories now covered in the base year, not covered in the previous inventory approach, thereby giving better representation of trends in activities for the different types of vessels, and
- update the activity indices for existing vessel categories to be more specific to the vessel type in question from the year 2000 (e.g. for container vessels instead of using statistics on “All ports freight units”, switched to using statistics for “Container traffic”)

Overall, there are now 15 vessel categories compared to the previous 8 categories that are each mapped to a DfT port statistic. This includes separating more cargo or freight commodity types, whereas previously the activity data for all cargo were split only into time-series trends for unitised and non-unitised types. The statistical time series cover all years back from 2014 to 1990 and forward to the most recent year of statistics (currently 2016). 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 3-29, against the index previously used. The main DfT statistics used are (DfT, 2017):

- PORT0102 UK major and minor port freight traffic, international and domestic by direction, annually: 1965 - 2016
- PORT0107 Domestic UK major port freight traffic by cargo type and direction, annually: 2000 – 2016
- PORT0202 UK major and minor ports main freight units, by route, annually: 1970 - 2016

Table 3-29 Summary of new activity indices

Vessel category	Activity index used in new model	Separate domestic index?	[Previous vessel category] and Activity index used in previous NAEI
Bulk carrier	2000-2016: Table PORT0107 – 'All dry bulk traffic' [Note 1]	✓	[Bulk carrier] Table PORT0102 [All ports freight traffic (t)] 'All domestic'
Chemical tanker	2000-2016: Table PORT0107 – 'Other liquid bulk products' [Note 1]	✓	N/A
Container	2000-2016: Table PORT0107 – 'Container traffic' [Note 1]	✓	[Container] Table PORT0202 [All ports freight units] 'All coastwise'
General cargo	2000-2016: Table PORT0107 – 'All other general cargo traffic' [Note 1]	✓	[General cargo] Table PORT0102 [All ports freight traffic (t)] 'All domestic'
Liquefied gas tanker	2000-2016: Table PORT0107 – 'liquefied gas' [Note 1]	✓	N/A
Oil tanker	2000-2016: Table PORT0107 – 'total of Crude Oil and Oil Products' [Note 1]	✓	[Tanker] Table PORT0102 [All ports freight traffic (t)] 'All domestic'
Ferry-pax only	Same as previous approach, extending use of Table SPAS0201 for the years 2015 and 2016	✓	[Passenger] 2003-2014: Table SPAS0201 - All domestic sea passengers 1994-2002: previous DfT publications of domestic sea passenger movements in Entec (2010) 1990-1993: linear trend based on 1994 to 2000.
Cruise	*Same approach as used for the Ferry-pax only vessel category*	✓	*N/A*
Refrigerated bulk	2000-2016: Table PORT0107 – 'Other dry bulk' [Note 1]	✓	N/A
Ro-Ro	2000-2016: Table PORT0107 – 'Roll-on/roll-off traffic' [Note 1]	✓	[Ro-ro cargo] Table PORT0202 [All ports freight units] 'All coastwise'
Service - tug	2000-2016: Table PORT0107 – 'total domestic traffic' [Note 1]	✓	N/A
Miscellaneous - fishing	*No change from previous approach*	No	[Fishing] UK Sea Fisheries Statistics: Landings into the UK by UK and foreign vessels.
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	N/A
Service – other	2000-2014: Table PORT0107 – 'total domestic traffic' [Note 1]	✓	N/A
Miscellaneous - other	2000-2014: Table PORT0107 – 'total domestic traffic' [Note 1]	✓	[Others] Table PORT0102 [All ports freight traffic (t)] 'Total all' [domestic and international]

Note 1 – pre-2000 trend uses previous approach.

In contrast with the previous NAEI shipping inventory, which gives a series discontinuity between 2006 and 2007 assuming there is a substantive fuel switch from HFO to MDO at this time for compliance with the North Sea and English Channel SECA sulphur limit (reduction from prevailing global limit to 1.5%), the new model does not include this assumption. The new model rather assumes that this switch from HFO to MDO occurs as a result of the tightening in 2015 of the SECA fuel sulphur limit from 0.5% to 0.1%. This updated 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 backcasted inventory prior to 2010, any vessels that would have used HFO, save for the at berth requirement of 0.1% S fuel, are assumed prior to 2010 to use HFO.

c) Emission factors

Pollutants covered in Scarbrough et al. (2017)

The source of the raw emission factors used for NO_x (as NO_2), SO_2, PM, CO, and NMVOCs is given in section 2.2.8 of Scarbrough et al. (2017). These emission factors derive from IMO (2015). Table 3-32 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_2 emission factor reduction of 90% (from 1% S HFO to 0.1% MDO) accordingly.

NO_x (as NO_2) 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 2020. IMO (2015) indicates NO_X emission factor reductions of around 0.5% per year for HFO and distillate. IVL (2016) appear to indicate slightly higher reduction rates of 0.7% to 0.8% over time. The figure of 0.7% annual reduction is selected from 2014 to 2020:

$$EF\ index_{NOx,\ 2014\ to\ 2021} = 0.993^{(y-2014)}$$

Changes affecting PM emission factors from 2014 to 2016 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 EMEP (2016) 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 (2016). 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 (EMEP (2016)). 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 2016.

e) Summary of fuel consumption trends and implied emission factors

A summary of fuel consumption trends for coastal shipping and implied emission factors for 2016 are provided in Section 3.3.5.4.

3.3.5.2.2 Military shipping (1A5b)

Emissions from military shipping are reported separately under NFR14 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, 2017). 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 (MDO) from Scarbrough et al. (2017) were assumed to apply for military shipping vessels. The exception to this is for NO_x (as NO_2)) emission factors where higher emission factors from the Entec (2010) study for marine distillate oil (MGO and MDO) were considered more appropriate.

3.3.5.2.3 Emissions from Deep Sea Fishing in Sea Territories outside UK Waters (1A4ciii)

Previously, a separate method was used to estimate emissions from UK fishing vessels operating in sea territories outside UK waters, as these had not been captured in the original Entec (2010) study, but are required to be included in the national totals of the UK's inventory. The new shipping methodology based on AIS includes emissions from all commercial fishing vessels so a separate calculation approach is no longer required. Although these fishing vessels go out of range of UK shore-based terrestrial AIS data capture, the time period between successive AIS messages from these vessels is known corresponding to the times when the vessels first go out of range en route to their fishing destination to the point when they return. Fuel consumption and emissions are then estimated based on the assumption that the vessels are travelling at the same speed and using fuel at the same rate during the period they are out of range. The method for calculating emissions is therefore essentially the same as that used for coastal shipping (1A3dii),

3.3.5.2.4 Emissions from Vessel Movements between the UK and Overseas Territories (1A3dii)

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 2016.

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 EMEP (2016). Distances for each voyage were taken from http://www.portworld.com/map/. This has a tool 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 2016.

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 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 2016 derived for vessels using fuel oil for international voyages including to/from the OTs are shown in Section 3.3.5.4.

3.3.5.2.5 Emissions from Inland Waterways (1A3dii)

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 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 2016 EMEP/EEA Emissions Inventory Guidebooks (EMEP, 2016). 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 Emissions inventory guidebook (EMEP, 2016) 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 new 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 were now 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 were therefore removed from 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 – 2016:

- Private leisure craft – ONS Social Trends 41: Expenditure, Table 1, Volume of household expenditure on “Recreation and culture”[31]. 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)[32];

- Commercial passenger/tourist craft – Visit England, Visitor Attraction Trends in England 2016, Full Report ("Total England Attractions")[33];

- Freight – DfT Waterborne Freight in the United Kingdom, Table DWF0101: Waterborne transport within the United Kingdom (Goods lifted - UK inland waters traffic - Non-seagoing traffic – Internal)[34]

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 3-30 shows the trend in fuel consumption by inland waterways from 1990-2016 developed for the inventory this year. More detail regarding the vessels and their fuel type can be found in the report by Walker *et al.,* 2011.

The removal of vessel types from inland waterways using gas oil now captured under coastal shipping leads to downward revisions of fuel consumption by 55-70% across the timeseries for this sector compared with the previous inventory. Changes in the proxy time-series data used for some of the remaining vessels included under inland waterways are responsible for minor changes in the activity data.

[31] http://www.ons.gov.uk/ons/rel/social-trends-rd/social-trends/social-trends-41/index.html
[32] http://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE5
[33] http://www.visitengland.org/insight-statistics/major-tourism-surveys/attractions/Annual_Survey/
[34] https://www.gov.uk/government/statistical-data-sets/dwf01-waterborne-transport

Table 3-30 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
1991	30.1	3.4	0.6	28.8	22.6	11.7
1992	30.4	3.8	0.7	31.5	24.1	12.8
1993	30.7	4.1	0.7	34.3	25.5	13.9
1994	31.3	4.5	0.8	37.0	27.0	15.0
1995	31.6	4.2	0.9	39.8	28.5	16.1
1996	31.8	3.6	0.9	42.5	29.9	17.2
1997	31.3	3.1	1.0	45.3	31.1	18.3
1998	30.7	2.7	1.0	48.0	32.2	19.4
1999	30.7	2.7	1.1	50.7	33.6	20.5
2000	30.4	2.7	1.1	53.5	34.8	21.6
2001	29.5	2.7	1.2	56.2	35.9	22.8
2002	32.1	2.5	1.3	60.4	38.7	24.4
2003	33.0	2.0	1.4	64.6	41.0	26.1
2004	33.3	1.7	1.5	68.8	43.2	27.8
2005	33.3	2.2	1.6	72.9	45.2	29.5
2006	34.5	2.3	1.7	77.1	47.6	31.2
2007	35.4	2.1	1.7	81.3	49.9	32.9
2008	36.3	2.3	1.8	85.5	52.2	34.6
2009	38.0	2.1	1.9	89.6	54.8	36.3
2010	39.2	2.2	2.0	90.8	55.7	36.7
2011	40.4	2.2	1.9	89.9	55.5	36.4
2012	40.1	2.3	2.0	91.8	56.4	37.1
2013	41.9	3.3	2.0	93.3	57.6	37.7
2014	43.6	3.2	2.1	95.5	59.2	38.6
2015	44.2	2.3	2.2	100.5	61.8	40.7
2016	45.1	2.3	2.3	106.6	65.1	43.1

c) Emission factors

The fuel-based emission factors used for all inland waterway vessels were taken from the EMEP Emissions Inventory Guidebook and implied factors for 2016 are presented later. The factors for SO_2 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 International Navigation (1A3di)

Emissions from international marine bunkers are calculated, but reported as a Memo item and not included in the UK totals.

a) Activity data

The previous approach taken in the NAEI for international navigation activity was by difference in the bottom-up estimates of fuel consumption for sources included in the national totals (national navigation, naval shipping, inland waterways, fishing, overseas territories) and the total fuel sales given in DUKES for international bunkers plus national navigation combined. This was on the basis that whilst the total amount of fuel made available for consumption in DUKES was reliable, the split between international bunkers and national navigation was more uncertain.

Further discussions with BEIS indicate that there is now higher confidence in the DUKES estimates of the international 'marine bunkers' fuel sales data than the portion allocated to national navigation such that marine bunkers fuel statistics in DUKES should now be used without further adjustment as the activity data for emissions from the international navigation Memo item under 1A3di. This procedure was adopted in this inventory.

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.

Notwithstanding uncertainties in the modelling approach which were discussed by Scarbrough et al (2017), one possible reason for this difference is that a significant 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 2016 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 since 1990. Fuel consumed in the OTs and for voyages from the OTs to the UK is not included in this table.

Table 3-31 Fuel consumption (Mtonnes) for UK marine derived from inventory method

	Gas oil				Fuel oil			
Mtonnes fuel	Domestic coastal and military	Fishing	Inland waterways	International bunkers	Domestic coastal and military	Fishing	Voyages from UK to OTs	International bunkers
1990	1.89	0.23	0.03	1.14	0.82	0.82	0.008	1.39
1991	1.89	0.23	0.03	1.19	0.80	0.80	0.008	1.28
1992	1.86	0.24	0.03	1.24	0.78	0.78	0.008	1.30
1993	1.84	0.25	0.03	1.16	0.77	0.77	0.008	1.31
1994	2.06	0.25	0.04	1.20	0.84	0.84	0.009	1.11
1995	2.13	0.26	0.04	1.11	0.89	0.89	0.009	1.35

	Gas oil				Fuel oil			
Mtonnes fuel	**Domestic coastal and military**	**Fishing**	**Inland waterways**	**International bunkers**	**Domestic coastal and military**	**Fishing**	**Voyages from UK to OTs**	**International bunkers**
1996	2.14	0.24	0.04	1.20	0.90	0.90	0.009	1.45
1997	2.12	0.21	0.03	1.16	0.86	0.86	0.010	1.80
1998	2.06	0.20	0.03	1.40	0.88	0.88	0.010	1.67
1999	2.12	0.19	0.03	1.15	0.89	0.89	0.011	1.17
2000	1.96	0.18	0.03	1.14	0.80	0.80	0.011	0.93
2001	1.84	0.18	0.03	1.43	0.76	0.76	0.011	0.83
2002	1.83	0.18	0.03	1.14	0.79	0.79	0.008	0.76
2003	1.76	0.19	0.04	0.90	0.75	0.75	0.009	0.86
2004	1.73	0.19	0.03	1.07	0.75	0.75	0.010	1.00
2005	1.64	0.19	0.04	0.89	0.78	0.78	0.009	1.16
2006	1.53	0.18	0.04	1.04	0.72	0.72	0.013	1.30
2007	1.54	0.18	0.04	0.90	0.74	0.74	0.019	1.45
2008	1.47	0.18	0.04	1.03	0.70	0.70	0.011	2.44
2009	1.43	0.16	0.04	1.05	0.66	0.66	0.009	2.25
2010	1.41	0.17	0.04	0.96	0.57	0.57	0.011	1.83
2011	1.29	0.16	0.04	0.99	0.56	0.56	0.011	2.13
2012	1.15	0.16	0.04	1.12	0.52	0.52	0.009	1.53
2013	1.06	0.15	0.05	1.34	0.47	0.47	0.008	1.37
2014	1.04	0.17	0.05	1.68	0.49	0.49	0.010	1.14
2015	1.41	0.16	0.05	1.67	0.18	0.18	0.009	0.83
2016	1.36	0.16	0.05	1.77	0.17	0.17	0.013	0.88

This inventory submission includes estimates of fuel consumption from fishing vessels consuming fuel oil. The previous submission assumed all of the fishing vessels consumed gas oil, however the results of Scarbrough et al. (2017), that are now applied, includes estimates of both fuel oil and gas oil for fishing vessels.

The figures in Table 3-31 indicate that much higher fuel consumption is allocated to domestic shipping and fishing from the new modelling approach compared with those previously estimated in the inventory. This is discussed in Scarborough et al (2017) but is mainly due to more complete coverage of vessel activities, including movements by vessels to UK offshore oil and gas installations, and improved engine emission calculations. The emission calculations are estimated to have relatively low uncertainty for most large vessels which are responsible for 85% of total emissions. Scarbrough et al (2017) also report that the model estimates compare well with those from other European shipping inventories when comparisons are made on a like-for-like basis.

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 3-32 shows the implied emission factors for each main pollutant, for both domestic and international vessel movements and fishing in 2016. The units are in g/kg fuel and are implied by the figures in Scarbrough et al. (2017) and the fuel sulphur content.

Table 3-32 2016 Inventory Implied Emission Factors for Shipping

Fuel	Source	NO_x (as NO_2)	SO_x as SO_2	NMVOC	PM_{10}	CO	NH_3
		g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
Gas Oil	Domestic (excl. fishing)	54.9	5.4	1.6	1.0	3.1	0.010
	Fishing	68.3	7.3	2.3	1.2	3.1	0.010
	International	65.3	6.7	1.7	1.1	3.3	0.010
Fuel Oil	Domestic	72.1	26.8	2.5	2.6	2.9	0.010
	Fishing	89.4	26.8	3.1	2.9	2.7	0.010
	International	81.5	26.8	2.9	2.7	2.9	0.010

Table 3-33 provides emission factors for each main pollutant, assumed for all vessel types operating on the UK's inland waterways in 2016.

Table 3-33 2016 Inventory Emission Factors for Inland Waterway Vessels

Fuel	NO_x (as NO_2)	SO_x as SO_2	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	0.016	4.7	4.1	10.9	0.007
Petrol	9	0.011	50	0.04	300	0.005

3.3.6 Other Emissions Associated with Transport Sectors (1A4)

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 BEIS reported fuel use data. The 1A4a Commercial and Institutional sector also contains emissions from stationary combustion at military installations, which should be reported under 1A5a Stationary.

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 3.3.5.

3.3.7 Off-Road Machinery

Emissions from a variety of off-road mobile machinery sources are included in 1A2gvii, 1A4bii, 1A4cii, 1A4ciii 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.

3.3.7.1 Estimation of Other Off-Road Sources (1A2gvii, 1A4bii, 1A4cii/iii, 1A3eii)

A Tier 3 methodology is used for calculating emissions from individual types of mobile machinery.

Machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from the EMEP Guidebook (2009). Emission factors for more modern machinery are based on engine or machinery-specific emission limits established in the EU Non-Road Mobile Machinery Directives.

Activity data are derived from bottom-up estimates from population and hours of use of equipment in 2004. Various proxy statistics are used as activity drivers for different groups of machinery types to estimate fuel consumption in other years.

Summary of activity data
Bottom-up estimates from population and hours of use of equipment in 2004. Various proxy statistics used as activity drivers for different groups of machinery types to estimate fuel consumption in other years.

Details of Methodology
Emissions are estimated for 77 different types of portable or mobile equipment powered by diesel or petrol driven engines. These range from 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; aircraft support equipment. In the inventory they are grouped into four main categories:

- domestic house & garden
- agricultural power units (includes forestry)
- industrial off-road (includes construction and quarrying)
- aircraft support machinery.

Emissions 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 are calculated using the methodology given in the EMEP Guidebook (2009). Emissions are calculated using the following equation for each machinery class:

$$E_j = N_j \cdot H_j \cdot P_j \cdot L_j \cdot W_j.(1 + Y_j \cdot a_j /2). e_j$$

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:

$$E_{vj} = N_j \cdot H_j \cdot e_{vj}$$

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 off-road machinery were updated following a study carried out by AEA on behalf of the Department for Transport (Netcen, 2004a). 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 by 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 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. There are no reliable national statistics on population and usage of off-road machinery nor figures from BEIS on how much fuel is consumed by mobile machinery separately from fuel used for stationary combustion by a particular industrial or commercial sector.

However, as part of the 2014 Inventory Improvement Programme a review was made of some of the activity data used in light of further evidence and information not available when the 2004 survey was carried out. The review did not consider all the different types of machinery, but focused on those that made a significant contribution to the overall total inventory for the sector. The activity parameters considered were population, lifetime, engine power, and hours of use per year. The engine size is important for several reasons including the fact that it defines the emission limits that apply to the machinery in question according to the EU Non-Road Mobile Machinery (NRMM) Directive. The main types of machinery where activity data were revised in the 2013 NAEI (submitted in 2015) relative to the original 2004 study were for airport support machinery, generator sets, rollers, cranes and tracked bulldozers and dumpers.

The above review only captured a small number of machinery types and provided updates for the core 2004 activity data. As in previous years, various activity drivers were used to estimate activity rates for the four main off-road categories from 2005. These drivers were applied to all machines, including those above which were the subject of the most recent review.

For industrial and construction machinery, a set of four drivers is used. Each of the individual machinery types is mapped to one of these four drivers depending on the typical industry sector in which the machinery type is usually used. The four categories and drivers used are described in Table 3-34.

For domestic house and garden machinery, historic and projected trends in number of households are used (CLG, 2016). For airport machinery, statistics on number of terminal passengers at UK airports are used (CAA, 2017). For agricultural off road machinery, the trends in gas oil allocated to agriculture in DUKES (BEIS, 2017) are used.

For the current inventory, minor revisions were made to some of the activity drivers used for agricultural machinery.

Table 3-34 Activity drivers used for off-road machinery in the industry and construction sector.

Category	Driver source	Machinery types
Construction	ONS construction statistics. “Output in the Construction Industry.”, http://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry Table 2b – Value of construction output in Great Britain: non-seasonally adjusted. The value of all new work (i.e. excluding repair and maintenance work) at constant (2010) prices. The seasonally non-adjusted figures were used and scaled to ensure time series consistency.	generator sets <5 kW
		generator sets 5-100 kW
		asphalt pavers
		tampers /rammers
		plate compactors
		concrete pavers
		rollers
		scrapers
		paving equip
		surfacing equip
		trenchers
		concrete /industrial saws
		cement & mortar mixers
		cranes
		graders
		rough terrain forklifts
Quarrying	Data on UK production of minerals, taken from UK Minerals Yearbook data, BGS (2017).	bore/drill rigs
		off highway trucks*
		crushing/processing equip
Construction and Quarrying	Growth driver based on the combination of the quarrying and construction drivers detailed above.	excavators
		loaders with pneumatic tyres
		bulldozers
		tracked loaders
		tracked bulldozers
		tractors/loaders

Category	Driver source	Machinery types
		crawler tractors
		off highway tractors
		dumpers /tenders
General Industry	Based on an average of growth indices for all industrial sectors, taken from data supplied by BEIS for use in energy and emissions projections.	generator sets 100-1000KW
		pumps
		air compressors
		gas compressors
		welding equip
		pressure washers
		aerial lifts
		forklifts*
		sweepers/ scrubbers
		other general industrial equip
		other material handling equip

Having calculated fuel consumption from a bottom-up method, the figures for diesel engine machinery were allocated between gas oil and road diesel. This was following a survey of fuelling practices of uses of off-road machinery where it was found that, particularly for small, non-commercial and domestic users who may only occasionally need to refuel, engines are filled with road diesel rather than gas oil. A further fuel reconciliation procedure was then followed for gas oil which took account of consumption from all sources, as described in Murrells et al (2011). If UK total consumption figures given in DUKES for gas oil exceeded that calculated for each source, the figure for gas oil consumption from industrial machinery was reduced to bring alignment with DUKES. The reason for making the reduction specifically to industrial and construction machinery use of gas oil rather than other sectors is because this source is considered to have the most uncertain estimates of activity due to the large and varied nature of machinery included.

As a consequence of this normalisation procedure, changes in fuel consumption and emissions for industrial machinery occur when revisions to the allocation of gas oil consumption to other sources are made.

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.

Figure 3-8 Fuel consumption by off-road machinery in kilotonnes fuel from 2000

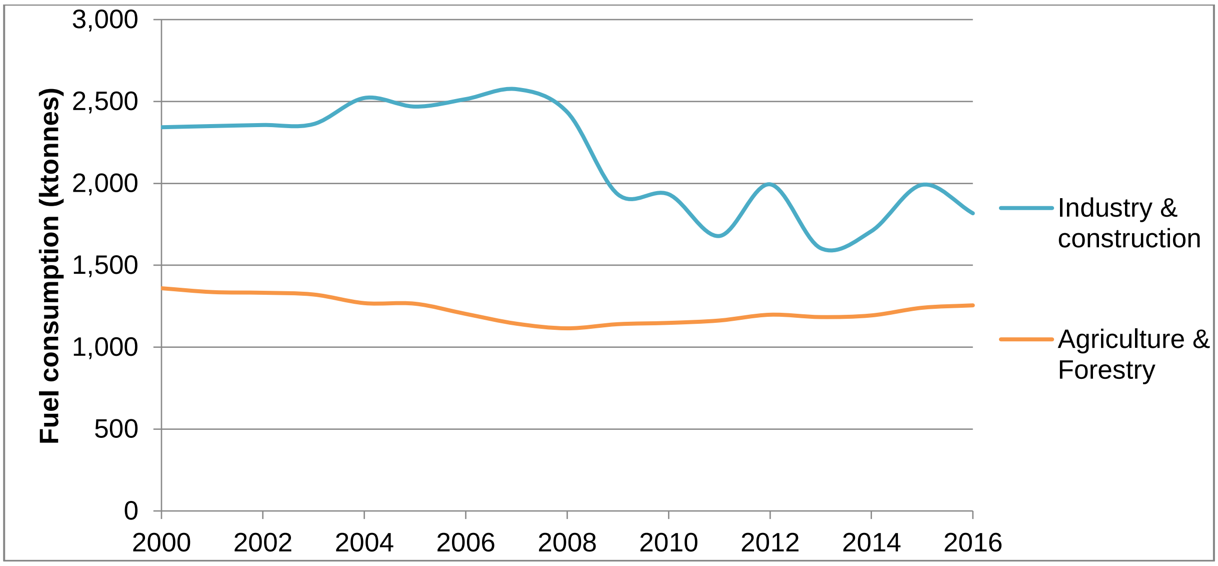
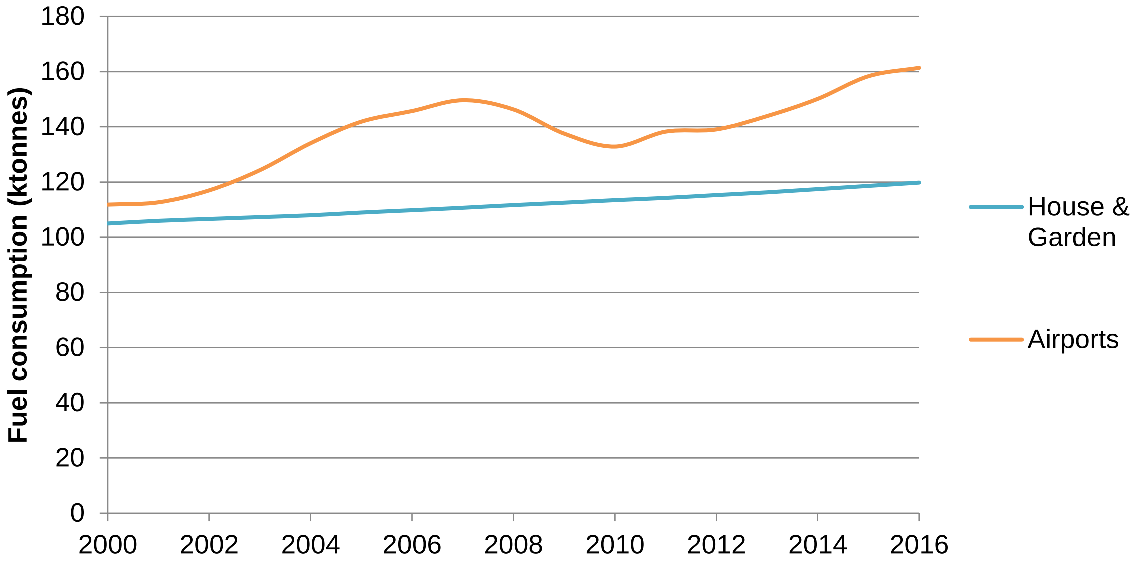


Figure 3-9 Fuel consumption by off-road machinery in kilotonnes fuel from 2000



A simple turnover model is used to characterise the population of each machinery type by age (year of manufacture/sale) and hence emission standard. For older units, the emission factors used came mostly from EMEP (2009) though a few of the more obscure classes were taken from Samaras & Zierock (1993). The load factors were taken from Samaras (1996). Emission factors for garden machinery, such as lawnmowers and chainsaws were updated following a review by Netcen (2004b). For equipment whose emissions are regulated by Directive 2002/88/EC or 2004/26/EC, the emission factors for a given unit were taken to be the maximum permitted by the directive at the year of manufacture. The emission regulations are quite complex in terms of how they apply to different machinery types. Each of the 77 different machinery types was mapped to the relevant regulation in terms of implementation date and limit value.

The methodology follows the Tier 3 methodology described in the EMEP/EEA emission inventory guidebook (EMEP, 2016).

For the industrial and construction machinery, the fuel reconciliation process described above essentially overrides any changes in estimates of fuel consumption calculated from the bottom-up procedure arising from the 2014 review of activity data for some selected machinery types. However, this review 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 and emission limit value.

Aggregated emission factors for the four main off-road machinery categories by fuel type in 2016 are shown in Table 3-35.

Most emission factors shown here for 2016 are generally similar to or slightly lower than the factors for 2015. A decrease is a consequence of the penetration of new machinery meeting the tighter emission regulations in the non-road mobile machinery fleet. The factors for SO_2 in 2016 reflect the sulphur content of fuels used, according to figures provided by UKPIA (2017).

Table 3-35 Aggregated Emission Factors for Off-Road Source Categories in 2016 (t/kt fuel)

Source	Fuel	CO	NO_x (as NO_2)	PM_{10}	SO_2[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	0.011	12.4
Agricultural Power Units	Gas oil	17.2	13.5	1.3	0.016	2.6
Agricultural Power Units	Petrol	716	1.4	0.03	0.011	249
Industrial Off-road	DERV	15.6	17.6	1.8	0.015	4.5
Industrial Off-road	Gas oil	15.6	17.6	1.8	0.016	4.5
Industrial Off-road	Petrol	1035	6.2	0.03	0.011	39.3
Aircraft Support	Gas oil	12.6	14.4	0.9	0.016	2.4

[1] Based on sulphur content of fuels in 2016 from UKPIA (2017).

3.3.8 Recalculations in transport sources

Aviation (1A3a)

The main recalculations for aircraft sources were due to revisions to the following:

- Further revisions to assignment of aircraft to EMEP-EEA cruise categories
- Further revisions to assumptions regarding the APU types fitted to aircraft
- Minor revisions to assignment of aircraft to other operational categories
- Revisions to the fuel consumptions and emission factors assumed for a number of smaller aircraft, particularly for piston aircraft, which consume aviation spirit, based on factors in the EMEP/EEA (2016) Emissions Inventory Guidebook.

Road transport (1A3b)

The main recalculation for road transport has been through the update in the methodology for estimating evaporative emissions of NMVOCs (1A3bv) to be in line with the 2016 EMEP/EEA Guidebook and was in response to recommendations from the NECD expert review of the UK inventory in 2017. This has led to an increase in NMVOC emissions between 2005 and 2015 of between 5 to 10 ktonnes compared with the previous submission.

Another notable change has been the assumption that all exhaust emissions of PM are in the $PM_{2.5}$ range, to be in line with the 2016 EMEP/EEA Guidebook assumption. Previously, the UK had assumed that 95% of PM_{10} emissions were in the $PM_{2.5}$ range. This led to an increase of 0.3 to 0.8 ktonnes of $PM_{2.5}$ exhaust emissions (1A3bi-iv) between 2005 and 2015.

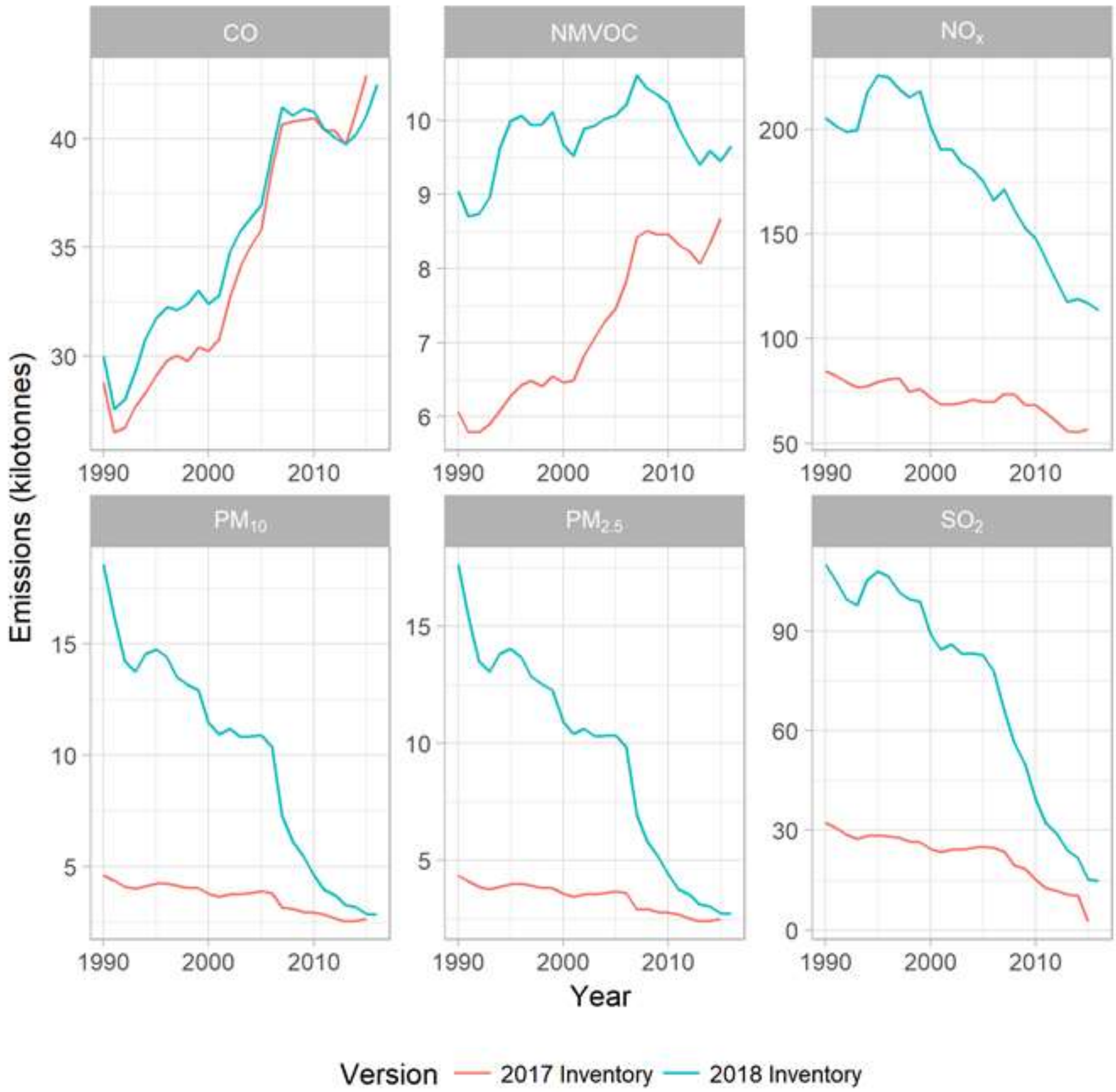
Other minor re-calculations have occurred due to:

- Inclusion of hybrid and electric vehicles, but this has an overall very small impact on the total road transport emissions as the penetration of these vehicles in the fleet is relatively small (compared to conventional vehicles) to date at national level.
- A review on the effect that low strength blends of bioethanol and biodiesel in conventional fossil fuel petrol and diesel has on exhaust emissions of PM. As the emission reducing effect of bioethanol is considered to be smaller than previously assumed, overall PM exhaust emission estimates in 2015 are 0.9% (0.06kt) higher than previously estimated, though this increase has been offset by other minor changes made.
- Revised data on the vehicle weight splits in the fleet of rigid HGVs. This gives a heavier fleet average, and leads to increases in weighted emission factors of pollutants of around 2%.

Rail (1A3c)
Actual Intercity and regional train kilometres from 2012-2016 are now obtained from ORR rather than using timetable train kilometres, leading to a slight reduction in emissions. Fuel consumption for 2015 was updated to reflect finalised ORR data. The large reduction in fuel consumption by freight trains from 2014 to 2015 estimated last year using trends in tonnes of freight moved, which showed a significant decline, has been replaced with a smaller decline based on actual fuel consumption statistics for rail freight in 2015 provided by the ORR which were not available at the time the previous inventory was compiled. This leads to lower aggregated implied emission factors for freight trains for this year.

Navigation (1A3d) and fishing (1A4ciii)
There have been significant recalculations due the change in methodology which is now based on detailed AIS vessel movement data available for 2014. The emissions differences for key pollutants summed for the domestic navigation (1Adii), fishing (1A4ciii) and naval (1A5b) sources are shown in Figure 3-10. These changes are mainly due to changes in fuel consumption estimates and to a lesser extent the emission factors applied.

Figure 3-10 Emissions by pollutant and inventory version for NFR codes 1A3d, 1A4ciii, 1A5b



Off-road machinery (1A2gvii, 1A4bii, 1A4cii/iii, 1A3eii)
The main re-calculation is due to changes in fuel consumption for industrial and construction mobile machinery affecting 1A2gvii arising from the re-allocation of changed gas oil activity data in DUKES.

The changes to this sector are made to retain fuel mass balance with DUKES and are affected by changes made to other sectors using gas oil.

Minor re-calculations arise from:

- Revision to DUKES gas oil consumed in agriculture used as a driver for the agricultural machinery sector. The 2014 and 2015 values are 36% greater than the previous values used.
- Consideration of emissions from Stage IIIA forklifts and dumpers. This affects emission factors from 2006 and the impact increases roughly steadily each year from 2006 as more Stage IIIA machines enter the fleet. This change leads to an increase in emissions from industrial machinery 1A2gvii (around 0.5% in 2006-2008 up to around 2-5% for 2012-2015) but is variable by pollutant.

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. Particularly for the road transport sector, the evidence to base changes in emission factors is a fast developing and changing area, particularly as new evidence on ‘real-world’ factors for NO_x emissions from modern diesel vehicles emerges.

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.

3.4 NFR14 1A4: Combustion in the Residential / Commercial / Public Sectors

Table 3-36 Mapping of NFR14 Source Categories to NAEI Source Categories: Residential / Commercial / Public Sectors

NFR14 Category (other 1A4)	Pollutant coverage	NAEI Source category
1 A 4 a i Commercial / institutional: Stationary	All CLRTAP pollutants	Miscellaneous industrial & commercial combustion
		Public sector combustion
		Railways - stationary combustion
1 A 4 b i Residential: Stationary plants	All CLRTAP pollutants	Domestic combustion
1 A 4 b ii Residential: Household and gardening (mobile)	All CLRTAP pollutants *(except HCB and PCBs)*	House and garden machinery
1 A 4 c i Agriculture/Forestry/Fishing: Stationary	All CLRTAP pollutants *(except HCB)*	Agriculture - stationary combustion
1 A 4 c ii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	All CLRTAP pollutants *(except HCB and PCBs)*	Agricultural engines
		Agriculture - mobile machinery
1A 4 c iii Agriculture/Forestry/Fishing: National fishing	All CLRTAP pollutants *(except NH_3, HCB, PCBs)*	Fishing vessels

Table 3-37 Summary of Emission Estimation Methods for NAEI Source Categories in NFR14 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	BEIS energy statistics	Default factors (USEPA, EMEP/EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Public sector combustion	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP/EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Railways - stationary combustion	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP/EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
Domestic combustion	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP/EEA, UK-specific research). Fuel analysis (UKPIA, others) for SO_x as SO_2.
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	Factors from EMEP/EEA Guidebook combined with estimates of effect of more recent NRMM emission regulations on more modern equipment.

NAEI Source Category	Method	Activity Data	Emission Factors
		based on trends in household numbers. See Section 3.3.7	See 3.3.7. Fuel analysis (UKPIA) for SO_x as SO_2.
Agriculture - stationary combustion	UK model for activity allocation to unit type; AD x EF	BEIS energy statistics	Default factors (USEPA, EMEP/EEA, UK-specific research). Fuel analysis (UKPIA) for SO_x as SO_2.
Agricultural engines	AD x EF	Inventory agency estimate of fuel use by different mobile units	See 3.3.7. Default factors mainly from UK-specific research / analysis based on UK stock of combustion units, fuels and assumed utilisation. Fuel analysis (UKPIA) for SO_x as SO_2.
Agriculture - mobile machinery	See Section 3.3.7 on off-road machinery	Inventory agency estimate of fuel use by different mobile units. Study on population and usage of machinery in 2004. 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 3.3.7. Fuel analysis (UKPIA) for SO_x as SO_2.
Fishing vessels	See Section 3.3.5 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 3.3.5	See 3.3.5. Default factors mainly from UK-specific research (2017 BEIS review of the NAEI shipping emissions methodology);, EMEP/EEA Guidebook and fuel analysis (UKPIA) for SO_x as SO_2.

3.4.1 Classification of activities and sources

The NAEI utilises energy statistics published annually in the Digest of UK Energy Statistics (BEIS, 2017). 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 3-36 relates the detailed NAEI source categories to the equivalent NFR14 source categories for stationary combustion. Most NAEI sources can be mapped directly to an NFR14 (Nomenclature for Reporting) source category, but there are some instances where the scope of NAEI and NFR14 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 NFR14 system is the reporting format used for submission of the UK inventories under the CLRTAP.

Almost all of the NFR14 source categories listed in Table 3-36 are key sources for one or more pollutants and so the description of the methodology will cover the whole of this NFR14 sector. However, the emission inventory methodology for the mobile sources listed in Table 3-36 is described elsewhere (Sections 3.3.5 and 3.3.7).

3.4.2 General approach for 1A4

NFR14 Sector 1A4bi is a key category for NO_x (as NO_2), TPM, $PM_{2.5}$, & PM_{10}, SO_x (as SO_2), NMVOC, CO, Pb, Cd, B[a]P, PAHs, Hg and PCDD/PCDFs. Sector 1A4bii is a key source only 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 utilizing reported emissions is not possible, and instead a top-down method using the UK activity data and literature emission factors is used extensively for 1A4.

3.4.3 Fuel consumption data

Fuel consumption data are primarily taken from DUKES, but for some emission sources the NAEI energy data deviates from the detailed statistics given in DUKES, for the reasons outlined in section 1.4.2 National Energy Statistics.

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 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 domestic sector (1A4b).
- 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.

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 2009-2016, 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 Method for commercial, domestic and public sector combustion sources

Individual combustion plants range in scale from domestic appliances such as central heating boilers and open fires, up to a few combustion facilities with thermal inputs exceeding 50 MW_{th} used in the commercial or public sectors. Even in the latter two sectors, most combustion plant will be small, and because of this, it is not possible to derive bottom-up estimates. Emissions are estimated using an appropriate emission factor applied to national fuel consumption statistics taken from DUKES.

Similar to 1A2, the approach for commercial and public sector combustion using the major fuels (coal, coke oven coke, fuel oil, gas oil, burning oil, natural gas) uses Tier 1 default factors from the EMEP/EEA Emission Inventory Guidebook 2016 for CO, NO_X and PM_{10} and a mixture of EMEP/EEA 2016, US EPA and UK-specific factors for other pollutants and for minor fuels. Emission factors for SO_2 are based on UK-specific data on the sulphur content of coals and oils, provided by fuel suppliers. There are limited data on appliance population and fuel use to allow a higher Tier approach, however, work to support development and implementation of the Medium Combustion Plant Directive may allow a more detailed inventory in future.

Emissions from domestic combustion are estimated using literature, Tier 1 and, for wood, Tier 2 emission factors. Suitable factors are not always available for some minor fuels, and so 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.

In the case of domestic combustion of **coal and coal-based solid fuels**, emission factors are derived that take into account the types of appliances used in the UK, applying emission factors for specific technologies from the EMEP/EEA Guidebook 2016. The proportions of each type of appliance using each fuel are estimated, based primarily on information from the 2007 report '*Preparatory Study for Eco-design Requirements of EuPs, Lot 15: Solid fuel small combustion installations*'[35], with some more detailed splits utilising expert elicitation. No other data are available regarding the population of appliance types over time, and therefore the assumptions are held constant over the 1970-2016 timescale of the inventory. This method will be reviewed and improved as new data becomes available, with the aim that changes in appliance use over time will be reflected in the NAEI emission trends. Recent work on residential wood combustion (see below) indicates that the Ecodesign preparatory study appliance profile for solid mineral fuels may not be appropriate.

In the case of residential combustion of **wood / biomass**, DECC (now BEIS) conducted research during 2014-15 into the use of wood for residential heating. This led to a very significant increase in the estimated use of wood in the residential sector within the DUKES 2015 publication, compared to previous UK energy statistics. The BEIS research led to a new time series of activity data in DUKES, back-revising the residential wood use activity from 2008 onwards but did not revise the published data for earlier years. To ensure consistency in reported inventory emissions trends across the entire time-series, the Inventory Agency (in consultation with the BEIS energy statistics team) derived a new time series for residential wood use from 2007 back to 1990 to supplement the published revisions for 2008-2013. The DUKES estimates for wood use have subsequently been recalculated in both the DUKES 2016 and DUKES 2017 publications (but to a much lesser scale than in DUKES 2015), and again the Inventory Agency has worked with the BEIS team of energy statisticians to ensure that the UK inventory activity data for wood use are based on consistent data and assumptions across the time series.

These recalculations to the wood activity data over the last 3 DUKES publications have a significant impact on the level and trend of emission estimates from the UK residential sector compared to earlier inventories. The most notable impact is that the recalculated DUKES data present a large increase in wood use during the 2000s and later years of the time series, and this leads to much higher reported

35 Available here: http://www.eceee.org/ecodesign/products/solid-fuel-small-combustion-installations/ (website checked 30 January 2017)

emissions (notably of particulate matter) from the sector in the later years of the time series. However, 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 for a fuel with a substantial component outside conventional fuel markets.

The BEIS research enables some improved assumptions regarding the use of wood within different appliance types through time. The Inventory Agency has consulted with industry experts to supplement the BEIS research information, aiming to ensure that the high growth in wood use in the residential sector in recent years is reflected as accurately as possible within the NAEI method.

Based on the BEIS research, most of the wood burned in 2014 (the survey year) was in non-automatic appliances including about half in open appliances. The BEIS survey data for 2014 has been applied to later years. Although the BEIS survey was primarily a 'snapshot' it also included information on appliance age. Details on assumptions for fuel use and appliance population are provided in a report[36] but the key assumption is that for open and closed appliances the proportion of wood fuel used in open appliance 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 and 2015).

Since combustion on open fires is less controlled, and therefore typically emits higher levels of many pollutants, the assumptions made on appliance technologies have a significant impact on the emission estimates.

The 2016 EMEP/EEA guidebook update included revised (higher) emission factors for particulate matter species from pellet stoves and these have been incorporated in the NAEI. Pellet stoves are only a small proportion of the appliance types in the UK, as most residential combustion occurs in open fireplaces and closed stoves using wood logs. As such, this change leads to only a minor increase in particulate matter emissions from residential combustion (<0.3% for all years and all PM species).

Although most of the emissions from wood combustion are calculated using a Tier 2 methodology, ammonia emissions are calculated at a Tier 1 level. Following review of the NAEI during the 2017 submission cycle, the ammonia emission factors in the EMEP/EEA Guidebook 2016 were assessed and determined to be based on wildland fires and consequently highly uncertain. The decision was therefore made to use a Tier 1 factor based on the original reference.

Following a recent revision, the EMEP/EEA Guidebook 2016 now includes emission factors for total particulate matter and filterable particulate matter (that is excluding the condensable fraction). Particulate matter emissions for residential wood combustion in the NAEI are based on emission factors for total particulate.

As with coal-based fuels, the methodology and assumptions for wood will be kept under review and improved should better data become available.

For domestic natural gas consumption, the NAEI also includes a modelled approach to estimate changes in appliance technologies. The method allocates almost all natural gas burnt to boilers (>95% is burned in boilers, there is a small contribution from natural gas use in room heaters) and that emission factors for new boilers are constant over the following three periods:

- 1970-1989 70 g NO_x (as NO_2)/GJ net
- 1990-2004 24 g NO_x (as NO_2)/GJ net
- 2005-2016 19.4 g NO_x (as NO_2)/GJ net

The three emission factors chosen are, respectively

i) the EMEP/EEA 2009 Guidebook default factor (Table 3-20) for domestic natural gas combustion – note that the EMEP/EEA 2016 Guidebook default factor is lower (42 g/GJ) but is believed to represent more modern boilers;

[36] Unpublished report - Air Quality Improvement Plan 2015: Residential Biomass Combustion, report ED 59801034 Issue 1.1 Date 05/01/2016 prepared by Ricardo Energy & Environment for Defra

ii) 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; and

iii) the Class 5 standard for new natural gas-fired boilers introduced in EN 483.

The EMEP/EEA 2009 Guidebook default factor for room heaters is used for natural gas burned in non-boiler appliances across all years (50 g NOx (as NO_2)/GJ net, from table 3-13). Following a review of the assumptions regarding emission factors used for natural gas boilers in the NAEI and the London Atmospheric Emission Inventory, the emission factors for the latter two periods have been revised (King and Stewart, 2017). The same review also identified a new age profile for gas boilers. In previous years, it was assumed that all boilers have a 15-year lifetime and that an equal number are replaced each year. Following the review, a new age profile has been adopted as it provides a more realistic view of the range of appliance ages. The new profile is based on a survey of 44,000 homes as part of the RE:NEW home energy retrofit scheme in London in 2012 and indicates that about 50% of boilers are up to five years old but 11% were more than 15 years old.

For residential combustion of oils, Tier 1 emission factors for CO, NO_x (as NO_2) and PM_{10} are taken from the EMEP/EEA Guidebook 2016, whereas factors for SO_x (as SO_2) and metals are, like the factors for 1A2, based on UK-specific data on fuel composition.

3.4.5 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.

3.4.6 Recalculations in NFR14 Sector 1A4

Revisions to estimates as compared with the previous submission include:

- NO_x estimates have been revised downward (mainly from 2010 onwards) for commercial/public sector combustion (1A4ai) due to revisions to the UK energy statistics (to account for findings from surveying a wider group of suppliers) that has led to a re-allocation in UK energy statistics of natural gas use from commercial users (1A4) to industrial users (1A2); NO_x estimates for domestic sector (1A4bi) have also been revised due to improvements to emission factors and domestic boiler age profile used in the inventory model for domestic gas combustion.
- Emission factors of POPs have been reviewed for the stationary combustion sector and the revisions seen in 1A4ai, 1A4bi and 1A4ci are mainly due to the switch to the 2016 EMEP/EEA Guidebook factors instead of UK-specific method, as well as inclusion of new sources. For some sources, the revisions are significant, for instance, inclusion of Benzo(a)pyrene emissions from agriculture use of straw as fuel has revised emissions for 1A4ci upward by more than 1000-fold in 2015.
- The 2016 EMEP/EEA Guidebook update included revised (higher) emission factors for particulate matter species from pellet stoves and these have been incorporated in the NAEI. Pellet stoves are only a small proportion of the appliance types in the UK, as most residential combustion occurs in open fireplaces and closed stoves using wood logs. As such, this change leads to only a minor increase in particulate matter emissions from residential combustion (<0.3% for all years and all PM species).
- The wood use data from DUKES has had minor revisions (changes of <0.5% since 2009).
- Recalculations for 1A4ciii - fishing vessels are given in section 3.3.8.

3.4.7 Planned Improvements in NFR14 Sector 1A4

The methodology for stationary combustion in 1A4 is based exclusively on the use of literature emission factors, including factors from the EMEP/EEA Guidebook, and factors based on UK-specific data (e.g. for SO_x as SO_2). To some extent the factors take account of the types of combustion devices in use, for example those for wood burning, for NO_x (as NO_2) emissions from the domestic combustion of natural gas and coal, and for particulate matter from coal combustion.

In the case of domestic wood and domestic natural gas combustion, the inventory methods aim to reflect the change in emission factors over time as lower-emitting technologies have penetrated the UK stock of combustion units. However, the methods are 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. At present, the inventory does not include any assessment of changes in technology over time for domestic combustion of coal, nor for changes in combustion technology for any fuels in the case of commercial and public sector combustion.

The influence of technology is greatest in the domestic sector, where wood and solid mineral fuel open fires typically emit significantly more particulate matter and VOC, for example, than boilers. Technology will also have differing impacts on different pollutants e.g. little or no impact on SO_x (as SO_2) emissions, and most impact on particulate matter (and related pollutants such as metals, POPs, CO, NO_x (as NO_2) and NMVOC. As a result, emission estimates within 1A4 are most uncertain for those pollutants that are most affected by technology.

Domestic wood combustion is a major source of emissions of particulate matter and Benzo[a[pyrene and so the uncertainty of estimates for 1A4 is a key component of overall uncertainty in the UK inventory for PM species and PAH.

Emissions from 1A4 are also significant for NO_x (as NO_2), NMVOC, benzene, CO and some persistent organic pollutants, and therefore uncertainty in 1A4 is important for the UK inventory as a whole. The sector is therefore one where improvements in methodology are a priority. Unfortunately, the scarcity of data makes it difficult to implement any major improvements to the inventory methodology.

The highest priority for improvement is to improve the information on the market shares of domestic wood burning appliances, and the further development of the methodology for domestic combustion of coal and smokeless fuels. A new project is now underway to obtain better data on domestic burning which we envisage will feed into compilation of the inventory in future years.
Gas combustion is the dominant source of NO_x (as NO_2) 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. Currently, no specific improvements are planned, but the methods will be kept under review, and could be improved if new data becomes available.

3.5 NFR14 1B1 & 1B2: Fugitive Emissions from Fuels

Table 3-38 Mapping of NFR14 Source Categories to NAEI Source Categories: Fugitive Emissions from Fuels.

NFR14 Category	Pollutant coverage	Source
1 B 1 a Fugitive emission from solid fuels: Coal mining and handling	NMVOC, Particulate Matter, PM_{10}, $PM_{2.5}$	Deep-mined coal
		Open-cast coal
1 B 1 b Solid fuel transformation	All CLRTAP pollutants *(except Se, HCB)*	Charcoal production
		Coke production
		Iron and steel flaring
		Solid smokeless fuel production
1 B 2 a i Oil (Exploration, production, transport)	NO_x (as NO_2), NMVOC, SO_x (as SO_2) and CO	Upstream Oil Production - Offshore Oil Loading
		Upstream Oil Production - Offshore Well Testing
		Upstream Oil Production - Oil terminal storage
		Upstream Oil Production - Onshore Oil Loading
		Upstream Oil Production - process emissions
		Petroleum processes
1 B 2 a iv Oil (Refining / Storage)	NMVOC and NH_3	Refineries – drainage
		Refineries – general
		Refineries – process
		Refineries – tankage
1 B 2 a v Distribution of oil products	NMVOC	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
1 B 2 b Natural gas (exploration, production, processing, transmission, storage, distribution and other)	NO_x (as NO_2), NMVOC, SO_x (as SO_2) and CO	Upstream Gas Production - Gas terminal storage
		Upstream Gas Production - Offshore Well Testing
		Upstream Gas Production - process emissions
		Gasification processes
		Gas transmission network leakage
		Gas distribution network leakage
		Gas leakage at point of use
1 B 2 c Venting and flaring (oil, gas, combined oil and gas)	NO_x (as NO_2), NMVOC, SO_x (as SO_2), Black carbon, CO, Particulate Matter, PM_{10} and $PM_{2.5}$	Upstream gas production - gas flaring
		Upstream gas production - gas venting
		Upstream oil production - gas flaring
		Upstream oil production - gas venting
		Refineries - flares
1 B 2 d Other fugitive emissions from energy production	NA (not applicable)	

Table 3-39 Summary of Emission Estimation Methods for NAEI Source Categories in NFR14 Category 1B

NAEI Source Category	Method	Activity Data	Emission Factors
Deep-mined coal	AD x EF	BEIS energy statistics	EMEP-EEA 2016
Open-cast coal	AD x EF	BEIS energy statistics	EMEP/EEA 2016
Charcoal production	AD x EF	FAOSTAT	Default factors (USEPA AP-42, EMEP/EEA 2016, IPCC 2006, IPCC 1996)
Coke production	UK I&S model, AD x EF	BEIS energy statistics, ISSB, EU ETS, Tata Steel	Operator data reported under IED/E-PRTR, Tata Steel, British Steel, default factors (USEPA, EIPPCB, EMEP/EEA 2016, UK research)
Iron and steel flaring	UK I&S model, AD x EF	BEIS energy statistics, EU ETS, Tata Steel	Operator data reported under IED/E-PRTR; Default factors (EMEP/EEA 2016, UK research)
Solid smokeless fuel production	UK model for SSF production, AD x EF	BEIS energy statistics	Operator data reported under IED/E-PRTR, default factors (EMEP/EEA 2016, EIPPCB, UK research)
Upstream Gas Production - Gas terminal storage Upstream Gas Production - process emissions Upstream Oil Production - process emissions Upstream Oil Production - Oil terminal storage	Operator data, time series assumptions	EEMS, Oil and Gas UK, BEIS energy statistics	Operator data reported under EEMS, with emissions reported since 1998. Earlier data based on estimates from UK Oil and Gas and using BEIS oil and gas production statistics.
Upstream Gas Production - Offshore Well Testing Upstream Oil Production - Offshore Well Testing Upstream Oil Production - Offshore Oil Loading Upstream Oil Production - Onshore Oil Loading	AD x EF	EEMS, Oil and Gas UK, BEIS energy statistics	Operator data reported under EEMS, with AD and emissions reported since 1998. Earlier emissions data and factors based on estimates from UK Oil and Gas, using BEIS oil and gas production statistics.
Gasification processes	AD x EF	BEIS energy statistics	Operator reported emissions under IED/E-PRTR
Petroleum processes	Operator reported emissions	BEIS energy statistics	Operator reported emissions under IED/E-PRTR; UK operators
Refineries – Drainage, General, Process, Tankage	Operator reported emissions	UKPIA, BEIS energy statistics	Operator reported emissions under IED/E-PRTR, UKPIA data for all refinery sources.
Petrol stations and terminals (all sources)	AD x EF	BEIS energy statistics	UK periodic research, annual data on fuel vapour pressures (UKPIA), UK mean temperature data (Met Office), and abatement controls (IoP annual surveys).
Refineries – road / rail loading	Trade association estimates	BEIS energy statistics	UKPIA estimates based on petroleum consumption. Pre-1994 data scaled on energy statistics data for UK petrol use.
Sea-going vessel loading	AD x EF	BEIS energy statistics	UK periodic research (IoP) and annual data on fuel vapour pressures (UKPIA) and temperature data (Met Office).
Gas transmission network leakage Gas distribution network leakage	UK gas leakage model	Cadent Gas, Northern Gas Networks, SGN,	Annual gas compositional analysis by the GB gas network operators.

NAEI Source Category	Method	Activity Data	Emission Factors
		Airtricity, Wales and West Utilities	
Gas leakage at point of use	UK model	BEIS 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 GB gas network operators.
Upstream gas production - gas flaring	AD x EF	EEMS, Oil and Gas UK, BEIS energy statistics	Operator data reported under EEMS, with AD and emissions reported since 1998. Earlier emissions data and factors based on estimates from UK Oil and Gas, using BEIS oil and gas production statistics.
Upstream oil production - gas flaring			
Upstream gas production - gas venting	Operator data, time series assumptions	EEMS, Oil and Gas UK, BEIS energy statistics	Operator data reported under EEMS, with emissions reported since 1998. Earlier data based on estimates from UK Oil and Gas and using BEIS oil and gas production statistics.
Upstream oil production - gas venting			
Refineries - flares	Trade association estimates	UKPIA, BEIS energy statistics	Operator reported emissions under IED/E-PRTR, UKPIA 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, 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 (BEIS, 2017);
- refinery activity and source emission estimates reported by refinery operators via the trade association (UKPIA, 2017);
- upstream oil & gas activity data from the EEMS reporting system managed by the BEIS Offshore Inspectorate (BEIS, 2017b); and
- natural gas leakage data provided annually by the gas supply network operators in the UK (Cadent Gas, Northern Gas Networks, SGN, Airtricity, Wales and West Utilities; all 2017).

The most significant emission estimates in the 1B sector are calculated using operator-reported data from refineries and from the oil & gas exploration and production sector. 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 EMEP-EEA 2016 Guidebook, EMEP-EEA 2013 Guidebook, but in some instances from IPCC 2006 Guidelines, IPCC 1996 Guidelines, USEPA AP-42 and from publications from the EIPPCB);
- annual sampling and analysis, e.g. to determine natural gas composition;
- 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 NFR14 1B1: Fugitive emissions from solid fuels

1B1a Fugitive Emissions from Solid Fuels: Coal mining and handling

Coal seams contain a proportion of highly volatile material which is released during the extraction, and then 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;
- disposal of spoils from the coal extraction system.

The extraction of deep-mine coal has almost ceased in the UK in 2016 with the closure of all remaining large-scale deep coal mines. As a consequence, fugitive emissions from deep-mined coal accounted for only 6% of total mining NMVOC emissions in 2016, and the whole mining sector only accounted for 0.1% of total UK NMVOC emissions in 2016, compared to 1.0% of the UK NMVOC inventory in 2015.

The inventory draws emission factors upon the EMEP/EEA air pollutant emission inventory 2016 guidebook (EMEP, 2016) for both open-cast and deep-mined coal extraction. The uncertainty in emission factors for NMVOC is very high. The EMEP/EEA 2016 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 is derived from UK energy statistics (BEIS, 2017), 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.

1B1b Fugitive Emissions from Solid Fuels: Solid fuel transformation

There are no key source categories in 1B1b of the UK inventory. The main source of emissions across the time series is coke production, which declined by 37% between 2015 and 2016 due to a down-turn in steel production at integrated steelworks in the UK, but was still responsible for 1.4% of UK lead emissions and 1.3% of UK benzo[a]pyrene emissions in 2016. The manufacture of other, patented solid fuels is a minor source in the UK inventory context.

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 IED/E-PRTR 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 IED/E-PRTR 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 UK inventory. 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 EMEP/EEA guidebook (EMEP, 2016), BREF notes, US EPA AP-42 and industry-specific studies.

Operator-reporting of annual emissions under IED/E-PRTR is less comprehensive for other solid smokeless fuel production, therefore emissions in the UK inventory are generally estimated using literature factors and in some cases (e.g. SO_x as SO_2) using a mass balance approach.

As of 2015, 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 significant 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 under the terms of their IED/E-PRTR permits. Emission estimates for the sector can be based on the emission data reported for individual sites:

UK Emission $= \Sigma$ 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. 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 significantly to the UK emission inventory totals.

3.5.3 NFR14 1B2: Fugitive emissions from oil & gas industries

The following are all key source categories for NMVOC (only) in 2016:

- 1B2c (3.0% 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. The emissions in 2016 are roughly a 50:50 split between flaring and venting sources, and 94% of 1B2c emissions in 2016 arise from oil production with the remainder from gas production;
- 1B2ai (4.3% 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. In 2016, the oil loading / unloading emissions account for 87% of 1B2ai emissions;
- 1B2b (3.0% 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). By far the most significant source (approximately 96% of 1b2b emissions in 2016) is the estimated fugitive losses from the downstream gas transmission and distribution networks;
- 1B2av (2.7% 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 significant source are vehicle refuelling and loading/unloading of refined petroleum products into sea-going tankers for transfer or export;
- 1B2aiv (2.5% 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.

There are no key source categories for any other pollutant in the 2016 UK inventories, however emissions from refinery processes and fugitive releases in oil distribution are significant emission sources 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 & 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 some 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 NFR14 sector are described below.

1B2ai Fugitive Emissions from Fuels, Oil - Exploration, Production, Transport

Emission estimates of all pollutants reported within the UK inventories are made based on operator-reported estimates where these are available (1998 onwards), and trade association (UK Oil and Gas) periodic research for earlier years. For upstream oil & gas production sites, since 1998 operators submit annual returns via the Environmental Emissions Monitoring System (EEMS) regulated by the BEIS Offshore Inspectorate, which includes emission estimates of NMVOC, CO_2, CH_4, CO, NO_x (as NO_2), SO_x (SO_2) and fluorinated gases reported by emission source and (where appropriate) fuel type. Under 1B2ai, emissions are reported from:

- processes (such as acid gas treatment or degassing of associated oil);
- oil loading at offshore platforms and storage units or from onshore terminals (in each case from storage tanks on the offshore installation or the terminal onto ships);
- fugitive releases (including tank storage emissions);
- emissions from well testing.

All upstream oil & gas production sites operate under license to BEIS, and the inventory estimates are therefore simply the sum of the EEMS site estimates. 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 BEIS and the site operators where necessary. For the years prior to the EEMS data reporting system, the UK Oil and Gas trade association has provided industry-wide estimates within periodic publications and data submissions to the Inventory Agency (in 1995, 1998, 2005), for direct use within the inventory.

In addition to these offshore and terminal sites, there are some additional onshore sites involved in oil extraction from onshore fields in England that report their emissions annually under IED/E-PRTR to the Environment Agency. The emission estimates from these sites are added to those from sites regulated under EEMS and reported within 1B2ai.

1B2aiv Fugitive Emissions from Fuels: Refining and Storage

In the UK, all refinery emissions from combustion and fugitive sources are reported under 1A1b, apart from VOC and NH_3 emissions from oil handling and process fugitive sources. Emissions of NMVOC 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 NFR14 1B2aiv. Emissions of NMVOC 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 the UK Petroleum Industry Association (UKPIA, 2017), the trade association for the refinery sector. The UKPIA estimates are compiled by the refinery operators using agreed industry standard methods. The UK inventory estimates are the sum of the data reported from each of the refineries operating each year (6 sites remained in operation at the end of 2016). Annual estimates have been provided by UKPIA 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 IED/E-PRTR reporting mechanisms to UK regulators have been used instead.

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 NMVOC occur from each storage stage and from each transfer stage.

Petrol distribution emissions are calculated using petrol sales data taken from the Digest of UK Energy Statistics 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 UKPIA supply RVP estimates for summer and winter blend petrol, and estimates of the level of control are based on statistics given in the Institute of Petroleum's annual petrol retail survey.

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: Cadent gas, SGN, Northern Gas Networks, Wales and West, Airtricity. 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, 2016);
- Losses from low pressure (distribution) networks (Cadent Gas, SGN, Northern Gas Networks, Wales & West, Airtricity; all 2017); and
- Other losses, from above-ground installations and other sources (Cadent Gas, SGN, Northern Gas Networks, Wales & West; all 2017).

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 (BEIS, 2017)
- Numbers of appliances in the UK in these sectors (Inventory agency estimate, 2017)
- 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, 2017, 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 NMVOC 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.

1B2c Oil and Natural Gas: Venting and Flaring

Emissions from gas flaring and venting at offshore oil & gas production sites and 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 there are both AD and emissions data reported by plant operators in EEMS, whereas for venting the operator reporting is merely “mass of gases vented” and therefore the inventory method for venting is merely to report the sum of operator-reported data (i.e.

there are no AD for venting). All upstream oil and gas production sites report annual emission estimates for these sources via the EEMS regulatory system to the BEIS Offshore Inspectorate (BEIS, 2017b), whilst refinery flaring estimates are generated by operators and reported annually to the Inventory Agency via the refinery trade association (UKPIA, 2017). 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: 1995, 1998, 2005).

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 1B2 and is described below.

1B2ai, 1B2c
BEIS Offshore Inspectorate as the sector regulator provides emission estimation guidance for all operators to assist in the completion of EEMS and EU ETS returns to the UK environmental regulators, including the provision of appropriate default emission factors for specific activities, where installation-specific factors are not available.

The emission estimates for the offshore industry are based on the BEIS-regulated EEMS dataset for 1998 onwards. Emission estimates for earlier years (i.e. pre-EEMS) are estimated based on industry studies (UKOOA 1995, 1998) which were revised and updated in 2005 (UKOOA, 2005); the approach to deriving emission estimates in the earlier years used oil and gas production data as a basis for back-calculating emission estimates from across the industry. EEMS data quality has improved over recent years through the development of the online reporting systems which have in-built quality checking functions (e.g. to check on completeness of operator reporting against an expected scope of source estimates for each installation). In addition, the Inventory Agency has also developed more quality checking routines, e.g. to compare EEMS emissions and activity data against 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 as reporting gaps for some sites are still evident and in some cases identical reported estimates are entered by operators 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 process fugitives. The Inventory Agency continues to work with the regulatory agency, BEIS, 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 BEIS and the UK environmental regulatory agencies, comparing and aligning data from DUKES, EEMS and EU ETS.

1B2aiv, 1B2av
The emission estimates from refineries and from petrol distribution are all derived based on consistent methods across the time series using 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 UK inventory context 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.

1B2a
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. The information provided directly by colliery operators regarding their methane recovery systems are also checked against the data published by BEIS on coal mine methane projects in the UK (which encompasses both operating and closed / abandoned mines with coal mine methane recovery systems).

3.5.5 Recalculations in NFR14 sectors 1B1 and 1B2

The most notable recalculations in NFR14 1B1 and 1B2 since the previous submission are:

- The introduction of estimates for TPM, PM_{10} and $PM_{2.5}$ emissions from the mining and handling of coal, reported in NFR14 sector 1B1a. This is due to the publication of new emission factors in the EMEP/EEA 2016 air pollutant emission inventory guidebook (EMEP, 2016) and so improves completeness, and addresses NECD review findings. In the case of open cast coal, emission estimates were previously based on a UK method and included in 2A5, whereas emissions were not estimated at all for deep-mined coal.;
- New emissions data were provided by Tata Steel to update the emission estimates from individual sub-sources in integrated steelworks in 2013-2015, which has led to revisions in emission allocations across NFR 1A1c, 1A2a, 2C1 and 1B1b. As a result of these new operator data, minor recalculations of estimates for fugitive releases and flaring in coke production are reported in the 2018 submission for pollutants including TPM, PM_{10}, $PM_{2.5}$, SO_2 and NMVOC;
- Revisions to the EEMS data for upstream oil and gas installations have led to minor recalculations; for example, the addition of new estimates for the Dunbar platform in 2015 have increased the UK inventory estimates for emissions of SO_2, NO_X and PM_{10} from 1B2c upstream oil production flaring;
- Errors in operator-reported NMVOC emissions to the Pollution Inventory from one onshore oil production installation were noted by the Inventory Agency and corrected through consultation with the plant operator, leading to recalculations of NMVOC emissions from 1B2ai petroleum processes from 2008 onwards;
- A methodological improvement to ensure that petrol consumption data in the inventory are consistent with the latest version of the UK energy statistics has led to recalculations to increase NMVOC emissions from 1B2av, with slight increases in the time series of emissions from storage at petroleum terminals and in downstream storage and delivery at petrol stations;
- Emissions of NMVOC from natural gas leakage at the point of use in 1B2b have been recalculated due to revisions in the DUKES energy statistics for natural gas use and also due to a method improvement to apply year-specific gas composition, rather than a default assumption for VOC content.
- Updated emission estimates for refinery fugitive emissions from tankage, drainage and process sources have been provided by UKPIA, which has led to small recalculations of NMVOC emissions in 1B2aiv in 2015 only, and from refinery flaring in 1B2c also in 2015.

3.5.6 Planned Improvements in Fugitive Emissions (NFR14 1B1 and 1B2)

No specific improvements are planned.

4 NFR14 2: Industrial Processes

Table 4-1 Mapping of NFR14 Source Categories to NAEI Source Categories: Industrial Processes and Product Use.

NFR14 Category	CRLTAP pollutant coverage	NAEI Source Category	Source of EFs
2A1 Cement Production	TSP, PM_{10}, $PM_{2.5}$, BC	Slag clement production	Literature factors (EMEP/EEA 2016; USEPA AP-42)
2A3 Glass Production	NMVOC, 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 – special – ballotini	Operator reporting under IED/E-PRTR; UK-specific factors / research, HMIP, EMEP/EEA 2016.
2A5a Quarrying & mining of minerals other than coal	TSP, PM_{10}, $PM_{2.5}$, Pb and Zn, BC	Dewatering lead concentrates Quarrying	EMEP/EEA 2016 and other literature factors
2A5b Construction and demolition	TSP, PM_{10}, $PM_{2.5}$, BC	Construction of apartments Construction of houses Non-residential construction Road construction	EMEP/EEA 2016
2A6 Other mineral products	CO, NMVOC, SO_2, Cr, TSP, PM_{10}, $PM_{2.5}$, PCDD/PCDF, BC	Cement & concrete batching	Operator-reported emissions; UK-specific factors / research, HMIP, EMEP/EEA 2016, USEPA AP-42.
		Fletton Bricks	
		Ceramics: – glazed – unglazed	
		Refractories: – chromite based – non chromite based	
		Non-Fletton Bricks	
2B2 Nitric Acid Production	NO_x (as NO_2)	Nitric acid production	Operator-reported activity and emissions
2B3 Adipic Acid Production	NO_x (as NO_2)	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 2016
2B7 Soda ash production	CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC	Soda ash Production	Operator-reported emissions. Literature factors, EMEP/EEA 2016, USEPA AP-42
2B10a Other chemical industry	All except B[b]F, I(123-cd)P, PCBs, BC	Chemical industry: – carbon tetrachloride – halogenated chemicals – pesticide production – picloram production – sodium pentachlorophenoxide – tetrachloroethylene – trichloroethylene	Literature factors (USEPA AP-42, HMIP, other UK references)
		Chemical industry: – alkyl lead – ammonia based fertilizer – ammonia use – cadmium pigments / stabilizers – carbon black	Operator reporting under IED/E-PRTR. Literature factors (EMEP/EEA 2016, UK research, USEPA AP-42)

NFR14 Category	CRLTAP pollutant coverage	NAEI Source Category	Source of EFs
		– chloralkali process – chromium chemicals – general chemicals – magnesia – nitric acid use – phosphate based fertilizers – pigment manufacture – reforming – sulphuric acid use	
		Coal tar distillation	
		Coal tar & bitumen processes	
		Solvent and oil recovery	
		Sulphuric acid production	
2B10b Storage, handling, transport of chemical products	NMVOC	Ship purging	Emission estimate from UK research
2C1 Iron and steel production	All *except* NH_3*, HCB*	Electric arc furnaces	Operator reporting under IED/E-PRTR, plus additional operator reporting and literature sources (EEA/EMEP, 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	All except NMVOC, NH_3, Se, PCBs, BC	Alumina production	Operator reporting under IED/E-PRTR, plus additional operator reporting and literature sources (HMIP, EMEP/EEA 2016, UK references)
		Primary aluminium: - anode baking - general - pre-baked anode process - vertical stud Soderberg process	
		Secondary aluminium production	
2C4 Magnesium production	PCDD/PCDF	Magnesium alloying	Literature factors (HMIP)
2C5 Lead production	CO, SO_2, TSP, PM_{10}, $PM_{2.5}$, metals (except Cr & Ni), PCBs & PCDD/ PCDF, BC	Lead battery manufacture	Operator reporting under IED/E-PRTR and literature sources (EMEP/EEA 2016, UK references)
		Secondary lead production	
2C6 Zinc production	CO, NO_x (as NO_2), TSP, PM_{10}, $PM_{2.5}$, BC, metals *(except Se), PCBs,*PCDD/ PCDF	Primary lead/zinc production	Operator reporting under IED/E-PRTR and literature sources (EMEP/EEA 2016, 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 under IED/E-PRTR and literature sources (EMEP/EEA 2016)
		Secondary copper production	
2C7b Nickel production	Ni, PCDD/PCDF	Nickel production	Operator reporting under IED/E-PRTR and literature sources (HMIP)
2C7c Other metal production	CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, metals & PCDD/ PCDF, BC	Foundries	Operator reporting under IED/E-PRTR. Literature sources (EMEP/EEA, HMIP, other references)
		Other non-ferrous metal processes	
		Tin production	
2D3a Domestic solvent use	NMVOC, NH_3	Agriculture – agrochemicals use	UK industry data (BAMA, CPA, ESIG)

NFR14 Category	CRLTAP pollutant coverage	NAEI Source Category	Source of EFs
		Aerosols: - cosmetics and toiletries - household products - car care products	
		Non-aerosol products: - automotive products - cosmetics and toiletries - domestic adhesives - household products - paint thinner	UK-specific and US emission factors (UK industry, USEPA)
2D3b Road paving with asphalt	NMVOC, TSP, PM_{10}, $PM_{2.5}$, PAHs, PCDD/PCDF, BC	Bitumen use	UK industry data and country-specific factors. Literature factors (EMEP/EEA 2016, HMIP, other references)
		Road dressings	
		Asphalt manufacture	
2D3d Coating applications	NMVOC, TSP, PM_{10}, $PM_{2.5}$, BC	Decorative paint - retail	UK industry data and literature factors (EMEP/EEA 2016, 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 2016, UK research)
		Paper coating	Operator-reported data
		Textile coating	
		Leather coating	
		Film coating	
2D3e Degreasing	NMVOC	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	NMVOC	Dry cleaning	UK industry data
2D3g Chemical products	NMVOC, TSP, PM_{10}, $PM_{2.5}$, BC	Coating manufacture: - adhesives - printing inks - other coatings	UK-specific & literature factors (EMEP/EEA 2016, USEPA AP-42)
		Tyre manufacture	UK industry data
		Other rubber products	
		Foam blowing	
		Pressure sensitive tapes	
2D3h Printing	NMVOC	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)

NFR14 Category	CRLTAP pollutant coverage	NAEI Source Category	Source of EFs
		Printing: - flexible packaging - publication gravure	Operator-reported data
2D3i Other solvent use	NMVOC, PAHs	Seed oil extraction	Operator-reported data
		Industrial adhesives - other	UK industry data (BASA, ESIG) and country-specific factors, Giddings et al)
		Other solvent use	
		Wood impregnation – LOSP	
		Wood impregnation - creosote	
2G Other product use	All except Se, PCBs, HCB	Cigarette smoking	EMEP/EEA Guidebook
		Fireworks	
2H1 Pulp and Paper Industry	NH_3	Paper production	Operator-reported data
2H2 Food and Drink	NMVOC and NH_3	Bread baking	Literature factors (UK research)
		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 (USEPA AP-42)
		Wine manufacture	EMEP/EEA Guidebook
2H3 Other	TSP, PM_{10}, $PM_{2.5}$, BC	Other industry - part B processes	Literature factors (UK research, EMEP/EEA)
2I Wood processing	NMVOC, 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 reported data under IED/E-PRTR & literature factors (EMEP/EEA, USEPA AP-42 and UK references)
2K Consumption of POPs and heavy metals	PCDD/ PCDFs, PCBs	Capacitors	Literature factors (Dyke et al)
		Fragmentisers	
		Transformers	

4.1 Classification of activities and sources

Table 4-1 relates the detailed NAEI source categories to the equivalent NFR14 source categories. Note that there are some reporting conventions in the UK inventory that may differ from the approaches used in other inventories:

- all emissions from cement and lime kilns are reported in 1A2f, rather than 2A1 and 2A2; 2A1 in the UK inventory 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 NMVOC, particulate matter and PAH.

The following NFR14 source categories are key sources for major pollutants in the UK in 2016:

- 2A5a: Quarrying and mining non-coal (TSP, PM_{10})
- 2A5b: Construction and demolition (TSP, PM_{10}, $PM_{2.5}$)
- 2A6: Other mineral products (SO_2)
- 2B10a: Other chemical industry (Pb)
- 2C1: Iron and steel production (CO, TSP, PM_{10}, $PM_{2.5}$, Pb, Hg, Cd, PCDD/ PCDFs)
- 2C7c: Other metal production (Hg, Pb)
- 2D3a: Domestic solvent use (NMVOC)
- 2D3d: Coating applications (NMVOC, TSP, PM_{10}, $PM_{2.5}$)
- 2D3i: Other solvent use (NMVOC)
- 2G: Other product use (Pb, Cd)
- 2H2: Food and drink (NMVOC)
- 2I: Wood processing (Pb)

The description of the inventory methodology in this chapter focuses primarily on these key sources.

4.2 Activity data

Key data suppliers for UK industrial production and emissions data that underpin UK inventory estimates include the Iron & 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), 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. These include the British Aerosol Manufacturers Association (BAMA), European Solvent Industry Group (ESIG) and the British Adhesives and Sealants Association (BASA). Activity data for several other UK industrial sources are available from national statistics published by the Office of National Statistics (ONS); in many industries, however, the ONS data are presented in economic terms only, as production indices across a time series (rather than actual production output statistics), or are only available at an aggregated level to minimise risk of data disclosure.

Complete and transparent activity data are therefore not available for all sources from UK industry, primarily due to the limited availability of production statistics for key commodities. There are no suitable UK Government statistics for many industrial sectors and products and even where there are publications covering industry sectors (such as the PRODuction COMmunautaire (PRODCOM) publications from ONS), these are frequently incomplete due to the need to suppress data that are commercially sensitive. Furthermore, the ONS production data are typically available on the basis of sales value or the number of items produced, rather than on the mass of product, and often disaggregate production into categories that don't align with inventory methods and reporting requirements. The usefulness of these ONS data for inventory compilation and reporting is therefore limited in many sectors. 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, in order 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 & 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 UK emission estimates are reported as 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 may apply a range of 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 NFR14 sector 2D3 are predominantly based on solvent consumption data supplied by industry or regulators as activity data, rather than production data, since this should be a more reliable indicator of NMVOC emissions, particularly in sectors with numerous different product types. National activity data are not used to any significant extent, as few data are available that can reliably be used for the purposes of estimating emissions from solvent use. For example, we are not aware of any Government statistics that provide suitable detail on the consumption of paints, inks, adhesives, or other coatings, cleaning solvents, aerosols, or other consumer products. Information direct from industrial contacts is therefore regarded as the best available. This information is rarely available on a routine basis and so the time-series of data that we use requires some assumptions or extrapolation to fill the many gaps in the information we have.

In many industrial sectors, the number of sites in the UK have declined significantly 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	20	4	35[b]	8
1995	6	1	4	20	4	35[b]	5
2000	6	1	4	19	4	35	3
2005	4	1	3	12	3	33	3
2010	2	0	2	7	2	24	2
2011	2	0	2	7	2	24	1
2012	2	0	3	6	1	24	1
2013	2	0	3	6	1	24	1
2014	2	0	3	6	1	23	1
2015	2	0	3	6	1	23	1
2016	2	0	2	6	1	23	1

[a] excludes very small glassworks producing lead crystal glass, frits etc.
[b] approximate figures only

4.3 Methodology for mining and quarrying (NFR14 2A5a)

The UK has currently 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 source 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 2016 Tier 2 emission factor, assuming a medium to high level of emissions. Quarries in the UK are regulated and at 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 British Geological Survey and consist of production data for each product type – igneous rock, sandstone, limestone, clays, metalliferous ores of various kinds, etc. Data for the latest inventory year are not available for all mineral types until after publication of the inventory, and so we have to assume for some minerals that production in 2016 was the same as in 2015.

4.4 Methodology for construction (NFR14 2A5b)

Emissions of particulate matter from construction are estimated using the default method given in the EMEP/EEA Guidebook 2016. 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 & 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 (Table 211, available from https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building). This dataset will cover both houses and apartments, but the percentage of new dwellings that are houses, as opposed to flats, is available from government house building statistics (Table 254, from the same source as above). The data in Table 211 and Table 254 can be 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 is taken from Table 5 of the NHBC New Home Statistics Review – 2016 (see http://www.nhbc.co.uk/cms/publish/consumer/Media-Centre/Downloads/2016-Annual-Stats.pdf), and 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 2016 Guidebook suggests using the total number of non-residential buildings constructed or total constructed utility floor area from national or industry statistics. Our review, and communication with an Economic Researcher at the Office for National Statistics, led to the conclusion that there are no such statistics for the UK. In such cases, the Guidebook suggests that estimates of the affected area can be based on financial data for commercial non-residential construction. Data on the value of construction output has therefore been used from Table 2a of the July 2017 version of the Office for National Statistics dataset “Output in the construction industry”, (see https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/datasets/outputintheconstructionindustry/current). This gives value statistics in £million but this needs to be converted to Euros and this is done assuming a conversion rate of 1.223 Euros to £1, which was the average given for 2016 at (https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/timeseries/thap/mret). The affected area is then estimated by multiplying the value of work in Euros by the scaling factor from the Guidebook of 0.001, 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. Since we have no breakdown of the infrastructure work, we cannot remove road construction and there may therefore be some double-counting in the figures.

For road construction, the Guidebook suggests 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.”. Our review, and communication with a member of the Road Conditions and Road Length Statistics team at the Department for Transport, found that there are no such statistics available for the UK. The Department for Transport produces statistics on “Road lengths by road type in Great Britain” i.e. total length of roads, including both new and existing road (Table RDL0203, available from

https://www.gov.uk/government/statistical-data-sets/rdl02-road-lengths-kms) that can, by comparing the values for each year, be used to calculate the net change in road length by road type. These changes seem to result from a range of factors, including step changes in methodology, as well as, presumably, the removal of some old roads. As such, the statistics do not separately identify the amount of road that has been constructed. It was concluded however that these data from the Department for Transport were the best option currently available for generating activity data for road construction. The data from Table RDL0203 was used to generate estimates for the length of new road constructed. For each road type, if there was an annual increase in the road length, then that increase in road length was considered as new road constructed. Otherwise, if there was an annual decrease in the road length, then that decrease in road length was assumed to be due to method change or removal of roads and not included in the estimates.
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 Methodology for fletton bricks (NFR14 2A6)

Fletton bricks are manufactured using the Lower Oxford Clay, found in South-East England only. 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 significant SO_2 emissions during firing. The few fletton brickworks have used coal in the past as a fuel in the brick kilns but the only remaining works uses natural gas. Emissions data for SO_2 have been reported in the PI since 1993. The Inventory Agency estimates the fuel usage at each brickworks (based on EU ETS data and PI data for CO_2 from fuel combustion) and then estimate the likely contribution to SO_2 emissions from the coal that is burnt, in order to minimise risk of double-counting with the SO_2 emissions from that coal use, which are reported within 1A2. This analysis typically indicates that process emissions are over 90% of the emission at the sites burning coal, and all of the SO_2 emissions reported by sites burning natural gas are assumed to originate in the sulphurous material in the clay.

Estimates of the tonnage of Fletton bricks produced each year are based on annual brick production data, available in Government Statistics (Monthly Statistics of Building Materials and Components, July 2017, available from www.gov.uk). These data are for total numbers of bricks produced, and it is necessary to consider what proportion of these bricks are of the fletton type. 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 at the end of 2017. Information on the market share is, however 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. We have therefore assumed a 25% share in 1990, falling to 20% in 1995, then falling to 10% by 2010. EU ETS data for the fletton works suggest production has fallen further since 2010 and so is used to estimate the trend for fletton bricks since 2010. Using these data and assumptions, it is possible to then generate estimates of the numbers of fletton bricks and non-fletton bricks produced each year.

We have no emissions data prior to 1993 and so use the emission factor we have derived for 1993 for earlier years.

4.6 Methodology for chemical processes (NFR14 2B10a)

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 UK inventory method for the chemical industry is based on the use of site-specific emissions data provided by each operator to the regulators for reporting under the Industrial Emissions Directive (IED) and PRTR, which 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 1990-2016 and all of 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 will be the total site emission of each pollutant and therefore will include process emissions but also fuel combustion emissions (from sources such as the site boilers) that are reported in the UK inventory 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 processes 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 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 we are required to report, 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, in cases where we obtain data specific to individual processes direct from the site operators, such as nitric acid and sulphuric acid manufacture, or where we are confident that the emissions reported for particular sites can be assumed to be from 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. We cannot distinguish between the emissions from different sources (combustion, individual chemical process sources etc.) at most sites, so we aggregate the operator-reported, installation-wide emissions and report these all in 2B10a. Currently, of the specific chemicals recognised in the NFR categories, we are able to separately estimate emissions for the following, based on reported emissions:

Ammonia	NO_x (as NO_2) *reported in 1A2c on basis combustion is dominant source*
Nitric acid	NO_x (as NO_2)
Adipic acid	NO_x (as NO_2)
Titanium dioxide	CO, TSP, PM_{10}, $PM_{2.5}$, BC
Soda ash	CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC

All other chemical industry process emissions of all pollutants are 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' VOC reported as well as individual VOC species. But 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 emissions. The NAEI estimates for NMVOC from chemical industry processes therefore rely upon a significant 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 NMVOC from chemical processes are associated with higher uncertainty than most other national estimates based on regulators' data.

Emission estimates for HCB, PAH and PCDD/PCDFs from NFR14 2B10a are mostly based on literature sources rather than reported data, due to the low levels of reporting for these pollutants (presumably because emissions at almost all sites are below the reporting thresholds). 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, and hence emissions of HCB from NFR14 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 Methodology for iron & steel processes (NFR14 2C1)

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 & 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 oven coke needed in the process, but emissions from this part of the works are reported elsewhere in the UK inventory.

Sintering involves the agglomeration of raw materials for the production of pig iron by mixing these materials with fine coke (coke breeze) and placing it on a travelling grate where it is ignited. The heat produced 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_2.

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 them. However, some blast furnace gas is not collected and is instead lost and emissions from these gas losses are reported under NFR14 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 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 and emissions are reported with blast furnace gas losses under NFR14 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 (as NO_2) occur due to oxidation of nitrogen in air at the high temperatures within the furnace. Emissions of NMVOC 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 processes are generally based on a bottom-up approach using:

1) data covering the period 2000 to 2016 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.

In recent years, there have been some gaps in the first of those data sets but since all of the integrated steelworks are located in England and Wales, data in the PI & WEI can be 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. We therefore have to split the reported emission into the various processes, based on the pattern of emissions in other years.

Literature emission factors are used, including defaults from the EMEP/EEA 2016 Guidebook, for some minor emission sources where operators do not report emissions on the grounds of triviality, while emissions for the earlier part of the time series for processes at integrated and electric arc steelworks are estimated by extrapolation back of emission factors from later years.

4.8 Methodology for aluminium processes (NFR14 2C3)

The UK had one small primary aluminium producing site at the end of 2016 following the closure of a large smelter in Wales and another in England in late 2009 and early 2012 respectively. The UK also has a number of secondary aluminium processes, including the recovery of aluminium from beverage cans, and the production of aluminium foil and alloys.

All of the 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 their anodes. One small smelter employed the vertical stud Soderberg process, but closed in 2000. All of the primary sites and the large secondary processes reported 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 significantly to the uncertainty in UK inventory estimates for the sector. Aluminium processes used to be a key source of PAHs but since the largest sites have now closed, emissions are zero or much lower than previously and therefore no longer a key source.

4.9 Methodology for zinc processes (NFR14 2C6)

UK production of many non-ferrous metals has been relatively small for many years and the only primary lead/zinc producer closed in 2003. Various smaller zinc processes remain in operation, manufacturing zinc oxide, or zinc alloys, but emissions from these processes are relatively trivial.

Emission estimates are based on a bottom-up approach using emissions reported in the PI & WEI only since no significant processes operate in Scotland or Northern Ireland.

4.10 Methodology for copper processes (NFR14 2C7a)

The UK has no primary copper production and the only secondary copper production process closed in 1999. Various small copper processes producing copper wire, alloys etc. are still in operation but emissions from these sites are relatively trivial.

Emission estimates are based on a bottom-up approach using emissions reported in the PI only since no significant processes operate in Scotland, Wales, or Northern Ireland.

4.11 Methodology for other non-ferrous processes (NFR14 2C7c)

The UK has a large number of mainly small foundries, most of which are 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 (solder manufacturers and production of precious metals for example) and do report in the PI, and emissions from these sites are also included in the estimates for 2C7c.

4.12 Methodology for solvent use (NFR14 2D3)

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 is also expected to be released to atmosphere when the product is used.

Emissions of NMVOC from use of these solvents can be assumed to be equal to solvent consumed in these products, less any solvent that is recovered or destroyed. In the case of consumer products and 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 the solvent consumption. Solvent recovery and destruction can be ignored for these processes.

In comparison, larger industrial solvent users such as flexible packaging print works, car manufacturing plants and specialist coating processes such as the manufacture of hot stamping foils are generally use using 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 avoid being captured and treated by that device. 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 & 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 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 can be made using solvent consumption data. Finally, there are some applications where solvent is used in products but is not entirely released to atmosphere. 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 & 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. Data for a number of Scottish sites is 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) has led to reductions in the NMVOC emissions from many solvent-using processes and this is a key challenge for the inventory. 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: - car care - cosmetics & toiletries - household products	Estimates for UK consumption of aerosols (in millions of units) and solvent / propellent consumption in these aerosols supplied by industry for 1991 and 1996-2002 but no recent estimates. Emissions assumed to equal solvent / propellent consumption. Estimates of UK aerosol consumption for other years are derived from industry statistics for aerosol manufactured each year. Since the UK is a net exporter of aerosols, UK consumption is estimated by assuming that exports in 1990 were at the same level as in 1991, by using a linear interpolation of the industry figures for 1991 and 1996 for exports in 1992-1995, and by assuming that exports after 2002 increased linearly from the 55% in 2002 to reach 65% in 2014 (figure from UK industry). The figure of 65% was also assumed for 2015-16. Emissions in 1990, 1992-1995 & 2003-2016 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 the 2002 figure is applicable for 2003 onwards. For 1992-1995 we interpolate between the 1991 and 1996 implied emission factors.
2D3a	Non aerosol products: - car care - cosmetics & toiletries - household, automotive	Industry data were used to produce UK activity and emission estimates for numerous sub-categories of consumer product for 1988 and 1994 in a study by Atlantic Consulting, 1995. These emission estimates are extrapolated to all other years in the time-series by generating a time-series of activity data for each type of consumer product, utilizing one of the following: - Industry data on sales value of major sub-categories within the cosmetics and toiletries sector - Population and numbers of households (for household products) - Vehicle numbers and vehicle-km (for car-care products) The activity data are then converted to emissions assuming the same implied emission factor as in 1988 and 1994.
2D3a	Non-aerosol products: domestic adhesives	Emission estimates are derived by assuming that 2% of emissions from adhesives (see below) are emitted from products used by the general public rather than industry etc. This figure is derived from data on solvent-based adhesive use in 1992.
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. Industry data on UK sales of agrochemicals are available for 1990-2001 and 2008-2011, and Government statistics on use are available for 2008-2016, however these suggest significantly 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. 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, and interpolation/extrapolation is used to generate emission factors for the remaining years.
2D3b	Asphalt manufacture	Activity data are for production of coated roadstone, and are obtained from the British Geological Survey (2017). Data are not available for 2015-2016 and so the 2014 value has been used for those years as well. Emission factors are taken from the EMEP/EEA 2016 Guidebook (tier 2 emission factor for batch mix plant).

NFR	NAEI Source Category	General method
2D3b	Road dressings	Estimates of emissions from kerosene use in 'cut-back' bitumens are available for 1988, 2008 and 2013. In the absence of other data we have generated implied emission factors for these three years using UK consumption of bitumen (from BEIS, 2017), and then used these factors to estimate kerosene emissions in all other years.
2D3d 2D3h	Decorative paint: - retail - trade Industrial coatings: - agricultural and 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 periodic data-sets are then used to generate emission estimates for years where we only have the trade association sales data only. 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. In general though, 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 take into account the gradual changes in coating formulations over time in response to UK regulation and SED/IED (for example, the replacement of high-solvent content coatings with high solids or waterborne coatings in order to avoid the need for the use of costly end-of-pipe abatement systems by users of 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 NMVOC are assumed to be the same as the solvent content of the coatings supplied.
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 IPPC, 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 E-PRTR and earlier UK estimates for E-PRTR processes (2002-2016). These data are used in preference to the sectoral emission estimates from trade associations, on the basis that site-specific and likely to be more reliable.
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 IED, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from E-PRTR and earlier UK estimates for E-PRTR processes (2002-2016). 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)	Various estimates of UK chlorinated solvent consumption are available for 1990-1996, 1999, 2008, 2009, and 2013, and these are used as the basis of a time-series of activity data for each solvent, with consumption after 2013 assumed to be at the same level as in 2013. 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 believe that degreasing and surface cleaning will be the dominant use.

NFR	NAEI Source Category	General method
	- trichloroethylene (TRI)	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 significant reductions in emission factors over the period 1996-2010 due to the requirements of UK legislation and 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 are taken from the EMEP/EEA 2016 Guidebook, and are based on the following assumptions: - All use of TRI from 2010 onwards being in enclosed machines (confirmed by industry sources) - 90% of PER in enclosed systems, 10% in semi-open systems (industry source state 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, on the basis of indices of manufacturing output from sectors such as production of electronics, machinery and vehicles (ONS, 2017). 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 SED/IED. The factor chosen is that for use of semi-open systems & good housekeeping, in the EMEP/EEA 2016 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, 2017).
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 were regulated under UK legislation and the SED/IED.
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 IED, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from E-PRTR and earlier UK estimates for E-PRTR processes (2002-2016). 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.
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 and 2013 for foam blowing (ESIG, 2015), 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, 2017)
2D3i	Seed oil extraction	Since there are only a few sites, all of which are thought to be regulated under IED, site-specific emissions data have been collected from local-authority regulators (1990-2001) and from the PI (2006-2016). Gaps are filled by means

NFR	NAEI Source Category	General method
		of interpolation/extrapolation from existing data, taking account also of site closures.
2D3i	Industrial adhesives	Data are sparse for this sector with industry estimates of emissions for 1991, 1993, 1996 and 1999. Activity data are available for parts of the time-series, but these data are not in a consistent basis or from consistent sources. For the purposes of estimating NMVOC emissions, we use a simple classification of adhesives: solvent-borne, water-borne, and hot-melt and assume that NMVOC emissions will depend on the basic type, as follows: - Solvent-borne: 70% solvent in 1990 (based on UK research / industry data), decreasing to 52.2% solvent by 2003 (EMEP/EEA 2016 Guidebook). - Water-borne: 12.5% organic solvent across time-series (based on UK research / industry data in early 1990s) - Hot melt: no emissions of NMVOC
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. Subsequent to these most recent data we have assumed that usage is in line with the index of manufacturing output for the wood sector (ONS, 2017). 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	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, water-treatment chemicals. Emission estimates are available from industry sources for 2008 and 2013 and estimates for other years are made by extrapolation using surrogate data such as indices of manufacturing output (ONS, 2017) or UK Government statistics (see Table 3.7 on drilling activities on the UK continental shelf at https://www.gov.uk/government/statistics/oil-and-oil-products-section-3-energy-trends).

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 based on a limited set of data for individual sites and these factors are used to calculate UK wide emissions.

The estimates for solvent use are 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 solvent – 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 EMEP/EEA Guidebook can't generally be used, and so the UK inventory 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 such data is resource-intensive both for the Inventory Agency and for industry and regulators, and has been assigned a lower priority to address compared to other tasks within the inventory improvement programme in recent years. The current estimates are therefore based on information gathered over a long period and some of the estimates are wholly dependent on very old data. The estimates for the period 1990-2005 are typically based on more data than is the case for estimates for 2006 onwards, and it is likely that estimates become marginally more uncertain each year because of the shortage of new data.

Consultation during 2016 with trade associations has resulted in new data and revisions to estimates, for sub-categories within 2D3a; 2D3d; 2D3e, 2D3g, 2D3h and 2D3i. The estimates for 2D3 in the 2018 submission of the UK inventory are therefore considered less uncertain than those published in the previous submission. However, estimates for most of the sub-categories that make up 2D3a and 2D3i were not updated, remain highly uncertain, and are a priority for research. In addition, the data collected during 2016 was supplied on an ad-hoc basis and further efforts will be needed in future to ensure updates over time.

4.13 Methodology for Other product use (NFR14 2G)

Emissions from cigarettes smoking and fireworks are reported under 2G. Emission factors for both sources are taken from the EMEP/EEA 2016 Guidebook.

Statistics from HM Revenue & Customs (see https://www.uktradeinfo.com/Statistics) are used to provide data on the quantity of both readymade cigarettes and loose tobacco. To convert all activity to the same units the Inventory Agency makes UK-specific assumptions about the average weight of tobacco in machine-rolled cigarettes to convert numbers of cigarettes into a mass of tobacco.

UK statistics (PRODCOM) from ONS, 2017 and data from the HM Revenue & Customs website listed above are used to quantify the amount 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 are manufactured for use at large, professional, fireworks displays, and we assume this adds an additional 5% of fireworks to those supplied by importers. We assume that all fireworks imported each year are used that year, although it is possible that some stocks may get carried over.

4.14 Methodology for food and drink processes (NFR14 2H2)

Emissions occur from a variety of processes including bakeries, malting, animal feed manufacture and production of fats and oils, but the most significant 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 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.

Emission factors for spirits manufacturing, brewing and bakeries 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 IED, and there is little or no NMVOC emissions data for these sites, and the industry data are therefore considered more reliable. We have no industry data for sugar production but all of the UK plant recovering sugar from sugar beet report emissions in the PI, including very limited data for NMVOC emissions, and this is used as the basis of the UK inventory estimate. Emission factors for other significant sources are taken from the EMEP/EEA Guidebook (EMEP, 2016).

Emission factors for significant 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 food production rather than manufacture of alcoholic beverages, are much more uncertain and are regarded as among the most uncertain sources within the NMVOC inventory.

4.15 Methodology for wood processes (NFR14 2I)

The manufacture of fibreboard, chipboard and oriented strand board is a key category for lead emissions. There were seven known sites manufacturing such products in 2016, with an eighth having closed in 2012. Three of these sites are located in Scotland and one in Northern Ireland, and these 4 sites have reported emissions data for metals to their respective UK regulators, and some emissions data for the remaining 3 sites is present in the E-PRTR. These data indicate that the sites emit significant 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. Metal emission estimates for the sector have been derived from the

emissions data reported by the eight sites in operation over the 2004-2016 period. The data are not complete: while there is an almost complete record of emissions of As, Cd, Cr, Cu, Hg, Ni & Pb for the three Scottish sites over the period 2004-2016, data for the remaining sites is more fragmentary. For example, the largest plant is believed to be the single site in Wales, for which we have a near-complete set of emissions for 2009, a handful of data for other years in the period 2007-2012, but no data for any metals for 2013-2016. This site may have lower emissions than those in Scotland, but it might instead be that reporting requirements in the SPRI and E-PRTR differ or that levels of reporting are higher for SPRI. We use the emissions data we have to fill in the gaps in reporting, using Inventory Agency estimates of the capacity of each site as activity data.
Together with the emissions of metals reported in 2I, estimates are also made of NMVOC, 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 statistics, and emission factors from literature sources including EMEP/EEA 2016 (for PAHs); HMIP 1995 (for dioxins); USEPA (NMVOC and PM); Erlich et al 2007 (for black carbon).

4.16 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 and 2C rely upon emissions data reported in the PI, SPRI, WEI, and NIPI. Section 3.1.7 discusses QA/QC issues regarding these data.

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 Tata steel 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.

4.17 Recalculations in Industrial processes (NFR14 2)

The most significant recalculations in NFR14 2 since the previous submission are:

- Emission estimates for particulate matter from quarrying and construction were updated to use emission factors from the EMEP/EEA 2016 Guidebook. In addition, data for coal were removed from the activity data for quarrying, since emissions from coal extraction are now reported separately (in 1B1a). The changes result in increases in PM_{10} / $PM_{2.5}$ emissions of +4.0/+0.4 ktonnes for 2A5a and +15.4/+1.5 ktonnes for 2A5b
- The updates to estimates for solvent and product use result in the following changes in NMVOC emissions (in ktonnes) for 2015 compared with the previous version: -6.0 (2D3a); -5.0 (2D3b); -28.4 (2D3d); +1.2 (2D3e); -4.6 (2D3h); +13.4 (2D3i). The overall change in 2D3 was a decrease of 29.3 ktonnes in 2015. Revisions also occurred across much of the rest of the time-series and estimates for 1990 and 2005, for example, were 21.7 ktonnes and 44.2 ktonnes lower.
- Note that as well as the updates to 2D3, there were also some re-allocations of emissions from 2D3d to 2D3g & 2D3i (for pressure-sensitive tapes and adhesives) and from 2D3i to 2D3e and 2D3g (for dichloromethane use and foam blowing). The effect of these changes is included in the figures give in the previous item.
- The updates to activity data for industrial coatings had an impact on PM_{10}/$PM_{2.5}$ estimates for spray coating processes (2D3d) where emission estimates for 2015 increased by 2.9/1.0 ktonnes.
- Revision to use of an EMEP/EEA 2016 Guidebook default factor for roadstone coating, instead of the USEPA factor used previously, increases PM_{10} in 2015 by 0.5 ktonne, although the change in $PM_{2.5}$ is just 0.1 ktonne.
- Revision to use of an EMEP/EEA 2016 Guidebook default factors for fireworks adds 0.7 ktonne PM_{10} and 0.4 ktonne $PM_{2.5}$ and the addition of cigarette smoking as a source for particulate matter emissions, adds 0.8 ktonnes for both PM_{10} and $PM_{2.5}$.

- The extension of our estimates for fireworks to new pollutants also adds 11% to the 2015 figures for Pb, and about 0.5% for Cr and Zn. The revision to an EMEP/EEA 2016 Guidebook factor for Cu emissions from fireworks increases the UK total for that pollutant by 4%.
- The addition of metal emission estimates for tobacco use also have a significant impact on UK totals for some of those metals: a 4% increase for Cd in 2015, and 0.3% for Cu.
- A speciality chemical works, producing chromium-based chemicals, was found to have closed, so that estimates for Cr from chemical processes needed to be revised down, decreasing the UK total for Cr in 2015 by about 10%.
- A revision to the activity data we calculate for wood products manufacture adds 0.4 ktonne PM_{10} and 0.3 ktonne $PM_{2.5}$.
- A re-evaluation of data for ore stockpiles at steelworks and at Redcar bulk terminal has resulted in some improvements to the time-series consistency of PM_{10} estimates for 2C1. Emission estimates for 2015 decrease by 0.2 ktonnes but estimates for earlier years rise, for example by 1.6 ktonnes for 2005.

4.18 Planned Improvements in Industrial Processes (NFR14 2)

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 source categories, such as processes at integrated steelworks consist solely of large plant emitting substantial quantities of pollutants and so reporting of emissions to regulators is complete or near-complete. Other categories, such as some types of non-ferrous metal works, are typically made up of much smaller operations and reporting is much less 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 simply report that their emissions do not exceed the threshold. A particular problem however, is those other processes for which the operators provide no information on emissions (i.e. no emission estimate or confirmation that emissions are below reporting thresholds) and little other industry data or government statistics is available. In many of these cases it is reasonable to assume that the process does have some emissions and so the emissions must be estimated. This is done by extrapolation using the data for sites that do report and this 'gap-filling' can constitute a significant proportion of the sectoral emissions for some pollutants. The current approach also tends to accentuate the inter-annual fluctuations in reported emissions, because the gap-filling each year relies just upon the reported data for that year. For example, if just one plant within a sector reported emissions each year, that data would be used each year to calculate emissions at the non-reporting sites. If that one site happened to provide a higher than normal emission in one year, then the extrapolated emissions for that year would also be higher than normal. This example is an extreme case, but does illustrate a weakness of the method used in the inventory due to the underlying scarcity of data. Fortunately, the sectors where gap-filling and extrapolation of data are most necessary are those that consist of small processes, and are typically of low significance in the context of UK emissions as a whole; good quality data are more generally available for key source categories. Improvements to the UK inventory are prioritised for key categories and where new research may be most effective in reducing uncertainty in the UK inventory.

One relatively recent problem concerns 2C1 and emissions from integrated steelworks. These steelworks have emissions that need to be reported in 1A2a, 1B1b, and 2C1 and in the past we have received very detailed emissions data each year from the operators. Data available now from PI/WEI for these sites are only gives a site total emission, so the emissions in each of 1A2a, 1B1b and 2C1 aren't given. The data direct from the operators can still give this breakdown. However, the detailed data is not available for all years and all sites – there are gaps for both the Teesside and Scunthorpe works. We still have site total emissions via the PI & WEI so the UK inventory totals still include all emissions at UK steelworks, but the reporting to 1A2a, 1B1b and 2C1 is far less accurate and based on extrapolation and assumptions. The situation has improved since last year however, since an important update was received from one operator, ensuring that we had a full set of data for Port Talbot steelworks as well as full data for Scunthorpe for the years that they operated the plant. Since the Teesside steelworks is now closed, there is no likelihood that further data can be obtained from the operator there. Ownership of the Scunthorpe steelworks changed in 2016 and it is a priority for the inventory to obtain detailed emissions data for that site in 2016 and in future years.

In the case of NMVOC sources in NFR14 2D3, emission estimates are largely based on data gathered over many years on an ad-hoc basis from process operators, trade associations, and regulators. Very little information had been gathered in the previous 10 years, but consultation with trade associations during 2016 did result in some new data being received, and the NMVOC estimates for 2D3 being revised to a significant extent. More needs to be done, however, and estimates for 2D3a and 2D3i in particular are still based on old data and probably overestimate emissions to some extent. Even for the remaining categories, the data collected during 2016 was supplied on an ad-hoc basis and further efforts will be needed in future to ensure updates over time. As a result, while the quality of the NMVOC inventory has been improved, it remains a priority area for further research. That research can be resource-intensive, and progress is very dependent upon assistance from industry or other stakeholders.

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, and there is no central database of emissions data for these processes (so nothing comparable to the PI, WEI, SPRI or NIPI). Emissions therefore have to 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. As with NMVOC, improvement of this area of the inventory is a priority, however it is difficult to identify options for making improvements that aren't resource-intensive and/or limited in their impact.

5 NFR14 3: Agriculture

5.1 Classification of activities and sources

Table 5-1 relates the detailed NAEI source categories for agriculture used in the inventory to the equivalent NFR14 source categories. A number of the NAEI source categories are only used to describe emissions of greenhouse gases and the methodologies used to produce estimates for these categories are therefore not covered in this report.

Table 5-1 Mapping of NFR14 Source Categories to NAEI Source Categories: Agriculture

NFR14 Category		Pollutant coverage	NAEI Source	Source of EFs
3B1a	Manure management - Dairy cattle	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - dairy cattle/waste	UK Factors[37]
3B1b	Manure management - Non-dairy cattle	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - other cattle/waste	
3B2	Manure management - Sheep	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - sheep/waste	
3B3	Manure management - Pigs	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – pigs/waste	
3B4d	Manure management - Goats	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – goats/manures	
3B4e	Manure management - Horses	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – horses/manures	
3B4gi	Manure management - Laying hens	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - laying hens/manures	
3B4gii	Manure management - Broilers	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – broilers/manures	
3B4giii	Manure management - Turkeys	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – turkeys/manures	
3B4giv	Manure management - Other poultry	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock - other poultry/manures	
3B4h	Manure management - Other animals (please specify in IIR)	NH_3, NOx, NMVOC, $PM_{2.5}$, PM_{10}, TSP	Agriculture livestock – deer/manures	
3Da1	Inorganic N-fertilizers (includes also urea application)	NH_3, NOx	Agricultural soils	UK factors (model)
3Da2a	Livestock manure applied to soils	NH_3, NOx	Agriculture livestock - Animal manure applied to soils	UK factors (model)

[37] Default Tier 1 EFs used for all other than NH_3.

NFR14 Category		Pollutant coverage	NAEI Source	Source of EFs
3Da2b	Sewage sludge applied to soils	NH_3, NOx, PCBs	Application to land	CEH, 2017
3Da2c	Other organic fertilisers applied to soils (including compost)	NH_3	Land spreading of non-manure digestate	Cumby et al., 2005; WRAP, 2016a (quoted by CEH)
3Da3	Urine and dung deposited by grazing animals	NH_3, NOx	N-excretion on pasture range and paddock unspecified	UK factors
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	NMVOC	Cultivated crops	2016 EMEP/EEA Emission Inventory Guidebook
3Df	Use of pesticides	HCB	Agricultural pesticide use - chlorothalonil use Agricultural pesticide use - chlorthal-dimethyl use Agricultural pesticide use - quintozine	UK Factors
3F	Field burning of agricultural residues	NH_3, NO_x (as NO_2), NMVOC, Particulate Matter, PCDD/ PCDFs, PAHs, PCBs for 1990-1992 only	Field burning	

The following NFR14 source categories are key sources for major pollutants: 3B1a (NH_3, NMVOC, TSP, PM_{10}), 3B1b (NH_3, NMVOC, TSP), 3B3 (NH_3), 3B4gi (TSP), 3B4gii (PM_{10}, TSP), 3Da1 (NH_3), 3Da2a (NH_3), 3Da3 (NH_3), 3Dc (PM_{10}, TSP), 3Df (HCB). Description of the inventory methodology will focus on these categories.

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. As the NH_3 emission factor from grazing tends to be less than from housed animals and subsequent manure management because of rapid infiltration of urine into the soil, the implied emission factor for UK beef and dairy cattle may be lower than for other European countries where grazing is not practised. Cattle housing also differs from that in many other European countries in that slatted floor systems are uncommon in the UK (particularly England) and for beef cattle in particular, 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 emissions. Numbers of cattle, sheep and pigs have declined significantly since 1990, partly through efficiency measures (i.e. greater production per animal) but also in response to economic drivers. Poultry numbers have increased, with the poultry sector now representing the next most important livestock sector in terms of NH_3 emissions after cattle.

Dominant crops grown are cereals (wheat, barley) and oilseed rape, representing approximately 90% of total crop area. Nitrogen fertiliser use has decreased significantly since 1990, mostly because of lower rates being applied to grassland, although there has been little overall trend in total fertiliser N use since 2006. The proportion of nitrogen fertiliser applied as urea (associated with a much larger NH_3 emission than other fertiliser types) fluctuates annually, based on market prices, but has shown an increasing trend since 1997, with 21% of total fertiliser N use being applied as urea-N in 2016.

Although improvements in production efficiency have resulted in lower emission intensities for a number of products, there has been slow uptake by the UK agriculture sector of mitigation measures specifically targeted at abating NH_3 emissions (e.g. low emission slurry spreading methods).

5.2 Activity statistics

5.2.1 Livestock Statistics

National Agricultural Survey

Livestock numbers are obtained at agricultural holding level for each Devolved Administration (England, Scotland, Wales and Northern Ireland) based on annual returns to the June Agricultural Survey and, for years from 2006 onwards, from the Cattle Tracing Scheme database for England, Wales and Scotland. 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 km grid square for association with soil type and climate as appropriate.

Devolved Administration (DA) level data are summed to provide UK population data for the livestock categories and subcategories as used in the inventory compilation (see further details below). Calculating at the DA level by RFT allows for the representation of 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 time-scale, are structured to be representative of the UK agricultural sectors and 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)[38].

Livestock Categorisation

The June survey data (and Cattle Tracing Scheme data) provide a number of 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 slaughter house statistics). 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., 2009. 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 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

[38] Defra report for project AC0114; report not published at the time of submission.

subcategories (Table 5-2) to reflect differences in live weight, feeding and management practices. Full details of the livestock characterisation and NH_3 and greenhouse gas emission calculation methods can be found in the sector-specific reports as part of the final project report to Defra AC0114[39].

Table 5-2 Livestock categories and sub-categories included in the UK inventory

Livestock type	Subcategories
Dairy cattle	Dairy cows[1]
	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 2015 and 2016 were a 1.0% increase in total cattle numbers, with 1.2% increase for dairy cows, 2.7% increase in pig numbers, 1.8% increase in sheep numbers and a 3.0% increase in total poultry numbers, comprising a 3.3% increase in broiler numbers and a 3.1% increase in laying hens.

Table 5-3 Animal numbers over the 1990-2016 period ('000 places)

Livestock Category	1990	1995	2000	2005	2010	2015	2016
Total cattle	12,125	11,760	11,048	10,698	10,014	9,785	9,886
- dairy cows	2,848	2,603	2,336	2,003	1,839	1,906	1,910
- all other cattle	9,277	9,157	8,713	8,695	8,175	7,879	7.977
Sheep	45,380	44,174	43,117	36,138	31,727	34,034	34,663

[39] Report not published at the time of submission.

Livestock Category	1990	1995	2000	2005	2010	2015	2016
Pigs	7,548	7,627	6,482	4,862	4,468	4,739	4,866
Total poultry (million)	138,381	142,267	169,773	173,909	163,842	167,579	172,607
- laying hens	33,624	31,837	28,687	29,544	28,751	28,311	29,184
- broilers	73,944	77,177	105,689	111,475	105,309	107,056	110,639
Horses on agricultural holdings	202	273	287	330	312	283	268
Goat	98	75	74	95	93	101	102
Deer	47	37	36	33	31	31	31

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 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 1990-2016

Dairy breed/production system	1990	1995	2000	2005	2010	2015	2016
Large (high yield)	6,003	6,188	6,768	7,600	7,875	8,640	8,381
Medium (medium yield)	5,007	5,129	5,536	6,069	6,231	6,625	6,330
Small (low yield)	3,893	4,102	4,522	4,933	5,297	5,500	5,237
UK average	5,151	5,398	5,979	6,986	7,303	7,894	7,636

For other livestock types, N excretion values specific to UK livestock and production practices are derived from a report by Cottrill and Smith (2007; Defra project report WT0715NVZ). 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 the report. For horses, goats and deer it has been assumed that there are no changes in N excretion over the time series. 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 2010 (with values constant since then).

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 project NT2006). 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	1995	2000	2005	2010	2015	2016
Dairy cows	86.6	88.2	94.5	102.2	105.5	109.6	107.6
Other cattle	48.4	48.8	49.6	48.7	48.7	48.5	48.3
Sows	23.6	22.5	21.4	20.1	18.1	18.1	18.1
Gilts	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Boars	28.8	27.4	26.1	24.5	21.8	21.8	21.8
Fatteners > 80 kg	20.2	19.3	18.4	17.2	15.4	15.4	15.4
Fatteners 20-80 kg	14.6	13.9	13.2	12.4	11.1	11.1	11.1
Weaners (<20 kg)	4.6	4.4	4.2	3.9	3.4	3.4	3.4
Ewes	6.7	6.8	6.8	6.8	6.8	7.0	6.8
Rams	9.1	9.1	9.1	8.9	8.9	9.0	8.9
Lambs	2.9	2.9	3.0	3.2	3.2	3.4	3.3
Goats	20.6	20.6	20.6	20.6	20.6	20.6	20.6
Horses on agricultural holdings	50	50	50	50	50	50	50
Deer	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Laying hens	0.85	0.82	0.78	0.74	0.67	0.67	0.67
Broilers	0.64	0.59	0.55	0.49	0.40	0.40	0.40
Turkeys	1.50	1.59	1.68	1.76	1.82	1.82	1.82
Pullets	0.42	0.39	0.36	0.34	0.33	0.33	0.33
Breeding flock	1.16	1.13	1.10	1.07	1.02	1.02	1.02
Ducks	1.30	1.41	1.52	1.62	1.71	1.71	1.71
Geese	1.30	1.41	1.52	1.62	1.71	1.71	1.71
Other poultry	1.30	1.41	1.52	1.62	1.71	1.71	1.71

5.2.3 Livestock Management Practices

A review of livestock housing and manure management practices conducted by Ken Smith (ADAS) as part of Defra project AC0114, updated with 2016 survey data on manure spreading practices from the British Survey of Fertiliser Practice 2016 (https://www.gov.uk/government/statistics/british-survey-of-fertiliser-practice-2016) was used as the basis of developing the time series 1990 to 2016 of livestock housing and manure management practices for each country (England, Wales, Scotland and Northern Ireland) from which a weighted average was derived for the UK. Broad management categories (managed as slurry, Farm Yard Manure 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. Estimates for these activity data across the time series are derived from a number of routine and ad-hoc surveys including the Defra Farm Practices Surveys (https://www.gov.uk/government/collections/farm-practices-survey) and published manure management surveys (Smith et al., 2000, 2001a, 2001b). Tonnages of poultry litter incinerated in each year were obtained directly from EPRL and Fibropower websites.

Table 5-6 Manure management systems for livestock categories 1990-2016

Livestock category	1990	1995	2000	2005	2010	2015	2016
Dairy cows							
% slurry	71	73	75	77	79	80	80
% FYM	29	27	25	23	21	20	20
Beef cattle							
% slurry	36	37	38	39	39	39	39
% FYM	64	63	62	61	61	61	61
Sows							
% slurry	61	56	52	35	36	36	36
% FYM	19	18	17	36	21	21	21
% outdoors	20	26	32	29	43	43	43
Weaners							
% slurry	90	67	50	47	40	41	41
% FYM	10	33	45	38	39	38	38
% outdoors	0	1	5	15	21	21	21
Finishing pigs							
% slurry	54	45	39	45	39	40	40
% FYM	46	54	60	52	59	58	58
% outdoors	0	1	1	3	2	2	2
Laying hens							
% indoors	86	80	74	68	62	65	63
% outdoors	14	20	26	32	38	35	37
Broilers							
% indoors	100	100	99	96	93	93	93
% outdoors	0	0	1	4	7	7	7

A review of the implementation of specific ammonia mitigation methods over the time series was also conducted as part of Defra project AC0114 and the estimated uptakes as included in the UK emission inventory are shown in Table 5-7. 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 5-7 Ammonia mitigation methods in UK agriculture

Mitigation	Emission source	% abatement	% implementation			
			1990	2000	2010	2016
Part-slatted floor with reduced pit area	Finishing pig housing	30	0	0	12	30
Litter drying	Broiler housing	30	0	0	26	66
Crust formation	Cattle slurry tanks/lagoons	50	80	80	80	80
Rigid (tent) cover	Pig slurry tanks	80	0	0	12	24
Floating cover	Pig slurry lagoons	60	0	0	12	24
Shallow injection	Cattle slurry	70	0	0	6	8
Shallow injection	Pig slurry	70	0	2	7	8
Trailing shoe	Cattle slurry	60	0	0	1	2
Trailing shoe	Pig slurry	60	0	0	1	2
Trailing hose	Cattle slurry	30	0	3	5	7
Trailing hose	Pig slurry	30	0	3	16	21
Rapid incorporation[1]	Cattle slurry	59	11	11	11	11
Rapid incorporation[1]	Pig slurry	67	13	13	13	13
Rapid incorporation[1]	Cattle FYM	71	3	3	3	3
Rapid incorporation[1]	Pig FYM	71	3	3	3	3
Rapid incorporation[1]	Poultry manure	82	8	8	8	8

[1]Incorporated by plough within 4h of application

5.2.4 Synthetic Fertiliser Usage

Fertiliser usage in England, Wales and Scotland are derived from the annual British Survey of Fertiliser Practice (https://www.gov.uk/government/collections/fertiliser-usage) and for Northern Ireland from DARDNI stats (https://www.daera-ni.gov.uk/articles/fertiliser-statistics) and for more recent years from the Northern Ireland Farm Business Survey, and these are used to derive total UK fertiliser N use for each year (Table 5-8). Estimates for total N use by fertiliser type are derived using the survey data for total fertiliser quantity used and expert opinion/industry data on the N content for each type.

Table 5-8. Total fertiliser N use ('000 tonnes) by land use and fertiliser type

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**
Total fertiliser N use	1567	1490	1347	1156	1103	1083	1090
Total to tillage	727	671	691	647	666	686	674
As urea-based fertiliser	144	64	63	107	141	191	195
Total to grassland	840	819	655	509	437	397	416
As urea-based fertiliser	62	29	21	20	29	31	34

Total fertiliser N use has declined since 1990, particularly to grassland, although the decline has levelled out to some extent since 2006. Use of urea-based fertilisers which are associated with much higher ammonia emission factors has increased as a proportion of total fertiliser N use. Total fertiliser N use increased by 0.6% from 2015 to 2016 and urea-based fertiliser use increased by 3.6%.

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://secure.fera.defra.gov.uk/pusstats/myindex.cfm) and by Agri-Food and Biosciences Institute (AFBINI) for Northern Ireland (http://www.afbini.gov.uk/index/services/services-specialist-advice/pesticide-usage/pesticide-reports-table.htm). Hexachlorobenzene (HCB) occurs as an impurity or a by-product in the manufacture of several pesticides currently in use in the UK (chlorothalonil and chlorthal-dimethyl) or used in the past (quintozene). Following the application to agricultural land, pesticides would volatilise from deposits on plant or soil into the atmosphere.

Estimates for HCB assume that more than 70% of the new HCB is emitted into atmosphere. Over 95% of the HCB emission into atmosphere is through the use of chlorthalonil.

Table 5-9. Total agricultural pesticide use in the UK (t)

	1990	1995	2000	2005	2010	2014	2015	2016
Chlorothalonil	545	839	467	1,583	1,671	1,628	1,616	1,616
Chlorthal-dimethyl	48	32	8.0	8.3	6.3	0	0	0
Quintozene	0.4	0.3	4.5	0	0	0	0	0

Quintozene was withdrawn from the UK market in 2002 and its use had to cease within 18 months.

The Bailey (2001) US EPA emission factor of 0.04 kg/t has been used for chlorthalonil between 1990-1998. Following a new monitoring and sampling in 2010, which gave a weighted average of 0.008 kg/t, 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 5-10 Pesticides emission factors (kg/t)

	1990	1995	2000	2005	2010	2014	2015	2016
Chlorothalonil	0.04	0.04	0.034	0.020	0.008	0.008	0.008	0.008
Chlorthal-dimethyl	3	3	3	3	3	3	3	3
Quintozene	1	0.84	0.69	0.53	0.5	0.5	0.5	0.5

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 to some uncertainty. Tier 3 EF, having confirmed the UK working concentrations of HCB from pesticides through the monitoring of in use pesticides in 2010, has improved the reliability of HCB emissions.

5.2.6 Field burning of agricultural residues

Burning of crop residues leads to the emission of a number of atmospheric pollutants including: NH_3, NO_x, NMVOCs, SO_2, 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 and trees and wildlife [http://hansard.millbanksystems.com/commons/1989/nov/30/straw-and-stubble-burning].

The practice of burning off 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. But as these are living plants they do not come under the category of 'crop residues'.

Table 5-11 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:

Activity data	Source
	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 (Defra AC0114, Williams and Goglio, 2017).
Fraction of the residue burned	These data are not reported in the UK.

5.3 Methods for estimating emissions from Livestock Housing and Manure Management

NH_3

Agricultural sources are the most significant emission sources in the UK ammonia inventory. 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 and country-specific emission factors for livestock housing (Table 5-11), manure storage (Table 5-12), 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#) GHG 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 nitrogen and total ammoniacal nitrogen through the livestock production and manure management system, using a mass-flow approach, as described by Webb and Misselbrook (2004). Ammonia EF at each management stage are expressed as a percentage of the ammoniacal nitrogen (TAN) present within that stage. Other nitrogen losses (gaseous as N_2, N_2O and NO and via N leaching) and transformations between organic and inorganic forms of nitrogen 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. N content of any added bedding material 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. A number of abatement practices are also incorporated in the methodology. The UK methodology and derivation of the country-specific emission factors is described in more detail in Misselbrook *et al.* (2018)[40].

Table 5-12 Ammonia emission factors for livestock housing (as a % of the total ammoniacal N 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	22.9	14.9 (2)
Dry sows on straw	43.9	9.62 (12)
Farrowing sows on slats	30.8	2.96 (7)

[40] Defra report for project AC0114; report not published at the time of submission.

Housing system	EF (% of TAN)	Standard error[a]
Farrowing sows on straw	43.9 (same value as dry sows on straw assumed)	
Boars on straw	43.9 (same value as dry sows on straw assumed)	
Finishing pigs on slats	29.4	2.27 (17)
Finishing pigs on straw	26.6	5.11 (15)
Weaners on slats	7.9	2.01 (2)
Weaners on straw	7.2 (based on weaners on slats value)	
Poultry		
Layers, deep pit (cages, perchery)	35.6	8.14 (7)
Layers, cages with belt-cleaning	14.5	4.79 (5)
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 are based

Table 5-13 Ammonia emission factors for livestock manure storage (as a % of the total ammoniacal N in the store)

Housing system	EF (% of TAN)	Uncertainty (95% CI)[a]
Slurry		
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 are assumed; [b]Numbers in parentheses are the number of studies on which the mean EF are based

NOx

Estimates of NO_x emissions from manure management 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 2016 EMEP/EEA Emission Inventory Guidebook default values for NO emissions as presented in Table 3.10 (Chapter 3.B. Manure management). The UK use a combination of IPCC default and country-specific N_2O EF, as described in the UK NIR.

NMVOC

A Tier 1 approach has been used to estimate NMVOC emissions from manure management, applying Tier 1 EF as given in Table 3.4 of the 2016 EMEP/EEA Emission Inventory Guidebook (Chapter 3.B. Manure management) to the UK-specific livestock numbers.

$PM_{2.5}$ 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 2016 EMEP/EEA Emission Inventory Guidebook. A Tier 1 methodology has been used (as the Guidebook no longer supports a Tier 2 methodology), full details of the default factors used are given in EMEP (2016).

The main source of PM emission is from 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 particulates. Poultry and pig farms are the main agricultural sources of PM.

5.4 Methods for estimating emissions from Soils

NH_3

NH_3 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 on the proportion of livestock associated with grazing and the proportion of the year those livestock spend outdoors (Table 5-13) and UK-specific EF derived from experimental measurements (Table 5-14; more detail given in Misselbrook et al., 2018).

Table 5-14 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	2016	1990	2005	2016
Dairy cows	100	94	85	34	34	34
Other cattle	100	100	100	54	54	54
Sheep	100	100	100	89	89	89
Goats	100	100	100	92	92	92
Horses	100	100	100	75	75	75
Deer	100	100	100	75	75	75
Sows	20	29	43	100	100	100
Finishing pigs	0	3	2	100	100	100
Weaners	0	15	21	100	100	100
Laying hens	14	32	37	12	20	20
Broilers	0	4	7	12	20	20

Table 5-15 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

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 10km grid level across the UK using land use (crop type) data at that resolution from DA June Agricultural Survey combined with fertiliser application rates specific to crop types derived from the British Survey of Fertiliser Practice (Farm Busines Survey for Northern Ireland) for each year and region.

Table 5-16 Emissions from different fertiliser types

Fertiliser type	EF_{max} (as % of N applied)	Modifiers†
Ammonium nitrate	1.8	None
Ammonium sulphate and diammonium phosphate	45	Soil pH
Urea	45	Application rate, rainfall, temperature
Urea ammonium nitrate	23	Application rate, rainfall, temperature

†Modifiers:
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 significant 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

$$RF_{temp} = e^{\left(0.1386 \times \left(T_{month} - T_{UKannual}\right)\right)} / 2$$

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 and grazing returns are assumed to be a factor of 0.1 of the N_2O emissions estimated for each source. The UK applies country-specific N_2O EF for these emission sources as described in the NIR.

NMVOC

Emissions of NMVOC from crops are estimated using the Tier 1 approach as described in the 2016 EMEP/EEA Emission Inventory Guidebook, using crop-specific EF for wheat, rye, oilseed rape and grassland as given in Table 3.3 of the 2016 EMEP/EEA Emission Inventory Guidebook (Chapter 3D Crop production and agricultural soils) and the Tier 1 default EF of 0.86 kg NMVOC ha^{-1} a^{-1} for all other crops.

PM

The UK estimate $PM_{2.5}$ and PM_{10} emissions from agriculture soil using the Guidebook EF; this covers the followings 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. 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 Methods for estimating emissions from Sewage sludge applied to soils

The emission estimates for ammonia from sewage disposal are based on research by the Centre of Ecology and Hydrology (CEH, 2016). The approach uses factors of kt NH_3-N per Mt sewage sludge and activity data estimates based on a time series of sewage sludge disposal data from the UK water companies.

The amount of sewage sludge applied to land was adjusted to match that used in the UK Greenhouse Gas Inventory, for emissions from spreading of sewage to agricultural land (Cardenas *et al*. 2016), of 1,434 kt total dry solids year^{-1}.

As the N content of 3.6% has not been updated by Cardenas *et al*. (2016), the emission factor of 2.4 kg (range 0.9-4.5) NH_3-N t^{-1} (dry solids) is still considered the best estimate (CEH, 2017).

All of these aspects have given rise to an emission estimate of 3.4 kt NH_3-N yr^{-1} (range 1.3 – 6.5 kt) for 2016, similar to the estimate for 2014.

Table 5-17 Application of sewage sludge to land (t DM/yr)

1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
507,855	546,746	590,160	1,216,378	1,281,602	1,259,683	1,269,713	1,286,915	1,332,056	1,429,629	1,433,791

5.6 Methods for estimating emissions from other organic fertilisers applied to soils (including compost)

Emissions of ammonia from composting and anaerobic digestion are based on national statistics for these activities and research conducted by the Centre of Ecology and Hydrology (CEH, 2016). Emissions from land spreading of non-manure digestate[41] are reported within other organic fertilisers applied to soils.

The emission factor for land spreading digestates from non-manure materials are based on latest evidence of spreading emissions (Cumby et al., 2005; WRAP, 2016a) combined with analysis of inputs to all AD sites in the UK (Biogas, 2016; WRAP, 2014; WRAP, 2016b) to produce an average emission factor of 1.39 kg NH_3-N t^{-1} feedstocks (range 1.39 – 1.59 kg). This average emission factor has accounted for the high N content of food-based digestates. Land spreading emissions for digestate from manure/slurry were excluded, to avoid double-counting with the estimates for manure management. A reduction factor of 0.84 (WRAP, 2014) was also used to reflect the fact that the amount of digestate produced (and therefore spread on land) in comparison to the amount of inputs used at the site is usually lower (due to the recycling of digestate to catalyse the process in the digester etc.).

5.7 Methods for estimating emissions from 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 2016 EMEP/EEA Emission Inventory Guidebook (Chapter 3F Field burning of agricultural wastes). The Tier 1 approach for emissions from field burning of agricultural residues uses the general equation:

$$E_{pollutant} = AR_{residue\_burnt} \cdot EF_{pollutant}$$

[41] Manure sources are assumed to be included in manure management, in terms of land spreading emissions, and were omitted here, to avoid potential double-counting.

$E_{pollutant}$ = 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^{-1} 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 2016 EMEP/EEA Guidebook. EF 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.

Legislation within the EU has largely outlawed the practice of field burning agricultural wastes. 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.

5.8 Source specific QA/QC and verification

The inventory spreadsheet model includes some internal nitrogen mass balance checks to capture calculation errors. Data are input by one member of Rothamsted staff and checked by a second member. Trends in emission per sub-category and activity data are plotted (from 1990 - present year) and the reasons for any large deviations are scrutinised.

NMVOC and $PM_{2.5}$ and PM_{10} data are input and compiled by one member of Ricardo Energy & Environment 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 and CEH), then sent to Ricardo Energy & Environment (the central Inventory Agency) and Defra for further checking prior to inclusion in the UK NAEI.

A bilateral review of the Agriculture sector GHG and ammonia inventories was held at a workshop in Dublin in July 2014. This was a very useful exchange of information at which the UK proposed improvements to the GHG inventory were discussed. Useful lessons were learned from the Irish approach regarding the structuring of their beef sector and also regarding the level and documentation of evidence required to underpin country-specific approaches and parameters, particularly regarding expert elicitation.

The UK also participate 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 were 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 (NFR14 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.

Recalculations from the 1990-2015 to 1990-2016 inventory submissions included the following (see Table 5-1 for NFR codes):

- **3B1a Agriculture livestock - dairy cattle wastes; 3B1b Agriculture livestock - other cattle wastes**
  In the previous submission, 'Dairy cattle' included dairy cows and dairy replacements (incl. calves); following reviewer comment, 'Dairy cattle' includes only dairy cows and all other cattle are in the 'other cattle' category. There has been some reallocation between these categories.

Additionally, there is increased cattle sector resolution in the new agriculture inventory model: calculation of N excretion is based on diet and production characteristics, there are some revisions to N-flow parameters in the manure management chain and an increase in the proportion of dairy cows fully housed.

- **3B2 Agriculture livestock - sheep wastes**
  No change to NH_3 EF; revisions to sheep numbers (model includes lambs not captured by survey data); revisions to N excretion (modelled based on diet and production parameters, previously a fixed value); new N_2O EF for solid manure management results in change to amount of N subsequently available for NH_3 loss at spreading.
- **3B3 Agriculture livestock - pigs wastes**
  No change to NH_3 EF; revisions of N_2O EF for solid manure management resulted in changes to amount of N subsequently available for NH_3 emission at land spreading.
- **3B4d Agriculture livestock - goats wastes**
  New model has some differences in N-flow through the manure management chain, with more 'other N' losses at housing (denitrification) and therefore less NH_3 loss at storage.
- **3B4e Agriculture livestock - horses wastes; 3B4e Manure management - Agricultural horses**
  The approach is more detailed than previously, when we had assumed an overall EF per horse based on comparison with dairy cows and the ratio of N excretion. Following the expert review we have now followed the N-flow through the manure management chain as with most other livestock types and this has significantly reduced the emission estimate for horses.
- **3B4gi Agriculture livestock - laying hens wastes; 3B4gii Agriculture livestock - broilers wastes**
  Changes to some parameters in the manure management N-flow model, particularly regarding denitrification losses in housing and storage.
- **3B4giii Agriculture livestock - turkeys wastes; 3B4giv Agriculture livestock - other poultry wastes**
  Revisions made to poultry subcategories for each Devolved Administration, based on better information obtained directly from Devolved Administrations; this particularly impacted on early data in the time series.
- **3B4h Agriculture livestock - deer wastes**
  The new model has some differences in N-flow through the manure management chain, with more 'other N' losses at housing (denitrification) and therefore less NH_3 loss at storage.
- **3Da1 Agricultural soils**
  Spatial disaggregation of fertiliser EF in the new model has significant changes on weighted average EF for each Devolved Administration; the weighted EF depends on proportion of each fertiliser type (urea etc.) for grassland and tillage used in each spatial cell for each year.
- **3Da2a Agriculture livestock - Animal manure applied to soils**
  See comments above under 3B codes; revised N excretion based on diet and production N balance; some revisions to N-flow parameters in manure management chain; revision to proportion of time housed based on new data.
- **3Da2b Agriculture soils - sewage sludge application -direct**
  Previously reported under 5D1.
- **3Da2c Land spreading of non-manure digestates (from AD)**
  Previously reported under NFR14 5 as above; previously calculated by CEH with an estimated EF per tonne of material, we have revised to provide an estimate of N content of digestate and an EF based on N content (as for manure application).
- **3Da3 N-excretion on pasture range and paddock unspecified**
  Change is largely due to revised estimates of N excretion for cattle and sheep based on diet and production characteristics and, for dairy cows in particular, a lower estimate of time spent at grazing.

The combined impact of these recalculations is a decrease in NH_3 emission (1990) from 250.5 to 241.3 kt NH_3/y.

Table 5-18 Impact of recalculations (kt NH_3/y)

NFR code and Source	1990 (2017 submission)	1990 (2018 submission	2015 (2017 submission)	2015 (2018 submission)
3B1a Agriculture livestock - dairy cattle wastes	43.7	30.5	43.7	35.7
3B1b Agriculture livestock - other cattle wastes	33.1	43.8	29.9	38.0
3B2 Agriculture livestock - sheep wastes	2.1	1.9	2.0	1.9
3B3 Agriculture livestock - pigs wastes	16.5	15.9	13.1	12.8
3B4d Agriculture livestock - goats wastes	0.0	0.0	0.0	0.0
3B4e Agriculture livestock - horses wastes	4.4		3.6	
3B4e Manure management - Agricultural horses		0.8		0.6
3B4gi Agriculture livestock - laying hens wastes	6.2	5.7	5.1	4.8
3B4gii Agriculture livestock - broilers wastes	5.8	5.9	3.9	4.0
3B4giii Agriculture livestock - turkeys wastes	3.8	3.9	2.3	2.3
3B4giv Agriculture livestock - other poultry wastes	3.6	3.7	3.8	3.9
3B4h Agriculture livestock - deer wastes	0.0	0.0	0.0	0.0
3Da1 Agricultural soils	39.2	41.8	44.3	51.2
3Da2a Agriculture livestock - Animal manure applied to soils	65.6	63.4	60.6	58.1
3Da2b Agriculture soils - sewage sludge application - direct		3.6		4.2
3Da2c Land spreading of non-manure digestates (from AD)		0.4		7.9
3Da3 N-excretion on pasture range and paddock unspecified	26.4	20.0	25.2	18.6

5.10 Planned Improvements in Agriculture (NFR14 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 of activity data and emission factors for anaerobic digestion of livestock manure and subsequent management of digestate
- Review of manure management practice activity data for the 4 Devolved Administrations of the UK with a view to developing robust evidence for trends over the reporting time series
- Review UK livestock feed data and revise inventory parameters according to outcomes of Defra project SCF0203.
- Continue to review the scientific literature to revise and refine UK-specific emission factors as relevant data arise.

6 NFR14 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 NFR14 source categories. NFR14 5 source categories are key sources for one or more pollutants in the UK inventory in 2016:

- 5A is a key source for Hg
- 5C1bv is a key source for Hg and PCDD/PCDF
- 5C2 is a key source for PCDD/PCDF

Table 6-1 Mapping of NFR14 Source Categories to NAEI Source Categories: Waste

NFR14 Category (5)	Pollutant coverage	NAEI Source Category	Source of EFs
5 A Biological treatment of waste - Solid waste disposal on land	NMVOC, 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 (NMVOC, benzene, 1,3-butadiene), international research (NH_3) and IPCC Guidelines (TSP, PM_{10} and $PM_{2.5}$)
		Application to land (PCB)	Dyke, 1997
		Waste disposal - batteries	Wenborn, 1998
		Waste disposal - electrical equipment	Wenborn, 1998
		Waste disposal - lighting fluorescent tubes	Wenborn, 1998
		Waste disposal - measurement and control equipment	Wenborn, 1998
5 B 1 Biological treatment of waste - Composting	NH_3	Composting (NH_3)	Literature factors (CEH)
5 B 2 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 CEH)
5 C 1 a Municipal waste incineration (d)	All CLRTAP pollutants *(except Se, Indeno(1,2,3-cd)pyrene)*	Incineration	Operator reporting under IED/E-PRTR and literature factors (EMEP/EEA, HMIP, USEPA)
5 C 1 bi Industrial waste incineration (d)		Incineration - chemical waste	
		Other industrial combustion	
		Regeneration of activated carbon	
5 C 1 bii Hazardous waste incineration (d)		Incineration - hazardous waste	
5 C 1 biii Clinical waste incineration (d)		Incineration - clinical waste	

NFR14 Category (5)	Pollutant coverage	NAEI Source Category	Source of EFs
5 C 1 biv Sewage sludge incineration (d)		Incineration - sewage sludge	
5 C 1 bv Cremation	NO_x (as NO_2), NMVOC, SO_x as SO_2, 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	
5 C 2 Open burning of waste	NO_x (as NO_2), NMVOC, 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	
5 D 1 Domestic wastewater handling	NMVOC	Sewage sludge decomposition	UK industry research
5 D 2 Industrial wastewater handling		Industrial wastewater treatment	
5 E Other waste	PCDD/PCDFs and PCBs	Regeneration of activated carbon	Literature factors (Wichmann, CEH, Dyke et al)
		RDF manufacture (PCB)	
	NO_x (as NO_2), NMVOC, 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

National 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 much better quality data now than it did in the earlier parts of the time series. There are some datasets that are of much lower quality than others. For example, the number of accidental fires will always be uncertain.

6.3 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. Annual data on waste landfilled extends 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 2015 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:

- Data on waste consignments landfilled in England for the period 2006 to 2016 are published by the Environment Agency
- Data on waste consignments landfilled in Scotland for the period 2005 to 2016 are published by the Scottish Environmental Protection Agency
- Data on waste consignments landfilled in Wales for the period 2006 to 2016 are published by Natural Resources Wales
- Data on waste consignments landfilled in Northern Ireland for the period 2008 to 2016 were provided by the Northern Ireland Environment Agency

This information is considered to be of good quality. The composition of waste landfilled was evaluated by allocating each EWC code to one of the categories used in the UK model, as set out in Table 6-2.

Table 6-2 Waste categories used in the UK landfill model

Waste category	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

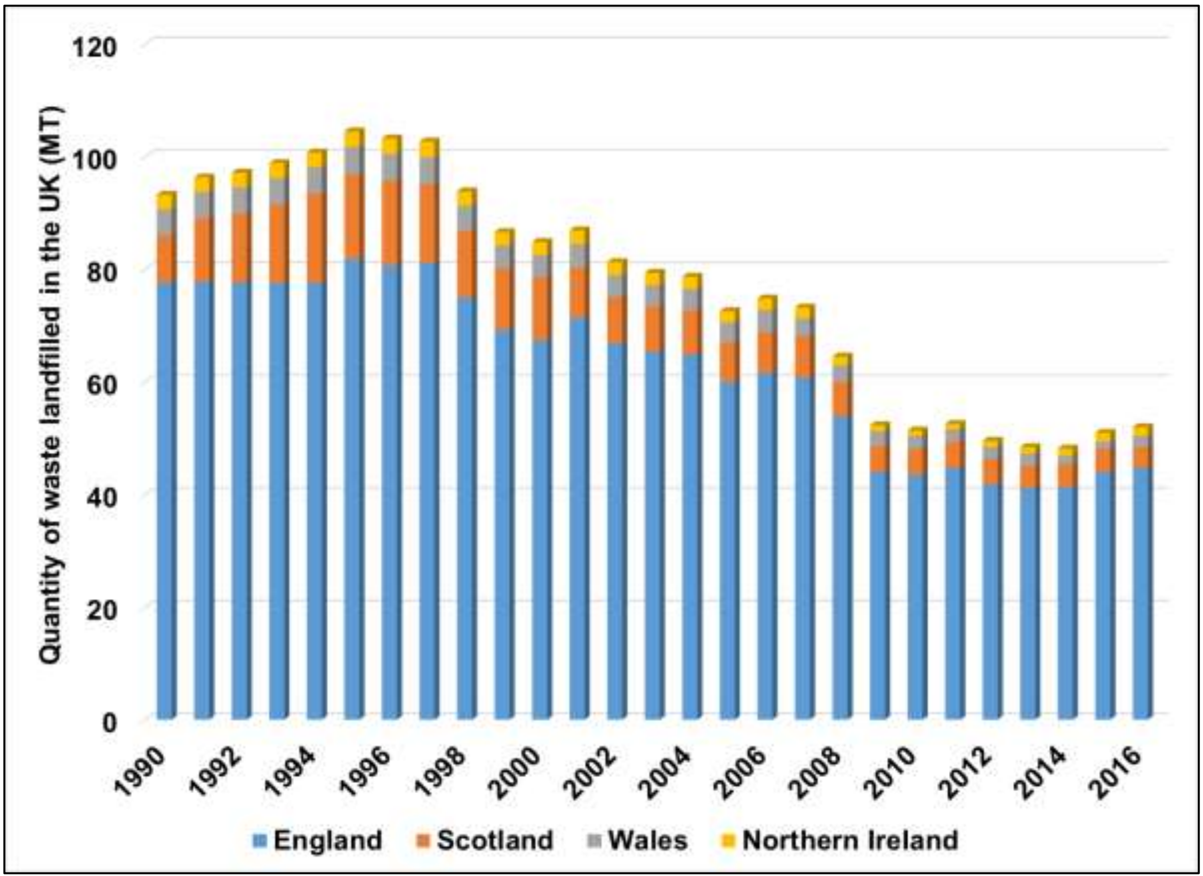
Material	19.12.12 (residues from waste sorting)	20.03.01 (mixed municipal waste
Paper	10.3%	10.6%
Card	9.1%	7.7%
Plastic film	9.4%	8.4%
Dense plastics	13.2%	9.6%
Sanitary waste	1.3%	3.1%

Material	19.12.12 (residues from waste sorting)	20.03.01 (mixed municipal waste
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; 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 2016 are shown in Figure 6-1.

Figure 6-1 Quantities of waste landfilled in the UK, 1990 to 2016



The quantity of waste landfilled in the UK peaked at 105 Mt in 1995, and has steadily reduced to about half of this quantity by 2016. Over this period, the estimated proportion of paper and card, and food waste landfilled has reduced by more than two-thirds, and the proportion of garden waste has reduced by over half. The estimated proportions of sanitary waste landfilled has remained more constant.

6.3.2 Estimating Emissions from Landfill

Landfill emission estimates 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 practicable 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 national 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, if anything, 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, NMVOC, 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 published data relevant to the UK.[42,43] The factors used are as follows:

Table 6-4 Emission factors for landfill emissions

Substance	Value	Units	Reference
NMVOC	0.0036	t NMVOC / t CH_4	Based on Broomfield et al., (2010)
benzene	0.000053	t benzene / t CH_4	Based on Parker et al., (2005)
1,3-butadiene	0.000000058	t benzene / t CH_4	Based on Parker et al., (2005)
TSP	0.000463	kg/Mg waste landfilled	Inventory guidelines (EMEP, 2016) quoting AP-42 (US EPA, 2009)
PM_{10}	0.000219	kg/Mg waste landfilled	Inventory guidelines (EMEP, 2016) quoting AP-42 (US EPA, 2009)
$PM_{2.5}$	0.000033	kg/Mg waste landfilled	Inventory guidelines (EMEP, 2016) quoting AP-42 (US EPA, 2009)

Emission factors are available in the EMEP/EEA Guidebook for NMVOC. However, the Guidebook references the UK 2004 inventory as the data source. The emission factor for NMVOC in data in Table 6-4 are considered to represent an improvement on the EMEP/EEA Guidebook value for NMVOC.

Ammonia emissions are estimated using emission factors provided by the Centre of Ecology and Hydrology (CEH, 2017). Research was carried out to update the estimated N content of land-filled materials from local authority waste streams. Various waste composition reports were used to analyse the tonnage of different materials going to landfill to produce a new N content estimate of 0.55% for 2013 (still the most up to date information, unchanged for 2016), a 10% increase from the figure of 0.5% used in inventory years prior to 2013. The input of 9.3 kt of sewage sludge to the landfill process in 2016 meant more high-nitrogen materials were going to landfill in 2016 (the best estimate of N content for sewage sludge remained at 3.6% as per previous years). The 2016 best estimate emission factor is 0.14 kg NH3-N t-1 of landfilled materials.

Emissions of mercury from waste disposal of batteries, electrical equipment, fluorescent lighting tubes and monitoring and control equipment are calculated based on factors derived from UK research (Wenborn et al, 1998).

[42] 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.
[43] Parker T, Hillier J, Kelly S, and O'Leary S (2005). "*Quantification of trace components in landfill gas,*" Environment Agency, Bristol.

6.4 Composting and Anaerobic Digestion

Emissions of ammonia from composting and anaerobic digestion are based on national statistics for these activities and research conducted by the Centre of Ecology and Hydrology (CEH, 2017).

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 mega-grams (Mg).. As new data source has been used for 2014 onwards, activity data for 2014-2015 have updated retrospectively in the current edition of the inventory.

Table 6-5 Inputs in the composting process (Amounts in Mg)

Type of waste	1990	1995	2000	2005	2010	2011	2012	2013
Non-household	0	140,000	1,034,000	3,424,000	5,444,092	6,053,273	5,850,257	5,867,640
Household	54,816	54,816	54,816	91,733	171,175	176,783	182,392	188,000

Type of waste	2014	2015	2016
Non-household	5,954,185	6,010,218	6,135,538
Household	202,787	212,067	221,347

NH_3 emissions associated with composting exhibit an upward trend throughout the inventory period, which has levelled off in recent years. The significant increase in NH_3 emission levels for this category 5.B.2 since 1997 is determined by the progressive increase in the amount of non-household composted waste.

The NH_3 emission factor used is generated by the Centre of Ecology and Hydrology (CEH). The emission factor for household composting is 0.45 kg NH_3-N /tonne dry matter. This emission factor is constant across the whole series. On the other hand, the emission factor for non-household composting is split into garden/green composting and kitchen/food composting. The EFs for the two streams are based on multiple factors such as N content, types of waste, type of composting facility, etc. so a flat rate emission factor is not used. This means the emission factor can change from year to year based on waste flows, amount of inputs, the compost facilities themselves. Table 6-6 lists the implied emission factors for recent years (note it is expressed as NH_3-N and not NH_3).

Table 6-6 NH_3 implied emission factors for non-household composting in recent years

Year	Value	Units	Value	Units
2016	0.887	NH_3-N per tonne fresh weight	2.23	kg NH_3-N per tonne dry matter
2015	0.813	NH_3-N per tonne fresh weight	2.04	kg NH_3-N per tonne dry matter
2014	0.813	NH_3-N per tonne fresh weight	2.04	kg NH_3-N per tonne dry matter
2013	0.813	NH_3-N per tonne fresh weight	2.04	kg NH_3-N per tonne dry matter
2012	0.809	NH_3-N per tonne fresh weight	2.03	kg NH_3-N per tonne dry matter
2011	0.751	NH_3-N per tonne fresh weight	1.88	kg NH_3-N per tonne dry matter
2010	0.751	NH_3-N per tonne fresh weight	1.88	kg NH_3-N per tonne dry matter
2009	0.751	NH_3-N per tonne fresh weight	1.88	kg NH_3-N per tonne dry matter

NH_3 emissions associated with anaerobic digestion (AD) are reported in the following NFR categories:

- Process (fugitive and storage) emissions from AD 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 AD plants were modified in the 2015 inventory following a thorough review of relevant literature and remain the same for the 2016 inventory. The best estimate emission factor for fugitive and storage emissions at UK AD plants is 0.056 kg NH_3-N t^{-1} feedstocks (range 0.053 – 0.205 kg), with this EF derived by careful re-analysis of existing data and new data from the UK and elsewhere to provide an emission factor for the three main stages of emissions at the site: pre-AD storage (0.004 kg NH_3-N t^{-1} feedstocks), process emissions (0.003 kg NH_3-N t^{-1} feedstocks) and post-AD storage (0.048 kg NH_3-N t^{-1} feedstocks) (Bell *et al*., 2016; Cuhls *et al.*, 2010; Cumby *et al.*, 2005). Post-AD storage incorporates an emissions reduction factor of 95% (Cumby *et al.*, 2005) from sealed covers on digestate materials on site (previously 80%). For the 2015 inventory and earlier versions, the proportion of sites using the covering was estimated to be 100% from 2010 onwards, with incremental steps back to 0% of sites using coverings in 2000, to account for legislation that requires all AD plants to cover input and output storage areas (WRAP/EA 2009). However, in the 2016 inventory, all sites throughout the time series are assumed to have had a storage covering, due to a reassessment of the AD sector's practices with new information. This has reduced estimated fugitive and storage emissions at AD plants by over 90% pre-2005.

The amounts of materials treated in UK AD plants are considerable, and this source has been growing rapidly. New NH_3 emission sources from anaerobic digestion were identified for the 2016 inventory, along with updates for existing sources. The comprehensive database for AD sites now contains 394 plants operational during 2016 (NNFCC, 2017), an increase from 356 in the 2015 methodology (265 in 2014). These plants are estimated to process 10,167 kt of materials (fresh weight) during 2016, an increase of approx. 8% on the 2015 methodology. Approximately 84% of input materials to AD were from non-manure sources, such as crops and food wastes, an increase from 75% in 2015. As per 2015, large volumes of materials (approx. 725 kt at 20 sites) were then removed from the non-farm based input stream after it was established they did not enter the AD process as characterised in this inventory. These materials were predominantly distillery and brewery wastes (and some vegetable washings) and were not included in the emissions estimate for 2016 as they are likely to be processed in other ways; these distillery and brewery wastes have also been removed from the historic timeline for AD as was done with the previous database. For estimating fugitive and storage emissions, all materials that are processed by AD were included in the calculations. A reduction factor of 0.84 (WRAP, 2014) was also used to reflect the fact that the amount of digestate produced in comparison to the amount of inputs used at the site is usually lower (due to the recycling of digestate to catalyse the process in the digester etc.).

It should be noted that the new site information database recorded in the NNFCC (2017) data differs from the previous data collections in 2015 (Biogas, 2016; WRAP, 2016b), as the reported inputs to each site in NNFCC reflect the actual tonnes inputted by feedstock category, as opposed to previously available datasets which utilised the capacity of the site as the presumed input. AD sites generally do not operate at 100% capacity so the increase in inputs from 2015 to 2016 was not as large as expected. Furthermore, input materials to each site are now reported with less uncertainty: each site has quantities listed for manures, crops, food and 'other', as opposed to material types only, thereby superseding the previously necessary approach of having to estimate proportions. This allows input materials and digestates to be characterised with more detail. In summary, the newly available NNFCC dataset provides a substantial improvement to the inventory, due to a large reduction in uncertainty on the quantities of different materials.

6.5 Incineration of Waste

The quantities of waste-derived fuels used for electricity and heat generation are reported in DUKES (BEIS, 2017) and these data are used to derive emission inventory estimates for municipal waste incinerators prior to 1997. Waste data reporting for later years are more comprehensive and the Inventory Agency obtains annual statistics on waste incineration facilities.

In the UK all facilities that incinerate municipal solid waste (MSW), chemical waste, clinical waste, and sewage sludge are regulated under IED/E-PRTR and all plant operators are required to report annual estimates of emissions to their respective Pollution Inventory (England and Wales, Scotland or Northern Ireland). Wherever possible, the operator-reported emissions are used directly in the national inventory, however the paucity 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 to the PI/SPRI/NIPI as "Below Reporting Threshold", and so the Inventory Agency 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 time-series of estimates, and the estimates for years prior to the PI (operator reporting to which began in 1998) are based on national waste activity statistics and emission factors.

Emissions from **clinical waste incinerators** are estimated from a combination of data reported to the Pollution Inventory (EA, 2017), supplemented using literature-based emission factors, largely taken from the EMEP/EEA Emission Inventory Guidebook (EMEP, 2016). The quantity of waste burnt annually is also estimated, these estimates being based on information given in the following sources in Table 6-7:

Table 6-7 Sources of waste burnt from clinical waste incinerators

Years	Source
1991	RCEP, 1993
1997	Wenborn *et* al, 1998
2002	Entec, 2003
2006-2014	Environment Agency, waste disposal data for individual sites in England and Wales
2004-2013 2015-2016	Scottish Environment Protection Agency, estimates of total clinical waste incinerated in Scotland

Interpolation between the various estimates is used to fill the gaps in the activity data time series.

Emissions from **chemical waste incinerators** are estimated based on analysis of data reported to the Pollution Inventory (EA, 2017) with the exception of benzene and polyaromatic hydrocarbons (PAHs), estimates for which are based on activity data for waste burnt at operational sites and literature emission factors from US EPA 42 profiles (for benzene) and Parma et al. (1995) atmospheric guidelines for POPs published by External Affairs Canada (for PAHs). Waste tonnages burnt at the largest individual chemical waste incinerators for the period 2006 – 2012 have been obtained from the Environment Agency, but the overall quantity of chemical waste burnt must then be estimated by the Inventory Agency, based on the capacity of the smaller plant. For the earlier part of the time series, we use the following estimates of waste burnt in Table 6-8:

Table 6-8 Sources and quantities of waste burnt from 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 we interpolate between the HMIP and Entec figures for the years 1994-2001. For the period 2003-2005, we interpolate between the Entec figure of 284,000 tonnes and our estimate for 2006 of 177,000 tonnes.

Emissions from **sewage sludge incinerators** are estimated from a combination of data reported to the Pollution Inventory (EA, 2017) and Scottish Pollutant Release Inventory (SEPA, 2017), supplemented with the use of literature-based emission factors where the IED/E-PRTR-reported data are incomplete. Emissions of NO_x (as NO_2) 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 Emission Inventory Guidebook (EMEP 2016). The quantity of waste burnt annually is estimated based on annual activity data from environmental regulators (EA, 2017 and SEPA, 2018) 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 are shown in Table 6-9:

Table 6-9 Sources of sewage sludge burnt from clinical waste incinerators

Years	Source
1990	RCEP, 1993
1991-1998	Digest of Environmental Statistics (Defra, 2004)
2006-2016	Environment Agency, waste disposal data for individual sites in England
2013, 2015, 2016	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.

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 Inventory Agency has also reviewed data on the small proportion of animal carcass incinerators that are covered in the Pollution Inventory (EA, 2016) but there is insufficient new data to warrant a revision to the estimates from the 2002 report, without more detailed industry-focussed research and consultation.

Emissions from **crematoria** are predominantly based on literature-based emission factors, expressed as emissions per corpse (USEPA, 2009). Data on the annual number of cremations is available from The Cremation Society of Great Britain (2016). Mercury emission estimates are based on calculations using UK population (ONS, 2016) and dental record data (2009 Dental Health Survey) produced by the UK National Health Service (NHS). The mercury estimation method was revised in 2011 through consultation with the Cremation Society of Great Britain to take account of the impact 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.

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 plants were closed down, if they did not meet new emission limits. Emissions from plants operated using incineration with energy recovery, i.e. generating heat or power, are reported within NFR14 1A1a. There were still emissions from Gibraltar until 2000 however. Estimates of emissions from MSW incineration up to 1996 are reported under NFR14 6C, 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 & 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 best ones. In addition, they 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 incineration of animal carcasses is input into the incineration waste process; however, the NAEI does not hold activity data for this activity. Instead, emissions are considered, by pollutant, from AEA Technology (2002).

Table 6-10 Inputs into waste incineration processes

Input	Units	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
Clinical waste	Megatonnes	0.35	0.27	0.25	0.14	0.11	0.11	0.10	0.10	0.10	0.09	0.09
Chemical waste	Megatonnes	0.29	0.29	0.29	0.20	0.14	0.14	0.16	0.17	0.17	0.16	0.17
Sewage sludge	Megatonnes	0.08	0.08	0.19	0.22	0.23	0.22	0.21	0.20	0.18	0.17	0.15
Crematoria	Million cremations	0.44	0.45	0.44	0.42	0.41	0.43	0.44	0.43	0.46	0.46	0.46
Municipal waste	Megatonnes	2.2	1.2	0.02	0	0	0	0	0	0	0	0

6.5.1 Open Burning of Waste

Emission estimates in the UK inventory from small-scale waste burning comprise emissions from combustion of agricultural and domestic waste, and also from burning of treated 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, and the Inventory Agency generates 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 were further refined in 2011 and 2012 in the light of a national waste burning habits survey of a thousand UK households completed on behalf of Defra in 2010 (Whiting et al 2011), and with improved representation of numbers of households and allotments across the time-series.

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 UK inventory have also been reviewed against the 2016 EMEP/EEA Emission Inventory Guidebook. The Guidebook refers users to the USEPA 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 USEPA AP42 guidance, thus they continued to be applied in the 2016 UK inventory. Emissions of NO_x (as NO_2), PM_{10} and NMVOCs from all the 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 (USEPA, 2004 and Perry, 2002).

Table 6-11 Inputs in the open burning waste process (Amounts in kilotonnes)

Source	1990	1995	2000	2005	2010	2012	2013	2014	2015	2016
Agriculture	97.8	97.8	97.8	97.8	2.93	2.93	2.93	2.93	2.93	2.93
Domestic waste (with treated wood)	188	148	131	107	108	107	107	106	107	107

6.6 Wastewater

The emission estimates for ammonia from sewage treatment are taken from data provided by the Centre of Ecology and Hydrology (CEH, 2017). Sewage treatment emissions were unchanged from previous year estimates, at 1.2 kT NH_3-N yr^{-1} (Lee and Dollard, 1994). Emissions from sewage sludge disposal to land are reported under Section 3Da2b, apart from sewage sludge used for land reclamation up to 2012, which is reported under 5D1.

NMVOC emissions from wastewater treatment (WWT) plants have been included in this year's inventory for the first time. Emissions from residential WWT are estimated using the Tier 1 method given in the 2016 EMEP/EEA Guidebook. The approach uses the default emission factor (15 mg NMOV/m^3 wastewater handled) and activity data estimates based on a time series of waste water generated from residential properties for treatment from the UK water companies.

An estimate of NMVOC emissions from industrial waste water treatment is also required to achieve completeness for the NMVOC inventory. As activity data are expressed as amount of 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 2011-2015 of 0.00205 kt NMVOC/ kt CH_4 was chosen as a representative and conservative value. This was applied to the derived CH_4 EF from industrial WWT to generate the EF for NMVOC from that source. NMVOC emissions from residential and industrial WWT are reported under Section 5B1 and 5B2, respectively. Overall, the resulting emissions are insignificant in the UK context.

6.7 5E – 'Other'

NFR14 category 5E – 'Other' captures those sources not covered in other parts of the waste sector of the inventory. National fire statistics produced by the UK's Office of National Statistics (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 and also for ammonia emissions linked to infant 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.

Accidental Fires

UK national 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 for the remaining years in the time series the Inventory Agency has constructed and makes use of 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 1987-2007. 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 1985-2008 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 polyaromatic hydrocarbons (PAHs), which make use of UK research by Coleman (2001) supported by UK ambient monitoring data.

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 NFR14 5.

Emission estimates for Bonfire night are based on the Inventory Agency estimates of the quantity of material burnt in bonfires and firework displays. Emission factors for domestic wood fires (in the case of CO, PM_{10} and PAH) and 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 NFR14 5 are based on facility-specific emissions reported to the PI, SPRI and NIPI, under IED/E-PRTR regulation. Section 3.1.7 discusses QA/QC issues regarding these data.

The emission estimates for NFR14 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 have been 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 rest of source categories are covered by the general QA/QC, please refer to Section 1.6.

6.9 Recalculations in Waste (NFR5)

A number of changes have been made for reporting in the 2017 submission, as summarised below:

- New sources of data on individual consignments of waste landfilled have been identified, analysed and used. This enables a more accurate representation of waste landfilled for the period 2005 – 2016 (Scotland), 2006 – 2016 (England and Wales), and 2008 – 2016 (Northern Ireland).
- Data on methane collection and combustion in landfill gas engines and flares have been updated
- An improved source of data on the quantities of waste processed by anaerobic digestion has been identified and used.
- A change has been made to assumptions regarding controls on digestate storage at anaerobic digestion facilities, resulting in a reduction in past emissions of NH_3
- Emissions from land spreading of digestates, other than manure digestates, are now reported under 3Da2c (other organic fertilisers applied to soils)

- Emissions from accidental fires and bonfire, previously reported under 6A, are now reported in NFR14 5, sector 5E – 'Other'.

6.10 Planned Improvements in Waste (NFR14 5)

The UK inventory 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.

There are no further sector-specific planned improvements in this sector.

7 NFR14 6: Other

Table 7-1 Mapping of NFR14 Source Categories to NAEI Source Categories: Other Sources

NFR14 Category (6)	Pollutant coverage	NAEI Source Category	Source of EFs
6 A Other (included in national total for entire territory)	NO_x (as NO_2), NMVOC, Particulate Matter,	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

NFR14 source category 6A is a key source for NH_3.

7.2 Activity Statistics

NFR14 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’ horses located on agricultural holdings (and counted in the agricultural census) – emissions from this category are reported under NFR14 3: Agriculture
2. ‘normal’ privately owned horses (not counted in the agricultural census) – emissions from this category are reported under NFR14 6A: Other
3. professional horses (i.e. horses on a higher protein diet) – emissions from this category are reported under NFR14 6A: Other

The UK population estimate for horses was updated in the previous (2017) submission with new figures on all horses registered in the UK with British Equestrian Trade Association’s National Equestrian Survey 2016 (personal communication made by the Centre of Ecology and Hydrology). No new population data for professional horses or ‘normal’ privately owned horses were found for year 2016 and thus it was assumed to remain at the 2015 level.

For year 2016, the UK population estimate for cats and dogs was based on the new survey data from the Pet Food Manufacturers Association (PFMA 2017). It shows that the UK population estimate for cats has increased by approx. 500,000 to 8 million from 2015 figures, while dogs have remained unchanged at 8.5 million.

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 for professional horses and 'normal' privately owned horses were taken from the latest submission of the agricultural inventory (Misselbrook et al., 2017). These new data reflect the new N-flow methodology used for horse emission estimates and are substantially lower than previous emission factors used in the 2017 UK inventory submission. For horses kept by professionals, the best estimate emission factor is now 16.1 kg NH_3-N horse^{-1} (range 14.5 – 17.8), a decrease of 41%. For 'normal' privately owned horses, the best estimate emission factor is now 3.9 kg NH_3-N horse^{-1} (range 3.5 – 4.3), a decrease of 63%.

NO_x and NMVOC emissions from horses were also taken from the latest submission of the agricultural inventory (Misselbrook et al., 2017). These emissions were estimated using the 2016 EMEP/EEA Emission Inventory Guidebook methods; for NO_x it is based on the Tier 3 N-flow approach while the Tier 1 method was used for NMVOC.

Infant Emissions from Nappies
The emission estimate for ammonia from infants' nappies is based on research by the Centre of Ecology and Hydrology (CEH, 2017). 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 Centre of Ecology and Hydrology (CEH, 2017), 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) while the best estimate emission factor for cats is 0.11 kg NH_3-N per animal (range 0.05 – 0.16).

Golf courses, parks and gardens
Ammonia emission estimates for this category are provided by the Centre of Ecology and Hydrology (CEH, 2017). 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 previous version of the UK inventory (Misselbrook et al., 2016) due to the unavailability of updated figures in time for the current inventory cycle. 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-N ha^{-1} (range 0.23 – 1.4). For golf courses, the best estimate emission factor is 0.72 kg NH_3-N ha^{-1} (range 0.42 – 1.18).

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., 2017).

Emission factors and activity data are available on the NAEI website: http://naei.defra.gov.uk/data/

7.4 Source specific QA/QC and verification

Many of the emission estimates reported in NFR14 6 come from sources with less well defined activity data and emission factors based on literature. Where possible national statistics have been used to help better define the sources with inbuilt QA/QC from the data utilised. Emission estimate methodologies have adopted innovative approaches to provide robust estimates.

7.5 Recalculations in “Other” (NFR14 6)

The most significant recalculations to the sources under NFR14 6 this year are due to revised NH_3 emission factors for horse as discussed above. These new data reflect the new N-flow methodology used for horse emission estimates and are substantially lower than previous emission factors used in the 2017 UK inventory submission. NH_3 emissions from horses kept by professionals and ‘normal’ privately owned horses have been revised downward by 41% and 63% respectively across the time series.

NMVOC emissions from horses have been revised upward across the time series due to the use of a Tier 1 method (instead of a Tier 2 method) in the new agriculture model developed by Rothamsted Research (Misselbrook et al., 2017). As a result, NMVOC emissions from horses kept by professionals have been revised upward by approximately 1.4 to 3.1 kt across the time series, while NMVOC emissions from ‘normal’ privately owned horses have been revised upward by approximately 0.3 to 0.4 kt across the time series.

NO_x emissions from horses were included in the UK inventory for the first time in response to the 2017 NECD review’s recommendation.

Emissions from accidental fires and bonfire night are now reported under NFR 5 instead of NFR 6, in response to the 2017 NECD review’s recommendations.

7.6 Planned Improvements in “Other” (NFR14 6)

In future submissions, Rothamsted Research is planning to implement the Tier 2 method for estimating NMVOC emissions from horses in its model when resources are available.

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.

Throughout the UK inventory, emission estimates are updated annually across the full time series in response to new research and revisions to data sources. In NFR14 source category 1A1 updates to emission estimates are caused mainly by the reallocation of combustion of biogas from anaerobic digestion from 1A2gviii to 1A1a. In NFR14 source category 1A2, updates to emission estimates are caused mainly by the introduction of Tata Steel emissions data for their steelmaking sites, and reallocations arising from coal model improvements. The main changes to 1A3b are caused by revisions to evaporative emission factors for road transport (NMVOC). The most significant updates to 1A3dii result from the improvements to the shipping inventory methodology using detailed AIS vessel movement data and updates to 1A4 emission estimates are caused mainly by revisions to DUKES and improved modelling of fishing vessel emissions. There have been a number of revisions to industrial processes (NFR 2) that primarily affect NMVOC from solvent use, and PM emissions from quarrying and construction. In the case of tobacco use and fireworks, emission estimates are now made for a wider range of pollutants than previously. Emission estimates for agriculture (NRF 3) have been revised as a result of the model rebuild at Rothamsted and the inclusion of NOx emissions from this sector. There has also been reallocation of source emissions between NRF 5 and NRF 6 and for sources of NH_3 emissions from land spreading of digestates from NFR 5 to NFR 3.

8.1 NO_x (as NO_2)

There have been a number of revisions to emission estimates. The most significant recalculations were made to the shipping sector as a result of the BEIS shipping improvement work using Automatic Identification System (AIS) data. The upward revision is largely due to increased estimates of fuel consumed from domestic shipping calculated by the new shipping emissions model.

NO_x (as NO_2) emissions have been revised up by 74 kilotonnes (8%) for the calendar year 2015 between the 2017 and 2018 UK inventory submission. This is made up of a number of changes to emissions, to revise categories both up and down. The top contributors to this change are:

- Emissions estimates for 1A3dii have been revised upwards to values approximately 2.4 to 3.0 times the previous values from 2005 to 2015. This is largely due to increased estimates of fuel consumed from domestic shipping calculated by the new shipping emissions model. Overall, non-road transport emission estimates have been revised upwards by 54 kilotonnes NO_x (as NO_2) for 2015.
- Emissions estimates for 1A4 have been revised upwards by 7 kilotonnes NO_x (as NO_2) for 2015 due to revisions to gas oil consumption estimates for agricultural vehicles and changes to both activity data and emission factors for fishing vessels. These are partially offset by downward revisions to both commercial/public sector combustion (due to revisions to DUKES) and the domestic sector (due to revisions to emission factors and the domestic boiler age profile used in the inventory model for domestic gas combustion).
- NOx emissions from the agriculture sector (NRF Code 3) were included in the inventory for the first time in the 2018 UK inventory submission. Sources include: animal waste arising in animal housing, application of chemical fertilizers, animal manure, and sewage sludge to agricultural soils, and deposition of urine and dung by grazing animals. These sources account for 7 kilotonnes for the calendar year 2015.
- Reallocation of sources from 1A2gviii to 1A1a and 1A1c to 1A2a have led to emissions estimates for 1A1 being revised upwards by 5 kilotonnes NO_x (as NO_2) for 2015.

- Revisions to DUKES' figures for natural gas for 2008 onwards, re-allocation of some emissions from 1A1c to 1A2a and changes to the overall gas oil total in DUKES that result in increases in the assumed consumption by mobile machinery and off-road vehicles (particularly for 2015) have led to emissions estimates for 1A2 being revised upwards. These increases are partially offset by the re-allocation of biogas combustion from 1A2gviii to 1A1a. Overall, NOx emissions estimates for 1A2 have been revised upwards by 4 kilotonnes NO_x (as NO_2) for 2015.
- Revisions to MoD naval shipping data and aviation fuel data have had a notable impact on emissions in 1A5 for 2015 with emissions decreasing by 3 kilotonnes NO_x (as NO_2).

8.2 CO

CO emissions have been revised up by 23 kilotonnes (1%) for the calendar year 2015 between the 2017 and 2018 UK inventory submission. This is made up of a number of changes to emissions, to revise categories both up and down. The top contributors to this change are:

- Updated emissions data provided by Tata Steel for 2015 results in an increase in 2015 emission estimates for 2C1 of 22 kilotonnes CO.
- Emission factors for the domestic combustion of petroleum coke have been revised to use a tier 2 technology specific approach, using default emission factors for solid fuels. This combined with other minor revisions results in an increase in 2015 emission estimates for 1A4 of 17 kilotonnes CO.
- Updated emissions data provided by Tata for 2015 and revisions to DUKES, offset by reallocations within DUKES for straw combustion have led to a reduction in 2015 emission estimates for 1A2 of 10 kilotonnes CO.

8.3 NMVOC

NMVOC emissions have been revised down by just 0.2 kilotonnes (0.03 %) for the calendar year 2015 between the 2017 and 2018 UK inventory submission. There are larger reductions in some earlier years, for example, a 0.6% decrease of 7 kilotonnes in 2005. At a more detailed level, however, there have been many improvements and revisions: these happen to largely cancel each other out in terms of the net change to UK totals. There are numerous small changes that result from revisions to UK energy statistics, other fuel use estimates (e.g. for shipping), and other routinely-provided datasets, but the main areas of revision are evaporative emissions from vehicles, solvent use, and agriculture.

The methodology for evaporative emissions from vehicles has been updated to be consistent with the 2016 edition of the EMEP/EEA Guidebook, whereas, previously, an older version had been used. Emission estimates for 2015 are now 9 kilotonnes higher than in the previous version of the inventory, while estimates for 1990 and 2005 are 78 ktonnes lower and 5 kilotonnes higher, respectively.

The estimates for solvent and other product use (2D3) have been extensively revised with changes to methodology for a few sources, incorporation of a lot of updated data, and re-allocation of a few sources within the sub-categories of 2D3. Most of the estimates rely upon data from industry that is supplied infrequently, but consultation with industry during 2017 resulted in much new information. Significant revisions have been made to the estimates for all sub-categories of 2D3, apart from 2D3c (which is not used in the UK inventory) and 2D3f. Because of the lack of recent data when compiling the 2017 submission, the estimates for 2D3 were thought likely to be too high and this proved to be so: the new estimates for 2005 are 44 kilotonnes (11%) lower and those for 2015 are 29 kilotonnes (8%) lower than in the previous inventory.

Estimates for agricultural sources have, for the first time, been provided by Rothamsted Research, and have increased (by 14 kilotonnes (13%) for 2015) in the current inventory due to the new model using the EMEP/EEA 2016 Guidebook Tier 1 method compared to Tier 2 methods used in previous years. This is due to some parameters not being available for the new model run by Rothamsted. The new model also now includes emissions from cultivated crops, one of the NECD review recommendations, adding 8 kilotonnes to the 2015 emission total (7% of the NFR 3 total).

8.4 SO_x (as SO_2)

Total SO_x emissions have been revised upward for all years, mainly due to the improvements made to the shipping inventory.

SO_x (as SO_2) emissions have been revised up by 17 kilotonnes (7%) for the calendar year 2015 between the 2017 and 2018 UK inventory submission. The top contributors to this change are:

- Emissions estimates for 1A3dii have been revised upwards to values approximately 2.6 to 4.1 times the previous values from 2005 to 2014. This is largely due to increased estimates of fuel consumed from domestic shipping calculated by the new shipping emissions model as well as revised assumptions around sulphur factors for shipping. Emissions have been revised most for 2015, with emissions approximately 9 times the previous 2015 value, which is largely due to revised assumptions around sulphur factors for shipping in non-SECA areas for that year as well as increases in estimates of fuel consumption. Overall, non-road transport emission estimates have been revised upwards by 11 kilotonnes SO_x (as SO_2) for 2015.
- Improved modelling of fishing vessel emissions allowing an improved estimate of time spent by ships in sulphur control areas and better informed judgements on the split of high/low sulphur fuel/gas oil plus recalculations in later years for residential combustion due to DUKES revisions have led to emissions estimates for 1A4 being revised upwards by 5 kilotonnes SO_x (as SO_2) for 2015.
- Recalculations for 2013 onwards, due to the introduction of Tata Steel emissions data for the Scunthorpe and Port Talbot steelworks, have led to emissions estimates for 1A2 being revised upwards by 1 kilotonnes SO_x (as SO_2) for 2015. Additionally, emission estimates for 1A2 have been revised for the late 90s due to reallocations arising from the coal model improvements.

8.5 NH_3

NH_3 emissions have been revised down by 13 kilotonnes (2%) for the calendar year 2015 between the 2017 and 2018 UK inventory submission. Significant changes to the inventory model for the agricultural sector were introduced, with the implementation of a combined ammonia and greenhouse gas inventory model with greatly improved spatial, temporal and sectoral resolution. While most ammonia emission factors have remained unchanged, those for nitrogen fertiliser applications, which are spatially and temporally sensitive, have changed as a result of the finer model resolution, and the introduction of dynamic modelling of nitrogen excretion by ruminant livestock based on detailed diet and production characteristics has resulted in changes in the nitrogen excretion estimates for these livestock types. Furthermore, emissions from sewage sludge spreading on agricultural land and from land spreading of non-manure digestates have been reallocated from NRF 5 to NFR 3 in line with the NECD recommendations. Overall, emission estimates for NRF 5 have been revised down by 13 kilotonnes NH_3 for 2015. Whereas emission estimates for NRF 3 have been revised up by 6 kilotonnes NH_3 for 2015.

Emission from NFR 6 have also been revised down by 6 kilotonnes NH_3 for 2015 due to revisions to the emission factor used for horses. Previously, a simple factor derived from that for dairy cattle was used, but in the new agricultural model, a factor is derived based on detailed modelling of nitrogen excretion by horses, using the same approach as for other livestock.

8.6 PM_{10} and $PM_{2.5}$

PM_{10} and $PM_{2.5}$ emissions have each been revised up due to a numbers of factors including revision to the emission factors to align with the 2016 Guidebook for various sources (fireworks, quarrying, construction), adding emissions from cigarettes, and inclusion of updated data such as that for emissions from steelworks, and for consumption of industrial paints. The methodology for particulate matter emissions from construction has been updated to the 2016 Guidebook method, having previously been based on the 2013 edition.

Between the 2017 and 2018 UK inventory submission, PM_{10} and $PM_{2.5}$ emissions been revised up by 28 kilotonnes (19%) and 7 kilotonnes (7%), respectively, for the calendar year 2015. The top contributors to this change are:

- Revision to the emission factors to align with the 2016 Guidebook for various sources (fireworks, quarrying, construction), adding emissions from cigarettes and incorporation of updated data for steelworks and industrial paint use, offset by the removal of opencast coal extraction activity data (now included in NFR 1B) from the quarrying estimates, have led to emissions estimates for NRF code 2 being revised upwards by 24 kilotonnes PM_{10} (4 kilotonnes $PM_{2.5}$) for 2015.
- Emissions from the agriculture sector have increased due to revisions to the animals included within each category in the new model developed by Rothamsted, affecting all livestock categories. The new model also updated/harmonised the emission factors across the sector to be in line with the latest 2016 Guidebook. This has resulted in emissions estimates for NRF 3 being revised upwards by 2 kilotonnes PM_{10} (<1 kilotonnes $PM_{2.5}$) for 2015.
- Revisions to DUKES particularly for wood, plus changes related to harmonisation of GCV assumptions used to convert literature emission factors, have led to emissions estimates for 1A2 being revised upwards by 2 kilotonnes PM_{10} (2 kilotonnes $PM_{2.5}$) for 2015.
- Emissions from accidental fires have been re-allocated from NFR 6 to NFR 5.

8.7 Metals

Pb emissions have been revised up due to the inclusion of emissions from fireworks (in response to the recommendation from the 2016 CLRTAP Stage 3 Review) and to a lesser extent, the inclusion of additional E-PRTR data for emissions from Hexham chipboard plant. Between the 2017 and 2018 UK inventory submission, Pb emissions been revised up by 12 tonnes (18%), for the calendar year 2015.

Cd emissions have been revised up due to the inclusion of emissions from cigarette smoking (in response to the recommendation from the 2016 CLRTAP Stage 3 Review) and updated emissions data provided by Tata for 2015. Between the 2017 and 2018 UK inventory submission, Cd emissions have been revised up by 0.3 tonnes (7%), for the calendar year 2015.

Emission estimates for other metals are broadly similar in both the 2017 and 2018 UK inventory submissions. The estimates for the calendar year 2015 are higher in the 2018 submission for Hg (0.1 tonnes), As (0.4 tonnes), Cu (3.0 tonnes), Ni (6.9 tonnes) Se (0.1 tonnes) and Zn (14.7 tonnes). Whereas the estimates for the calendar year 2015 are lower in the 2018 submission for Cr (2.3 tonnes) due to the removal of emission estimates for a chemical process which was found to have closed in 2009.

8.8 POPs

Emissions of PCDD/PCDFs have been revised down by 8% (17.3 g-I-TEQ) for the calendar year 2015 between the 2017 and 2018 emissions inventory. The reduction is largely due to revisions to estimates for non-residential use of biomass fuels: downward revisions to activity data in the case of industrial use of waste wood fuels; addition of industrial use of other biomass as a new source; and, particularly, downward revisions to both the activity data and emission factor for agricultural sector use of straw-based fuels. There have been many other revisions to factors with defaults from the EMEP/EEA 2016 Guidebook being used for many stationary combustion sources. Guidebook defaults have also been adopted for many uses of fuel that were not previously included in the UK inventory for dioxins, including the use of natural gas, LPG, other petroleum gases and other light petroleum fractions like burning oil (kerosene). These new sources are mostly very trivial and so only offset some of the reduction in emissions from biomass use.

Emission estimates have also been revised for PAHs in 2015. These revisions are as follows; benzo[a]pyrene (+2.5%), benzo[b]fluoranthene (+1.3%), benzo[k]fluoranthene (+1.1%) and Indeno(1,2,3-cd) pyrene (+0.9%). These increases result mainly from the addition of emission estimates for many uses of fuel that were not previously included in the UK inventories for PAHs, including the use of natural gas, LPG, other petroleum gases and other light petroleum fractions like burning oil (kerosene). Emission factors for other fuels have been revised with older UK-specific (but very uncertain) factors being replaced for many fuels with factors taken from the EMEP/EEA 2016 Guidebook. In the earlier part of the time-series, there are very large increases in the UK totals, for example, the 1990 estimate for B[a]P is now about four times the value in the previous version of the inventory. This is because of the replacement of UK-specific factors for field burning with factors from the 2016 Guidebook. Since field burning was banned in 1993, this methodological revision only affects the UK totals for 1990-1993.

PCB emissions have been revised down by 2% for the calendar year 2015, largely due to the replacement of UK specific factors with defaults from the EMEP/EEA 2016 Guidebook for processes at steelworks (blast furnaces, sinter production, basic oxygen furnaces).

HCB emission estimates for the calendar year 2015 are broadly unchanged from the previous inventory version. Revisions to activity data – for chlorinated solvents, municipal solid waste, and aluminium consumption – result in more significant revisions in earlier years. The revisions to aluminium consumption data are particularly significant and cause emission totals for 1990-1998 to decrease by between 16% and 22% each year.

9 Projections

Projected emissions for the five pollutants for which emission reduction commitments apply under the revised NECD (2016/2284/EU) and the amended Gothenburg Protocol are compiled by the Inventory Agency to enable comparisons with international commitments. Emission projections are required under the CLRTAP every 4 years starting from 2015 while reporting of projections is required every 2 years starting from 2017 under the revised NECD. The dataset being provided in March 2018 is based on the latest version of the UK inventory (the 2016 NAEI), as submitted to the NECD and CLRTAP on 15th February 2018. The projections rely upon data from various sources, key among which are the 2017 version of the Updated Energy and Emissions Projections, issued by BEIS in January 2018[44] and data from Dft, including the latest (2015) road traffic projections and other forecasts. Further details of data and assumptions are given in section 9.1. The emission projections take account of measures in place as far as is possible, given the data available, but do not reflect measures under development for the Clean Air Strategy.

9.1 Data and input assumptions

The projections are based on the latest version of the UK inventory as submitted to the NECD and CLRTAP on 15th February 2018 (NECD submission and CLRTAP submission). Data from this inventory for the year 2016 are used as a baseline for the projections:

- activity data for 2016 are used to derive activity projections for 2020, 2025, and 2030 by applying suitable assumptions about the growth or decline in each activity;
- emission factors for 2016 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.

Most assumptions about changes in fuel consumption and industrial activity are based on the 'Energy & Emissions Projections' published by the Department for Business, Energy & Industrial Strategy (BEIS) in January 2018, hereafter referred to as EEP2017. A summary of the EEP2017 modelling is available from https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017. The EEP2017 data received are for the EEP2017 central reference scenario, and include the following for 2020, 2025 and 2030:

- a site-by-site forecast for coal use at coal-fired power stations;
- sectoral projections for use of each fuel type (coal, fuel oil, gas oil, gas, biomass) by other major industrial sub-sectors such as other power stations, refineries, 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 BEIS are used to generate our own estimates of activity data in 2020, 2025 & 2030 as required for the inventory forecasts for almost all NAEI stationary combustion source categories and for many industrial process-related source categories. Other Government projections, such as those for population, are used to forecast activity for non-combustion sources e.g. for use of domestic products such as cosmetics and toiletries which are sources of NMVOC emissions. For a handful of minor combustion source categories relating to use of fuels in narrowly-defined sectors (e.g. use of certain fuels at blast furnaces, dolomitic lime kilns, and collieries), we consider the use of the broad-sector BEIS forecasts less ideal, and so in these cases we will normally assume no change in fuel use or use other projections instead.

[44] https://www.gov.uk/government/collections/energy-and-emissions-projections

The BEIS energy projections will include the impact on fuel consumption of emission source regulation, including the EU Emissions Trading System and the Industrial Emissions Directive.

Details of assumptions and data that are specific for sub-sectors of the inventory are given below.

Road transport
Key input assumptions include:

- DfT's road traffic projections (2015) for Great Britain (GB) – no updated forecasts were available from DfT so this dataset is continued to be used in the current set of emission projections; however, the future vehicle-km have been recalculated by applying the same relative growth rates re-based to the 2016 NAEI. For Northern Ireland, traffic is assumed to follow the GB growth rates due to lack of suitable traffic projections data for Northern Ireland. For London, Transport for London (TfL) has provided updated traffic projections (Jan 2018).
- Updated future sales of cars (Feb 2018) provided by DfT – however, the assumptions on the petrol/diesel sales mix, uptake rates of hybrid and electric cars remain the same as those provided by DfT in January 2017. It assumes assumptions on OLEV policies in line with when it was updated so it includes the Office for Low Emission Vehicles (OLEV) Plug-in car grant, and existing EU new car CO_2 regulations up to 2022. It doesn't make specific assumptions about new car CO_2 assumptions beyond that point, nor take account of any of the changes in funding for electric vehicles announced in the 2016 Autumn Statement. No new updates were provided for light good vehicles (LGVs), so future sales of LGVs have been recalculated based on forecasts provided by The Society of Motor Manufacturers and Traders (SMMT) for 2017-2018[45] and the relative growth rates provided by DfT (Jan 2017) from 2020 onwards.
- Future fleet composition data for London provided by TfL (Jan 2018) – this assumes that the Ultra Low Emission Zone (ULEZ) in central London will be introduced in 2019, and that the TfL bus fleet will meet the ULEZ requirements London-wide in 2020 (which is committed regardless of the ULEZ expansion consultation outcome).
- COPERT 5 emission factors continue to be used with inclusion of 3 staged reduction in Euro 6 NO_x factors for diesel cars and LGVs.

Aviation
Projections are based on DfT's 2017 Baseline Central Growth forecasts[46].

Off-road
Machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from the EMEP Guidebook (2009). 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. The projections cover the stages of the Directive up to Stage IV. Emission factors for engines meeting Stage V limits to be introduced from 2019 have not yet been introduced in to the projections.

Activity data are derived from bottom-up estimates from population and hours of use of equipment in 2004. 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 2016 base year. For machinery used in industry, a BEIS sector-weighted energy projections driver for industry is used; for machinery used in construction the BEIS energy projections driver for 'construction' is used; for machinery used in quarrying the BEIS energy projections driver for 'Non-metallic mineral products' is used. For machinery used in agriculture, the activity driver is held constant at 2016 levels. For domestic house and garden machinery, a driver based on future trends in the number of households from the Ministry of Housing, Communities & Local Government is used. For machinery used in airports, projections in the number of terminal passengers at UK airports are used taken from DfT's aviation forecasts.

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[45] SMMT forecasts: UK new car and LCV registrations 2018 and 2019, downloaded on 7 Feb 2018 (https://www.smmt.co.uk/2018/02/uk-new-car-van-registrations-forecast-january-2018/)
[46] https://www.gov.uk/government/publications/uk-aviation-forecasts-2017

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 IV, no specific emission reduction policies and measures are taken into account for the off-road sector.

Inland waterways
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 2016. For future activities by inland waterways, the latest BEIS sector-weighted energy projections driver for industry is used, re-based to the latest 2016 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.

Rail
The activity projections for passenger and freight trains are based on BEIS EEP2017 energy projections for total gas oil used in the rail sector. These are consistent with forecasts in gas oil consumption for passenger and freight trains developed by DfT in the Rail Emissions Model. These are normalised to the EEP2017 energy projections to provide separate activity drivers for Intercity, regional passenger and freight trains in the emission projections. These are re-based to rail activities in the latest 2016 inventory year. According to DfT, the forecasts in gas oil consumption are based on the following assumptions:

- Future years are extrapolated from 2014/15 and 2018/19 model years using the Carbon Trajectory Model
- Forecasts include impact of electrification schemes as originally planned in HLOS2 for a 2019 completion date (many have now been delayed as far as 2024)
- No Carbon Budget 5 schemes are included such as battery trains or further electrification
- No further schemes are included other than general expected industry efficiencies

Assumptions are made on the gradual introduction of trains with engines meeting Stage IIIB emission limits in the fleet based on expert judgement. 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.

Shipping
The method for forecasting emissions from shipping is described in the forecasting section of the report on the new methodology for estimating emissions from shipping by Scarbrough et al. (2017).

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, 2016. 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. The relevant fuel sulphur requirements from MARPOL Annex VI and from Directive 1999/32/EC are taken into account. Within Sulphur Emission Control Areas, 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_2 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 III NO_x emission reduction requirements placed on engines in ships constructed from 2021. It is assumed that this will be partially achieved by switching to LNG which will also lead to further reductions in $PM_{2.5}$.

Agriculture
NH_3 emission projections for the agriculture sector are compiled by Rothamsted Research under a separate contract with Defra and feed into the NAEI. The combined ammonia and GHG inventory model for the agriculture sector (1990-2016) is used as the base model from which projections are made. Activity data projections (livestock numbers, crop production) to 2026 provided by FAPRI were used to derive ratio multipliers to the inventory model 2016 input data on livestock numbers, dairy milk yield, crop areas, crop production and fertiliser N use, for the years 2017 to 2026. Projections were flatlined from 2027 to 2030. Management practice data were kept constant at the 2016 values. Projected livestock numbers are used as a driver to derive NMVOCs and PM emission projections for agriculture sources.

Anaerobic digestion
Projected ammonia emissions from Anaerobic Digestion (AD) have been calculated based on data in DUKES for electricity generation from AD in 2013 – 2016, and with the assumption that the UK will meet the aspiration for electricity generation from this sector as set out in Defra's "Anaerobic Digestion Strategy and Action Plan" (2011). Projected increases in emissions from anaerobic digestion processes and spreading of AD residues are partially offset by reductions in emissions from spreading of agricultural manures where they have been diverted to AD. These offsets have been accounted for in the data provided.

Residential combustion
Projections of future fuel use by the residential sector are based on EEP2017. For residential use of gas, oil and wood, we assume that new appliances will replace old ones going forward and that these replacement appliances will have lower emission characteristics than those they replace. For gas and oil-fired boilers, we assume an age profile based on data for London (UK-wide data are not available), whereas for wood we assume that the strong growth in consumption will be fuel burnt in new appliances. Since the use of coal is forecast to dwindle significantly, we do not currently assume any change in appliances for that fuel.

We assume lower emission factors for gas and oil-fired boilers to reflect the Ecodesign Directive, using the limits set out in the regulation. For new biomass fuel appliances, we use EMEP/EEA Guidebook factors for ecolabelled appliances.

Non-residential stationary combustion, solvent use, and industrial processes
Projections of future fuel use by industry and other non-residential sectors are almost always based on EEP2017, and most of the non-fuel activity projections are also derived using EEP2017 data.

For most industrial sources, emissions of air quality pollutants have been regulated for several decades, however, while we have a lot of information on the historical annual emissions at many sites (via operator reporting to regulators and via them, the PRTR), we do not have access to information on the emission limit values (ELVs) and other conditions placed on individual operators that achieve those annual emissions. We also have very little information on the requirements that are being placed on those individual operators in order to ensure future compliance with regulations. Even where such information is available, it is difficult to quantify what this might mean for annual emissions, given the lack of information on, for example, the performance against current ELVs.

As a result, projections for stationary combustion and process sources often have to assume a somewhat 'worst-case' scenario where emission factors in future years are the same as in the 2016 base year. This is not a particularly significant issue for NH_3, where combustion and processes are trivial sources, or for SO_2 where changes in fuel use, included through the use of EEP2017 data, are likely to be far more significant than changes in emission factors. It could be a more significant issue for the remaining pollutants simply because stationary combustion and processes are significant sources. Emission projections might therefore be somewhat too high for these pollutants, although it is also possible that the impact is trivial. In some cases, we have been able to obtain information that allows a less conservative approach to be adopted. For example:

- The British Coatings Federation (BCF) has provided estimates for VOC emissions in 2020 from the use of decorative paints, industrial paints, and inks, which we have used as a basis for forecasts. The BCF do not envisage very dramatic changes in the period to 2020, and so the inclusion of more realistic projections for this sector do not result in a very significant change compared with a ‘worst-case’ scenario.

- Documents relating to permitted cement kilns and integrated steelworks have been obtained which provide some information on improvements required by the regulators, in order for these processes to comply with the relevant standards. The improvements relate to emissions of NO_X, SO_2, and particulate matter from cement kilns, but SO_2 only for integrated steelworks. We have estimated the impact on emission factors, which are expected to be significantly lower than would occur using the ‘worst-case’ approach used elsewhere, particularly for SO_2 and PM.

It should be noted that the assessment of the cement and steel sites also identified that many aspects of the current operation of those sites were already compliant with BAT requirements. This may be true for other sectors as well, which would mean that the use of 2016 emission factors for 2020 and 2030 would not be particularly conservative.

9.2 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 under development for the Clean Air Strategy.

The amended Gothenburg Protocol sets emission reduction commitments for NO_x (as NO_2), SO_x (as SO_2), NMVOCs, NH_3 and for $PM_{2.5}$ to be achieved in 2020 and beyond. The revised NECD sets emission reduction commitments for 2020 (in line with the amended Gothenburg Protocol commitments) as well as more stringent targets for 2030 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. The UK Government will publish its Clean Air Strategy later this year setting out how it will work towards its 2020 and 2030 ERCs. This will be followed by a National Air Pollution Control Programme by 1 April 2019, as required under the revised NECD.

Table 9-1 shows how the latest projections of emission totals compare with 2020 targets based on applying the NECD and Gothenburg emission reduction commitments to the current 2005 baseline. The progress made towards the 2020 targets has been shown in two ways. Firstly, the reduction achieved in emissions between the 2005 base year and 2016 has been shown as a percentage of the reduction required to meet the emission reduction commitment (see row ‘Progress to date towards 2020 reductions’). This shows that the reduction commitments for SOx (as SO2) and NMVOC emissions have already been met, and more than half of the required mass reduction has also been achieved for NOx (as NO2). Emissions of NH3 have increased slightly between 2005 and 2016, showing a negative progress to date towards the 2020 reductions. Secondly, the row ‘Emission reduction required from 2016’ shows the amount of reduction required from current (i.e. 2016) emissions to reach the 2020 commitment.

Similarly, Table 9-2 shows how the latest emission totals compare with 2030 targets based on applying the NECD emission reduction commitments to the current 2005 baseline.

Table 9-1 Comparison of UK 2016 national emissions, projected emission estimates for year 2020 and 2020 NECD / Gothenburg emission targets. Emission values have been rounded.

Pollutant	NH_3	NO_x (as NO_2) (include 3B and 3D)[b]	NO_x (as NO_2) (exclude 3B and 3D)[c]	SO_x (as SO_2)	NMVOC (include 3B and 3D)[b]	NMVOC (exclude 3B and 3D)[c]	$PM_{2.5}$
2005 National Total, kilotonnes	288.11	1721.57	1714.11	772.75	1166.95	1042.49	127.27
2016 National Total, kilotonnes	289.06	892.91	885.70	179.16	818.57	701.10	107.91
Emission reduction commitment	8%	NR[d]	55%	59%	NR	32%	30%
2020 target, kilotonnes[a]	265.06	NR	771.35	316.83	NR	708.90	89.09
Progress to date towards 2020 reductions	-4%	NR	88%	130%	NR	102%	51%
Emission reduction required from 2016, kilotonnes	24.01	NR	114.35	0.00	NR	0.00	18.82
Projected 2020 National Total, kilotonnes	298.17	NR	735.29	126.45	NR	685.86	103.55
Above or below 2020 targets by, kilotonnes	**33.11**	NR	-36.06	-190.38	NR	-23.04	**14.46**

Table 9-2 Comparison of UK 2016 national emissions, projected emission estimates for year 2030 and 2030 NECD emission targets. Emission values have been rounded.

Pollutant	NH_3	NO_x (as NO_2) (include 3B and 3D)[b]	NO_x (as NO_2) (exclude 3B and 3D)[c]	SO_x (as SO_2)	NMVOC (include 3B and 3D)[b]	NMVOC (exclude 3B and 3D)[c]	$PM_{2.5}$
2005 National Total, kilotonnes	288.11	1721.57	1714.11	772.75	1166.95	1042.49	127.27
2016 National Total, kilotonnes	289.06	892.91	885.70	179.16	818.57	701.10	107.91
Emission reduction commitment	16%	NR	73%	88%	NR	39%	46%
2030 target, kilotonnes[a]	242.01	NR	462.81	92.73	NR	635.92	68.72
Progress to date towards 2030 reductions	-2%	NR	66%	87%	NR	84%	33%
Emission reduction required from 2016, kilotonnes	47.06	NR	422.89	86.43	NR	65.18	39.19
Projected 2030 National Total, kilotonnes	295.84	NR	557.66	96.69	NR	719.26	99.42
Above or below 2030 targets by, kilotonnes	**53.83**	NR	**94.85**	**3.96**	NR	**83.34**	**30.70**

[a] The 2020 and 2030 emission targets have been calculated using the 2005 emissions of the current inventory submission as the base year.
[b] The NMVOCs and NO_x figures quoted in this column include emissions from 3B and 3D, which are the currently reported national totals for NO_x and NMVOCs consistent with the Defra national statistics (Table 1[47]) and the recent NECD/CLRTAP submissions in February 2018. This is to be in line with the reporting requirement for the current (2010) emission ceiling.
[c] Under the revised NECD, NMVOCs and NO_x emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020 (or 2030) emission reduction commitments.
[d] NR = not relevant

Based on these latest projections, the UK will need to take further action to meet its commitments. The UK Government is currently developing its comprehensive Clean Air Strategy, which will be published for consultation in 2018 and will set out how it will work towards its 2020 and 2030 emission reduction commitments. 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 under development for the Clean Air Strategy.

[47] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/681445/Emissions_of_air_pollutants_statistical_release_FINALv4.pdf

10 Adjustment

10.1 Adjustment mechanisms under the Gothenburg Protocol and NECD

The 1999 Gothenburg Protocol to the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the original EU National Emission Ceiling Directive (2001/81/EC) set upper limits on Parties/Member States' total annual emissions from 2010 onwards of sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and ammonia (NH_3). These 2010 emission ceilings were set based on the scientific understanding of emission sources in the late 1990s.

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/Member States 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). Therefore, under the 2012 amendment to the Gothenburg Protocol and the "revised NECD" (EU 2016/2284), a mechanism has been established that allows Parties/Member States 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.

As defined in the EMEP Executive Body Decisions 2012/3, 2012/12 and 2014/1, there are three extraordinary 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. Or
3) The methodologies used for determining emissions from specific source categories have undergone significant changes between the time when emission reduction commitments were set and the year they are to be attained.

For the 2018 inventory submission, the UK total emissions (as calculated using best current science) exceeds the 2010 ceilings for NO_x for the year 2010 only under both the Gothenburg Protocol and the NECD (see Table 10-1). The UK notified the UNECE Secretariat and the European Commission by 15 February 2018 of its intention to apply an adjustment to its NO_x emissions inventory as permitted under the Gothenburg Protocol and the NECD. The UK submitted an adjustment application for the following sector by the submission deadline of 15 March 2018:

- **NFR 1A3b road transport** – on the basis that successive Euro standards have not delivered the expected reduction in real world NO_x emissions from diesel vehicles and as a result, emission factors [for this source] have changed significantly since the ceilings were set. Road transport contributed to around 31% of total NOx emissions in 2010.

Table 10-1 shows the UK exceedance against its 2010 NO_x emission ceilings as set in the 1999 Gothenburg Protocol and the 2001 NECD for year 2010, and to what extent the adjustment to the emission inventory eliminates the exceedance and brings the UK into compliance. From year 2011 up to the latest inventory year (2016), the UK has met its 2010 emissions ceilings for NOx as set in both the Gothenburg Protocol and NECD without the need for an adjustment.

Table 10-1 Summary of the UK NO_x emissions inventory for year 2010 and the adjusted national emissions total for compliance

NO_x	2010 Gothenburg Protocol	2010 NECD
2010 Emission Ceiling (kt)	**1181**	**1167**
2010 UK National Total (kt)	**1223**	**1223**
Exceedances (kt)	**42**	**56**
Total Adjustment (kt)	**-102**	**-102**
1A3b	*-102*	*-102*
National Total for Compliance (kt)	**1121**	**1121**

The remaining sections of this chapter provide the rationales and supporting information for this adjustment application made for the road transport. Detailed adjustment calculations can be found at Annex VII (Excel file) for reporting on adjustments, by NFR, year and pollutant.

10.2 Adjustment for NOx from 1A3b Road Transport

The adjustment for NO_x from 1A3b road transport is consistent with the following extraordinary circumstances as defined in paragraph 6 of EMEP Executive Body Decision 2012/3:

- *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*

10.2.1 Justification

In accordance with Decision 2012/12, Annex, paragraph 2(ii)e, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- *The rationale for deciding whether the changes in emission factors are significant.*

There is now well-established evidence across Europe showing that the real-world NO_x emission performance of diesel vehicles has not delivered the reductions expected in accordance with the emission limits set in successive Euro Standard (e.g. Rexeis et al. 2013, Chen and Borken-Kleefeld 2014, Franco et al. 2014). The UK Department for Transport (DfT) has carried out its own vehicle testing programme and found large discrepancies between test cycle NO_x emissions and on-road emissions (DfT, 2016). For instance, on-road tests using portable emission measurements (PEMS) showed on-road NO_x emissions to be approximately 6 times higher than the type-approval limit for Euro 5 and Euro 6 cars (DfT, 2016).

The most common models used to estimate road transport emissions in the EU are COPERT and the Swiss-German Handbook of Emission Factors (HBEFA). The UK uses the emission factors developed in the COPERT model which have been revised over time to reflect new evidence of emission measurement from in-use vehicles. For example, NO_x emission factors of Euro 5 diesel passenger cars in these models are ~4.5 times higher than the emission limit value (0.18 g NO_x/km), close to 0.8 g NO_x/km for urban conditions (Ntziachristos et al., 2016). These show that the emission factors are significantly different compared with those used at the time when the ceilings were set, whereby emission reductions from vehicles were expected to follow reductions implied by the emission limit values set for successive Euro standards.

10.2.2 Description of the original emission factors used

In accordance with Decision 2012/12, Annex, paragraph 2(ii)a and 2(ii)b, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- *A description of the original emission factors (when the ceilings were set), including a detailed description of the scientific basis upon which the emission factor was derived*
- *Evidence that the original emission factors were used for determining the emission reductions at the time when they were set*

As referenced in the Technical Guidance for Parties Making Adjustment (ECE/EB.AIR/130), the RAINS model was used as a basis for setting the 2010 ceilings for the 1999 Gothenburg Protocol. Emission factors from COPERT II were used by RAINS to calculate road transport emissions. The COPERT version used by the UK for the purpose of adjustment calculation is COPERT III (Version 2.1, November 2000). COPERT III was also used by Spain and France for their already approved inventory adjustment applications for the road transport sector [48,49].

The development of COPERT III was financed by the European Environment Agency, in the framework of the activities of the European Topic Centre on Air Emissions. In comparison with COPERT II, COPERT III provides hot exhaust emission factors for Euro 1 petrol and diesel passenger cars and light duty vehicles.

For heavy-duty vehicles[50] and mopeds, COPERT III provides NO_x emission factors for Pre-Euro 1/I. For light-duty vehicles (LDVs) and motorcycles (2 strokes and 4 strokes), COPERT III covers emission factors up to Euro 1. COPERT III provides assumptions of emission reduction percentage for (then) the 'future' Euro standard (i.e. up to Euro 4 for LDVs and up to Euro V for HDVs).

One challenging aspect of quantifying the adjustment is determining the emission factors to include in the "original" calculation (in this case the COPERT III model) for vehicles that would only be introduced into the fleet in much later years i.e. vehicles manufactured to later Euro standards for which there was no information at that time or any understanding as to what reductions the later standards would require. For example, COPERT III did not include any information on Euro 5 light-duty vehicles, which appeared in the fleet for year 2010. This issue has been discussed by adjustment review experts, and it has been agreed that the best practice for handling this particular issue is to assume that all Euro 5 light-duty vehicles (and onwards) shall be assumed to be equivalent to Euro 4 vehicles in the original COPERT III calculations. This is therefore the approach that has been used in all of the calculations presented in this report.

10.2.3 Description of the updated emission factors used

In accordance with Decision 2012/12, Annex, paragraph 2(ii)c, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- *A description of the updated emission factors, including detailed information on the scientific basis upon which the emission factor was derived*

The road transport NO_x emission factors used in the current UK inventory are taken from the 2016 EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016), consistent with the speed-emission factor functions given in COPERT 4.11.4 and COPERT 5 (Emisia, 2016). Further details on the methodology used by the UK are provided at section 3.3.3 above. The scientific development of the COPERT model is overseen by the European Commission's Joint Research Centre (JRC) through the European Research Group on Mobile Emissions (ERMES) activity. ERMES aims to coordinate research (and measurement programmes) for the improvement of transport emission inventories in Europe and provides a clearinghouse for data and modelling tools. Its aim is to provide harmonised data for all EU transport emission models including the Swiss-German Handbook of Emission Factors (HBEFA) and

[48] Review of the 2015 Adjustment Application by Spain: http://webdab1.umweltbundesamt.at/download/adjustments2015/Spain2015-adj.pdf?cgiproxy_skip=1
[49] Review of the 2015 Adjustment Application by France: http://webdab1.umweltbundesamt.at/download/adjustments2015/France2015-adj.pdf?cgiproxy_skip=1
[50] Heavy-duty vehicles include rigid, articulated heavy good vehicles, buses and coaches.

COPERT. These sources provide emission factors for all Euro standards up to Euro 5 (light duty vehicles) and Euro V (heavy duty vehicles) based on the best available evidence on real-world emissions.

10.2.4 Comparison between the original and updated emission factors

In accordance with Decision 2012/12, Annex, paragraph 2(ii)d, a Party's supporting documentation for an adjustment to its emission inventory shall include:

- *A comparison of emission estimates made using the original and the updated emission factors, demonstrating that the change in emission factors contributes to a Party being unable to meet its reduction commitments*

Figure 10-1 and Figure 10-2 provide a comparison of the original (COPERT III) and the current emissions factors (COPERT 5) for diesel passenger cars and heavy-duty vehicles, respectively. The factors shown represent the current fleet and traffic conditions in the UK. These vehicle types have the biggest changes in emission factors (e.g. the emission factor for Euro III HDV is now twice as high as the original emission factor). Comparison of all vehicle types (1A3bi to 1A3biv) can be found in Table 2 of the Annex VII (Excel file) for reporting on adjustments, by NFR, year and pollutant. These changes in emission factors contribute to the reported UK exceedance of the 2010 NOx ceiling set in the Gothenburg Protocol and the NECD in the year 2010. .

Figure 10-1 Average NO_X emission factor (g/km) for diesel passenger cars.

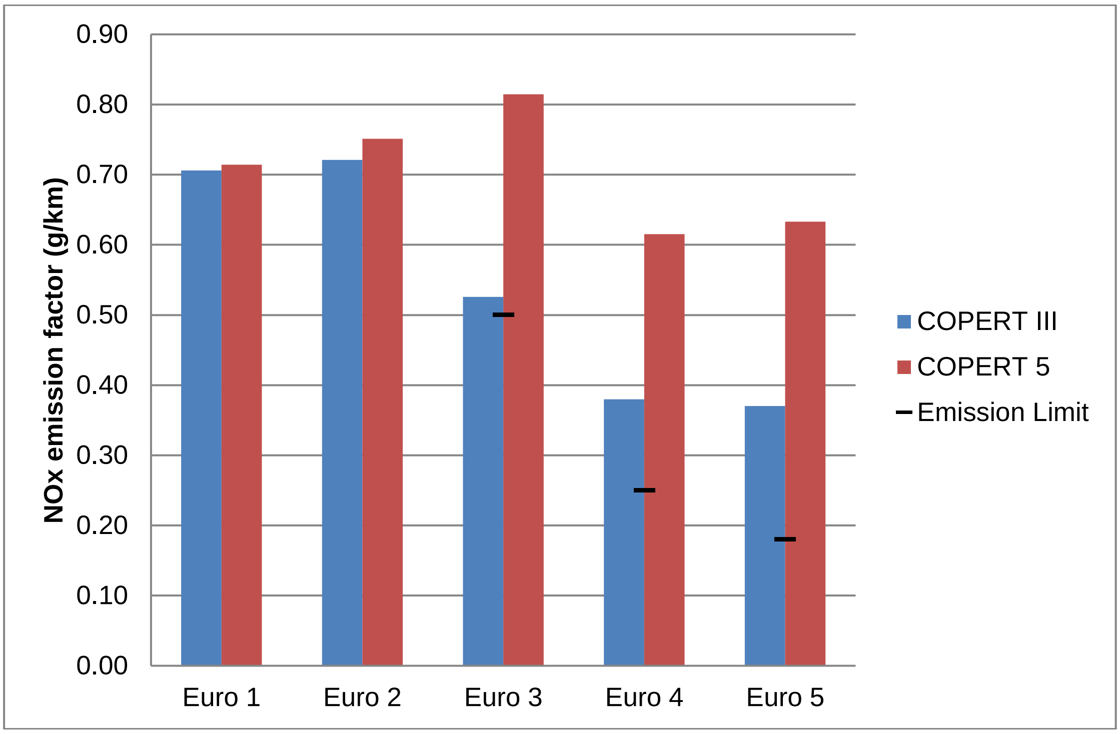
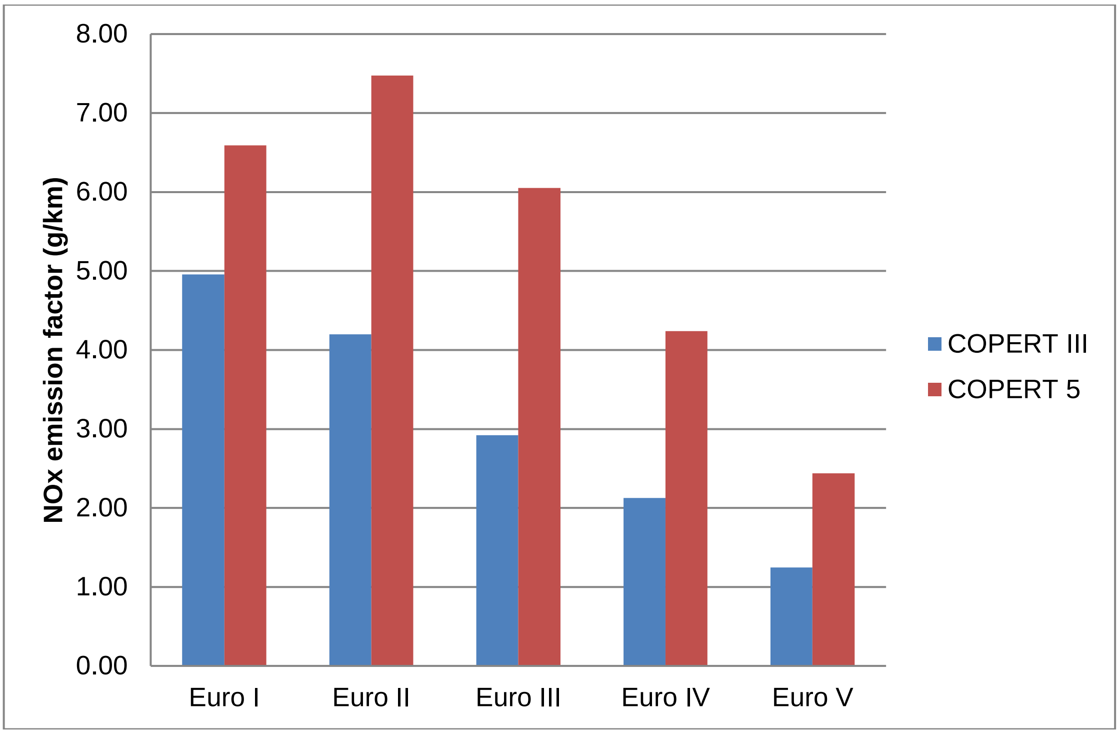


Figure 10-2 Average NO_X emission factor (g/km) for heavy-duty vehicles.



10.2.5 Quantifying the adjustment

In accordance with the Technical Guidance for Parties Making Adjustment (ECE/EB.AIR/130), for the adjustment applications related to changes in emission factors, the following principle is used for quantifying the adjustments:

$$A_Y = AD_{Y\ Current} \times (EF_{Original} - EF_{current})$$

Where:
A_Y is the value for the adjustment for inventory year Y
$EF_{Current}$ is the current emission factor used
$EF_{Original}$ is the original emission factor used when the ceilings were set
$AD_{Y\ Current}$ is the current activity data for inventory year Y.

Fuel Used vs Fuel Sold

The UK inventory for road transport emissions of key air pollutants as submitted to the NECD and CLRTAP for tracking compliance with the UK's emissions ceilings is based on fuel consumption derived from kilometres driven rather than fuel sales. Paragraph 23 of the revised Guidelines on Reporting (ECE/EB.AIR/125) and references under the revised NECD (2016/2284/EU) allow the UK to report emissions on the basis of fuel used or kilometres driven. Thus, the quantification of the adjustment amount for the road transport sector is also on the basis of fuel used.

The proposed adjustment for the road transport sector (1A3bi-iv) is **102.21 kt**. Detailed breakdown of the adjustment by NFR can be found in Table 10-2 below (or in Table 2 of the Annex VII (Excel file) for reporting on adjustments, by NFR, year and pollutant).

Table 10-2 Quantification of NO_x adjustments for the UK road transport sector (1A3bi-iv)

Title	NFR Code	Year	Current Activity data (bvkm)	Original EF (g/km) COPERT III	Current[51] EF (g/km) COPERT 5	Difference in %	Emissions (kt) based on COPERT III	Adjusted emissions (kt) based on COPERT 5	Adjustment (kt)[52]
Passenger cars_Diesel_Pre-Euro 1	1A3bi	2010	0.15	0.70	0.70	0%	0.10	0.10	0.00
Passenger cars_Diesel_Euro 1	1A3bi	2010	1.85	0.71	0.71	1%	1.31	1.32	-0.02
Passenger cars_Diesel_Euro 2	1A3bi	2010	7.32	0.72	0.75	4%	5.28	5.50	-0.22
Passenger cars_Diesel_Euro 3	1A3bi	2010	43.12	0.53	0.81	55%	22.68	35.11	-12.43
Passenger cars_Diesel_Euro 4	1A3bi	2010	86.11	0.38	0.62	62%	32.71	52.98	-20.27
Passenger cars_Diesel_Euro 5	1A3bi	2010	13.94	0.37	0.63	71%	5.17	8.83	-3.66
Passenger cars_Petrol_Pre-Euro 1	1A3bi	2010	1.89	2.53	2.53	0%	4.78	4.78	0.00
Passenger cars_Petrol_Euro 1	1A3bi	2010	6.73	1.65	1.38	-16%	11.09	9.30	1.79
Passenger cars_Petrol_Euro 2	1A3bi	2010	34.54	0.71	0.83	16%	24.65	28.59	-3.94
Passenger cars_Petrol_Euro 3	1A3bi	2010	85.26	0.16	0.12	-28%	13.79	9.89	3.90
Passenger cars_Petrol_Euro 4	1A3bi	2010	109.21	0.12	0.07	-38%	13.15	8.14	5.01
Passenger cars_Petrol_Euro 5	1A3bi	2010	12.55	0.11	0.04	-64%	1.38	0.50	0.88
Light good vehicles_Diesel_Pre-Euro 1	1A3bii	2010	0.36	1.60	1.60	0%	0.57	0.57	0.00
Light good vehicles_Diesel_Euro 1	1A3bii	2010	0.85	1.25	1.25	0%	1.07	1.07	0.00
Light good vehicles_Diesel_Euro 2	1A3bii	2010	6.12	1.27	1.27	0%	7.77	7.77	0.00
Light good vehicles_Diesel_Euro 3	1A3bii	2010	17.01	1.04	1.04	0%	17.70	17.70	0.00
Light good vehicles_Diesel_Euro 4	1A3bii	2010	39.14	0.83	0.83	0%	32.59	32.59	0.00
Light good vehicles_Diesel_Euro 5	1A3bii	2010	0.16	0.36	0.62	69%	0.06	0.10	-0.04
Light good vehicles_Petrol_Pre-Euro 1	1A3bii	2010	0.15	3.14	3.14	0%	0.46	0.46	0.00
Light good vehicles_Petrol_Euro 1	1A3bii	2010	0.20	1.57	1.57	0%	0.31	0.31	0.00
Light good vehicles_Petrol_Euro 2	1A3bii	2010	0.78	0.88	0.88	0%	0.69	0.69	0.00
Light good vehicles_Petrol_Euro 3	1A3bii	2010	1.31	0.16	0.16	0%	0.21	0.21	0.00
Light good vehicles_Petrol_Euro 4	1A3bii	2010	1.07	0.09	0.09	0%	0.10	0.10	0.00
Light good vehicles_Petrol_Euro 5	1A3bii	2010	0.00	0.12	0.04	-66%	0.00	0.00	0.00

[51] Or referred to as “Adjusted EF” in Table 2 of the Annex VII (Excel file) for reporting on adjustments, by NFR, year and pollutant
[52] Negative adjustment values represent downward revisions of the “current” emission estimates, and vice versa.

Title	NFR Code	Year	Current Activity data (bvkm)	Original EF (g/km) COPERT III	Current[51] EF (g/km) COPERT 5	Difference in %	Emissions (kt) based on COPERT III	Adjusted emissions (kt) based on COPERT 5	Adjustment (kt)[52]
Heavy duty vehicles_Diesel_Euro I	1A3biii	2010	0.26	4.96	6.59	33%	1.27	1.69	-0.42
Heavy duty vehicles_Diesel_Euro II	1A3biii	2010	2.51	4.20	7.48	78%	10.56	18.80	-8.24
Heavy duty vehicles_Diesel_Euro III	1A3biii	2010	11.17	2.92	6.05	107%	32.62	67.61	-34.98
Heavy duty vehicles_Diesel_Euro IV	1A3biii	2010	8.33	2.13	4.24	100%	17.71	35.35	-17.63
Heavy duty vehicles_Diesel_Euro V	1A3biii	2010	10.05	1.24	2.44	96%	12.50	24.52	-12.01
Mopeds & motorcycles_Petrol Pre-Euro 1	1A3biv	2010	0.93	0.22	0.31	38%	0.21	0.29	-0.08
Mopeds & motorcycles_Petrol Euro 1	1A3biv	2010	1.31	0.26	0.32	22%	0.34	0.42	-0.08
Mopeds & motorcycles_Petrol Euro 2	1A3biv	2010	0.63	0.27	0.23	-15%	0.17	0.15	0.02
Mopeds & motorcycles_Petrol Euro 3	1A3biv	2010	1.84	0.26	0.15	-43%	0.48	0.28	0.21

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Appendix 1- NECD Recommendations

The UK has prioritised its effort to implement the recommendations of the 2017 Comprehensive Technical Review of the UK's National Emission Inventories that might have an impact on the emission estimates as far as possible in the 2018 submission. Recommendations that have been addressed are shaded in grey in Table A-1. The remaining recommendations are mainly related to transparency and will be implemented in future submissions when resources are available.

Table A-1 Status of Implementation of NECD Recommendations.

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
GB-1A1-2017-0001	No	1A1 Energy Industries, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2000-2015	For category 1A1 Energy Industries the TERT noted that detailed emission factors are available in the link: http://naei.defra.gov.uk/data_warehouse.php" but the emission factors described are unavailable for the year 2015. In response to a question raised during the review, the United Kingdom explained that the United Kingdom is in the process of updating the NAEI website with the 1990-2015 data. The TERT acknowledged the explanation provided by the United Kingdom. In order to improve the transparency of the IIR, the TERT recommends the United Kingdom to provide an updated database simultaneously with the submission of the IIR in future submissions.	no	Not feasible to achieve – the NAEI website is scheduled to update during April to May period due to resourcing reason.	Not relevant
GB-1A1-2017-0002	No	1A2 Stationary combustion in manufacturing industries and construction, NH_3, NMVOC, $PM_{2.5}$, 2000-2015	For category 1A2 Stationary Combustion in Manufacturing Industries and Construction and pollutants NMVOC, $PM_{2.5}$ and NH_3 for the entire time series the TERT noted in the IIR a lack of transparency on the version of the EMEP/EEA Guidebook used. In response to a question raised during the review, the United Kingdom explained that in all cases the 2016 EMEP/EEA Guidebook has been used. The TERT agreed with the explanation provided by the United Kingdom. The TERT	no	Yes	3.2

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			recommends that in its next submission for the category 1A2 and pollutants NMVOC, $PM_{2.5}$ and NH_3, the United Kingdom states the version of the Guidebook used (2016) more clearly.			
GB-1A1-2017-0003	No	1A1 Energy Industries & 1A2 Stationary combustion in manufacturing industries and construction, NH_3, 2000-2015	For categories 1A1b, 1A1c and 1A2a to 1A2e and pollutant NH_3 for the entire time series the TERT noted that in terms of completeness the NFR tables indicate the notation key 'NA' whereas the 2016 EMEP/EEA Guidebook mentions 'NE'. For category 1A1b Petroleum Refining and pollutant NH_3, in response to a question raised during the review, the United Kingdom explained that emissions of ammonia from refineries are reported in category 1B2aiv Fugitive Emissions Oil: Refining / Storage, with these estimates being based on total site emissions as reported by site operators to the regulators. These site emissions will include combustion-related as well as fugitive and process-related emissions but because the United Kingdom has no split, the United Kingdom proposes to change the notation key to IE in future submissions. The TERT agreed with the explanation provided by the United Kingdom. The TERT recommends that the United Kingdom states in the IIR that ammonia from refineries are taken into account in the category 1B2aiv and not in category 1A1b and explains the reason. The TERT also recommends that the United Kingdom indicates in the NFR tables 'IE' instead of 'NA' and adds in the IIR in the appropriate section this notation key used (probably in the section "Assessment of completeness"). For category 1A1c Manufacture of Solid Fuels and Other Energy Industries and pollutant NH_3, in response to a question raised during the review, the United Kingdom explained that	no	Yes	1.8

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			emissions from coke ovens are reported in 1B1b Fugitive Emission from Solid Fuels: Solid Fuel Transformation, since these are based on total site emissions as reported by site operators to the regulators. These site emissions will include combustion-related as well as fugitive and process-related emissions, but because the United Kingdom has no split, the United Kingdom reports as a single category in 1B1b. The United Kingdom does not estimate NH_3 emissions for oil and gas production and distribution since the operators does not report any emissions of NH_3 and the 2016 EMEP/EEA Guidebook does not suggest any default factors for the gaseous and liquid fuels burnt at these sites. The United Kingdom proposes to change the notation key to 'IE' in future. The TERT agreed with the explanation provided by the United Kingdom. The TERT recommends, that the United Kingdom states in the IIR that ammonia emissions from coke ovens are taken into account in category 1B1b and not in category 1A1c and explains the reason. The TERT also recommends, that the United Kingdom indicates in the NFR tables 'IE' instead of 'NA' and adds in the IIR in the appropriate section this notation key used (probably in the section "Assessment of completeness"). For category 1A2a to 1A2e and pollutant NH_3, in response to a question raised during the review, the United Kingdom explained that the United Kingdom does not have emissions reported by operators, and no other reliable data specific to the United Kingdom are available. Since there are no default emission factors in the 2016 EMEP/EEA Guidebook for the coal, oil or gas used in these source categories, the United Kingdom does not estimate emissions for			

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			these fuels in the inventory. The United Kingdom could perhaps change the notation key to 'NE' in the future. The TERT agreed with the explanation provided by the United Kingdom. The TERT recommends that the United Kingdom indicates in the NFR tables 'NE' instead of 'NA' for ammonia emissions and for categories 1A2a to 1A2e. The TERT recommends also that the United Kingdom adds in the IIR in the appropriate section this notation key used (probably in the section "Assessment of completeness").			
GB-1A1a-2017-0001	No	1A1a Public electricity and heat production, SO_2, NO_X, $PM_{2.5}$, 2000-2015	For the Energy sector (including waste incineration with energy recovery), the TERT noted that these sectors are estimating NECD emissions using annual emissions reported by operators on the basis of stack measurements. When continuous measurements are used to estimate annual emissions, there is a risk that operators have misinterpreted the IED (Industrial Emissions Directive) and have used validated average values (after having subtracted the value of the confidence interval) although this subtraction must not be applied in the context of reporting annual emissions. In response to a question raised during the review, the United Kingdom stated it believes that the emissions data used will not include any subtraction. In the opinion of the TERT, bottom-up data based on the "validated average values" defined in the IED cannot be used by the inventory team without adjustment in the framework of a national inventory. The TERT notes that this issue could relate to an underestimate for the energy sector, which could correspond to 20% of SO_2, 20% of NO_X, 30% of dust of the sector (depending on the fraction of the operators subtracting confidence interval). The TERT recommends the United	no	Yes. Protocols for operator reporting to UK regulators does not allow any subtraction of confidence intervals, unless the operator has been given written permission from the regulator to do so. The UK regulators have not identified any sites where this permission has been given and so we are confident that UK estimates are complete, with no under-reports.	

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			Kingdom to organise a survey among operators to identify which ones are reporting emissions on the basis of the validated average values and try to derive a methodology to adjust the national emissions over the time series in order to compensate the fact that national emissions are estimated on the basis of data reported by operators using validated average values.			
GB-1A1b-2017-0001	No	1A1b Petroleum refining, SO_2, 2000-2015	For category 1A1b Petroleum Refining and pollutant SO2 for the entire time series the TERT noted that in the spreadsheet "1A1-factors" joined with the question GB-1A1-2017-0001, no SO2 EF is available for natural gas whereas natural gas consumption is available. In response to a question raised during the review, the United Kingdom explained that the SO2 emissions in the inventory for 1A1b are based on the emissions data provided by refinery operators for each site. These data are not broken down by process or fuel and so the emissions are split between refinery fuels by the Inventory Agency. Currently the United Kingdom does not allocate any of the SO2 to natural gas. The TERT notes that this issue doesn't relate to an over- or under-estimate. For category 1A1b if emissions data from industry are based on data measured and not on data estimated with an emission factor, then the TERT recommends that the United Kingdom allocates emissions based on fuel specific emission allocation.	no	Yes	
GB-1A2-2017-0001	Yes	1A2 Stationary Combustion in Manufacturing Industries and Constructio	For categories 1A2 Stationary Combustion in Manufacturing Industries and Construction and 1A4 Small Combustion and pollutant SO_2 for the entire time series the TERT noted that in the spreadsheet "1A2-factors" joined with the question GB-1A2-2017-0001, no SO_2 EF is available for	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
		n, SO_2, NO_X, $PM_{2.5}$, 2000-2015	natural gas and liquefied petroleum gas whereas in the NFR tables, gaseous fuel consumption is available. The TERT noted that the issue is below the threshold of significance for a technical correction. For natural gas, in response to a question raised during the review, the United Kingdom explained that the assumption is that there is no SO_2 in natural gas used in 1A2. This assumption is based on evidence provided by gas suppliers based on the average composition of the gas over that 2004-2015 period. The data provided makes no mention of any sulphur compounds, and so the Inventory Agency has concluded that natural gas in the United Kingdom contains negligible amounts of sulphur so that any emissions would be too trivial to warrant further investigation and/or analyses. The TERT recommends that the United Kingdom indicates clearly in its IIR in the next submission that the SO_2 EF for natural gas is equal to 0 and adds the reference of natural gas composition. For LPG, in response to a question raised during the review, the United Kingdom explained that the United Kingdom doesn't have similar data for LPG but has assumed that sulphur is similarly negligible in that fuel. The TERT recommends that the United Kingdom, either realises some analysis on LPG to determine the SO_2 EF, or uses the value suggested for gaseous fuels in the 2016 EMEP/EEA guidebook.			
GB-1A2gvii-2017-0001	No	1A2gvii Mobile Combustion in manufacturing industries and	For category 1A2gvii Mobile Combustion in Manufacturing Industries and Construction: Other, along with other categories including non-road mobile sources, the TERT noted that activity data for biomass are reported as 'not applicable'. In response to a	no	Yes	(See Annex I submission on Excel file[53])

[53] http://cdr.eionet.europa.eu/gb/eu/nec_revised/inventories/envwnwqzg/

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
		construction: (please specify in the IIR), SO_2, NO_X, NH_3, $PM_{2.5}$, 1990-2015	question raised during the review, the United Kingdom explained that the total consumption of these fuels is reported under category 1A3b Road Transport, further proposing to use the notation key 'IE' ('included elsewhere') for the relevant NFR categories. The TERT agreed with the answer provided, recommending the United Kingdom to revise the notation keys applied in the next submission.			
GB-1A3-2017-0001	Yes	1A3 Transport: Fuel Used - Memo Item, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2005, 2010, 2015	For 1A3b fuel used vs fuel sold/All pollutants/years 2005, 2010, 2015 the TERT noted that the United Kingdom report emissions on a fuel used basis in rows 27-33 (road transport) and row 141 (national total). In response to a question raised during the review, the United Kingdom provided emission estimates on a fuel sold basis. After further discussion, the United Kingdom confirmed that these data could be used for a revised estimate (noting that with one exception all of these figures are below the threshold of significance, and that the United Kingdom retain the right to use emissions on a fuel used basis for compliance purposes). The TERT recommends that the United Kingdom include a revised estimate in its next submission.	RE	Yes	(See Annex I submission on Excel file)
GB-1A3aii(i)-2017-0001	No	1A3aii(i) Domestic aviation LTO (civil), NH_3, 1990-2015	For category 1A3aii(i) Domestic Aviation LTO (Civil) together with 1A3ai(i) International Aviation LTO (civil) and NH_3, the TERT noted that emissions are reported as 'not applicable' ('NA'), further noting that in the 2016 EMEP/EEA Guidebook the notation key 'NE' ('not estimated') is proposed for ammonia emissions from the consumption of aviation gasoline. In response to a question raised during the review, the United Kingdom confirmed that aviation	no	Yes	(See Annex I submission on Excel file)

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			gasoline is used in the United Kingdom. The TERT acknowledged the answer provided, recommending revising the notation key to 'not estimated' ('NE').			
GB-1A3b-2017-0001	No	1A3b Road Transport, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2005, 2010, 2015	For categories 1A3bi-iv, biomass, for all years, the TERT noted that in NFR tables column AI (biomass activity data) the biomass activity data are summed in 1A3bii Road transport: Light Duty Vehicles. In response to a question raised during the review, the United Kingdom explained that all biofuels used for road transport in the United Kingdom are as weak <10% blends, so it would be assumed that their consumption between vehicle categories and NFR codes is pro-rata to the distribution for gasoline and diesel fuels between vehicle categories. The TERT agreed with the explanation provided by the United Kingdom. The TERT recommends the United Kingdom to split biomass activity data by NFR (road transport) categories in the next submission, in order to be able to check biomass blends.	no	Yes – notation key 'IE' is used for 1A3bi, 1A3biii and 1A3biv	(See Annex I submission Excel file)
GB-1A3b-2017-0002	No	1A3b Road transport, $PM_{2.5}$, 2005, 2010, 2015	For category 1A3bi-iv and pollutant $PM_{2.5}$ for years 2005, 2010 and 2015 the TERT noted that in NFR tables, cells I27 to J30 that the ratio between PM_{10} and $PM_{2.5}$ is higher than 1. In response to a question raised during the review, the United Kingdom explained that the value of 1.05 that is used was based on an older assessment. However, now that the United Kingdom has adopted the COPERT 4 factors for PM exhaust emissions, the United Kingdom agreed it should use this ratio of 1 and assume all PM is in the $PM_{2.5}$ range in future submissions. The TERT agreed with the explanation provided by United Kingdom. The United Kingdom also explained that $PM_{2.5}$ was calculated as	no	Yes	3.3.3

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			$PM_{2.5}$=PM_{10}*0.95 so the $PM_{2.5}$ emissions are too low by 5%. The TERT calculated the impact and noted that the issue is below the threshold of significance for technical corrections. The TERT recommends that the United Kingdom reports the revised estimates in its next submission.			
GB-1A3b-2017-0003	No	1A3b Road Transport, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2005, 2010, 2015	For category 1A3bi-iv Road Transport and lubricants for all years, the TERT noted that there is a lack of transparency regarding the lubricant consumption calculation (2- and 4-stroke engines) and the associated reporting. In NFR tables, column AK and line 27 and 30, it seems that only non-energy use of lubricants (i.e. 4-stroke engines) is reported. The 2-stroke engines lubricant consumption has to be reported in 1A3b Road Transport (in general associated with 2 wheels) but 4-stroke engines lubricant consumption has to be reported in 2D3 Other Solvent and Product Use / 2G Other Product Use. In response to a question raised during the review, the United Kingdom explained that this is an allocation issue and not an under- or over-estimation of emissions. The emissions from lubricant consumption by 2-stroke engines are included in 1A3biv Road Transport: Mopeds & Motorcycles. The emissions of lubricant consumption by all 4-stroke engines are included in 1A3b categories rather than 2D3. The United Kingdom further responded that in their view, the measured emission factors, which form the basis of the exhaust EFs in COPERT and the Guidebook, include the contribution of lubricants, i.e. it is the combined effect of both fuel and lubricants that is measured. The United Kingdom indicated that they would make it clear in the IIR in the future that emissions from the lubricant combustion for 2-	no	Yes	3.3.3.4

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			stroke and 4-stroke vehicles are included in the 1A3bi-iv sources. The TERT recommends that the United Kingdom includes the explanations of the allocation issue in its next submission.			
GB-1A3bv-2017-0001	Yes	1A3bv Road transport: Gasoline evaporation, NMVOC, 2005, 2010, 2015	For category 1A3bv Road Transport: Gasoline Evaporation and NMVOC for all years, the TERT noted that in the IIR, page 153, it is stated that the United Kingdom is using the 2007 EMEP/CORINAIR Guidebook for calculating NMVOC emissions from evaporation. The 2013 and 2016 EMEP/EEA Guidebook provide new emission factors. In response to a question raised during the review, the United Kingdom explained that it will be included in the next submission. The TERT noted that the issue is below the threshold of significance for technical corrections. The TERT recommends that the United Kingdom improves the methodology by implementing the 2016 EMEP/EEA Guidebook in its next submission.	no	Yes	
GB-1A3bvi-2017-0001	No	1A3bvi Road transport: Automobile tyre and brake wear, $PM_{2.5}$, 2005, 2010, 2015	For category 1A3bvi Road transport: Automobile Tyre and Brake Wear for years 2005, 2010, 2015 the TERT noted that in NFR tables the reported unit of the traffic is wrong. In the IIR table 3-16 p 138, the traffic is around 500 billion veh.km, but in the NFR tables the unit is 10^6 (i.e million) veh.km. In response to a question raised during the review, the United Kingdom explained that the vehicle-km/traffic data provided in the NFR tables are in billion vehicle-km. This does not affect the emissions. The United Kingdom provided a file with revised activity data and stated that it will be corrected in the next submission. The TERT agreed with the explanation and revised activity data provided by the United Kingdom. The TERT recommends	no	Yes	(See Annex I Submission Excel file)

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			that the United Kingdom corrects the activity data in its next submission.			
GB-1A3bvii-2017-0001	No	1A3bvii Road Transport: Automobile Road Abrasion, $PM_{2.5}$, 2005, 2010, 2015	For category 1A3bvii Road transport: Automobile Road Abrasion for years 2005, 2010, 2015 the TERT noted that in NFR tables row 33, the reported unit of the traffic is wrong. In the IIR table 3-16 p 138, the traffic is around 500 billion veh.km, but in the NFR tables the unit is 10^6 (i.e million) veh.km. In response to a question raised during the review, United Kingdom explained that the vehicle-km/traffic data provided in the NFR tables are in billion vehicle-km. This does not affect the emissions. The United Kingdom provided a file with revised activity data and stated that it will be corrected in the next submission. The TERT agreed with the explanation and revised activity data provided by the United Kingdom. The TERT recommends that the United Kingdom corrects the activity data in its next submission.	no	Yes	(See Annex I Submission Excel file)
GB-1A3c-2017-0001	No	1A3c Railways, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2015	For category 1A3c Railways the TERT noted a significant drop in the fuel consumption reported for 2015. In response to a question raised during the review and in addition to the information already provided in the IIR, the United Kingdom explained that whereas the fuel consumption from passenger trains has only decreased marginally, the amount of freight moved has decreased significantly, by about 20 per cent. The TERT agreed with the additional explanation provided, recommending that the United Kingdom includes this additional information in the next submission.	no	Fuel consumption for freight in 2015 revised in this submission following new data from ORR not previously available. Shows fuel consumption did not decrease as much as amount of freight moved had declined	3.3.4
GB-1A3ei-2017-0001	No	1A3ei Pipeline transport, SO_2, NO_X,	For category 1A3ei Pipeline Transport, the TERT noted that activity data and emissions are reported as 'included elsewhere'	no	Yes – for simplicity, this is explained in Table 3-8 rather than providing a separate chapter	Table 3-8

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
		NH_3, NMVOC, $PM_{2.5}$, 1990-2015	('IE') in category 1A1c Manufacture of Solid Fuels and Other Energy Industries with no separate chapter on NFR category 1A3ei provided in the IIR explaining this allocation. In response to a question raised during the review, the United Kingdom explained that a separation of the fuel used in compressors is not possible based on the information from the official energy statistics. The TERT agreed with the answer provided, and recommends that the United Kingdom provide this explanatory information in a separate chapter for category 1A3ei in the IIR.			
GB-1A4ai-2017-0001	No	1A4ai Commercial/institutional: Stationary, NMVOC, $PM_{2.5}$, 2000-2015	For category 1A4a Commercial/institutional Combustion and 1A4b Residential Combustion and NECD pollutants for the entire time series, the TERT noted a lack of transparency in the IIR on the references used (mixture of EMEP/EEA, US EPA, IPCC and country-specific factors for other pollutants and for minor fuels). In response to a question raised during the review, the United Kingdom explained that in all cases where EMEP/EEA Guidebook factors are used, these are consistent with the 2016 version. To ensure transparency, the TERT recommends that the United Kingdom states more clearly in its next submission for these sectors the exact reference used depending on the type of fuel.	no	Further references are added	3.4
GB-1A4ai-2017-0002	No	1A4ai Commercial/institutional: Stationary, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2000-2015	For category 1A4ai Commercial/Institutional: Stationary and the entire time series the TERT noted that in the NFR tables, for fuels consumption, it is indicated 'IE' for biomass. In response to a question raised during the review, the United Kingdom explained that the official energy statistics only include data for overall usage of waste wood and other biomass by non-residential 'final users' and it is	no	Yes	1.8.2

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			possible that as well as industrial users, these final users could include some in the commercial and public sectors. Because the United Kingdom only has the total use of fuel, the United Kingdom reports emissions in a single category – 1A2gviii Stationary Combustion in Manufacturing Industries and Construction: Other – but the fuel is also likely to be used in other sectors of 1A2 Stationary Combustion in Manufacturing Industries and Construction and also in 1A4ai as well. Currently, the United Kingdom has no data that would allow them to make a reliable split of fuel use between the various sub-categories of 1A2 and 1A4ai, although the United Kingdom suspects that most of the fuel is used in industrial plants. The TERT notes that the issue does not relate to an over- or under-estimate. The TERT recommends that the United Kingdom adds this explanation in the next submission.			
GB-1A4aii-2017-0001	No	1A4aii Commercial/institutional: Mobile, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 1990-2015	For category 1A4aii Commercial/Institutional: Mobile, the TERT noted that activity data and emissions reported as 'included elsewhere' ('IE') in category 1A4ai Commercial/institutional: Stationary. In response to a question raised during the review, the United Kingdom explained that instead, all data are currently reported in category 1A2gvii Mobile Combustion in Manufacturing Industries and Construction: Other as further disaggregation is not possible at the moment. The United Kingdom further confirmed that the information provided in IIR Table 1-21 is not correct in relation to 1A4aii and will be corrected for the next IIR submission. The TERT welcomed the answer provided by the United Kingdom. However, as the chapter on non-road mobile	no	Yes	1.8.2

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			sources and machinery of the 2016 EMEP/EEA Guidebook provides proxy data for the distribution of fuels consumed by non-road mobile machinery on the different NFR categories, the TERT recommends checking the implementation of these proxy data.			
GB-1A4ciii-2017-0001	No	1A4ciii Agriculture/Forestry/Fishing: National fishing, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2008-2010	For category 1A4ciii Agriculture/Forestry/Fishing: National Fishing and the years 2008 and 2010, the TERT noted rather high activity data. In response to a question raised during the review, the United Kingdom explained that the main cause is the peak in fishing activities by vessels outside the territorial waters of the United Kingdom in these years according to fish landing statistics provided by the Marine Management Organisation (MMO). The TERT agreed with the answer provided by the United Kingdom and recommends that the United Kingdom provides such explanatory information in a separate IIR chapter for category 1A4ciii.	no	Activity data have been revised in the 2018 submission - please review the updated methodology	3.3.5
GB-1A5a-2017-0001	No	1A5a Other stationary (including military), SO_2, NO_X, NH_3, NMVOC, 2000-2015	For category 1A5a Other Stationary (Including Military) and NECD pollutants for the entire time series the TERT noted that the NFR tables indicate the notation key ‘IE’. In response to a question raised during the review, the United Kingdom explained that emissions from 1A5a (stationary combustion for military purposes) is not reported separately in the energy statistics and are included under 1A4ai (Commercial/institutional: Stationary). The United Kingdom will also amend the description in the IIR. In terms of transparency, the TERT recommends that the United Kingdom adds this description in the next submission of its IIR. The TERT further	no	Yes	1.8

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			recommends that the United Kingdom check with the energy statistics team to see whether it is possible to separate out the stationary fuel use for military purposes in the future.			
GB-1B1a-2017-0001	No	1B1a Fugitive Emission from Solid Fuels: Coal Mining and Handling, $PM_{2.5}$, 1990-2015	For category 1B1a Fugitive Emission from Solid Fuels: Coal Mining and Handling and $PM_{2.5}$ the TERT noted that the 'NA' notation key had been reported. In response to a question raised during the review, the United Kingdom acknowledged that the notation key should be 'IE' as emissions from open-cast mining had been included within the NFR category 2A5a Quarrying and Mining of Minerals Other Than Coal. The United Kingdom explained that, even so, particulate emissions from deep mining, where production had decreased since the early 1990s, had not been estimated. The United Kingdom stated that a fraction of the mine ventilation had been recovered and used in the last ten years, and those emissions have been estimated and reported under NFR 1A1c Manufacture of Solid Fuels and Other Energy Industries and 1A2gvii Mobile Combustion in Manufacturing Industries and Construction: Other. The United Kingdom assessed that the effect on the overall PM_{10} emissions would be lower than 0.1% for 2015 using the 2016 EMEP/EEA Guidebook Tier 1 emission factor (which refers to open-cast mining). The TERT partly agreed with the explanation provided by the United Kingdom. The TERT noted that the issue would be below the threshold of significance for a technical correction. The TERT recommends that the United Kingdom includes an overall estimate for this NFR category to the extent possible, including the emissions from the storage and handling of coal imported, or, if	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			not, include the appropriate notation key in the NFR and a detailed explanation in the IIR.			
GB-1B-2017-0001	Yes	1B Fugitive emission from fuels, SO_2, NO_X, NMVOC, 1990-2015	For category 1B2c Venting and Flaring (Oil, Gas, Combined Oil and Gas) and pollutants NMVOC, NO_X and SO_X the TERT noted that the contribution of the United Kingdom to the overall EU28 NMVOC emissions from this source category was significantly higher than its production share; on the contrary, its contributions to NO_X or SO_X emissions were less important or even marginal. In response to a question raised during the review, the United Kingdom provided the guidelines used for operators for estimating the emissions which the estimation of the inventory was based on. The United Kingdom identified the main point sources emitting NMVOC from flaring or from venting and stated the accuracy of its estimations as it was essentially a Tier 3 methodology. The TERT agreed with the explanation provided by the United Kingdom even though no validation could be done as the United Kingdom did not provide data. The TERT recommends that the United Kingdom enhances the transparency in the IIR including as far as possible proxies, variables, implied emissions factors and explanation of trends.	no		
GB-1B2ai-2017-0001	No	1B2ai Fugitive emissions oil: Exploration, production, transport, SO_2, NO_X, 1990-2015	For category 1B2ai Fugitive Emissions Oil: Exploration, Production, Transport and pollutant NO_X and SO_X the TERT noted that the emissions time series showed very high fluctuations not explained by changes in the activity rates. In response to a question raised during the review, the United Kingdom pointed out that the oil and gas exploration and production sector are based on emissions data provided by	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			process operators at facility and source level. The United Kingdom explained that most of the fluctuations for NO_X are due to the non-routine 'direct process emissions' reported by the operator of two platforms and to the changes in the level of well testing activity. For SO_X, the United Kingdom identified the emissions from direct process sources reported in some years, including a mine regeneration process. The United Kingdom pointed out that 'direct process' might be flaring of acid gas and sour gas and proposed to reallocate these to category 1B2c Venting and Flaring (Oil, Gas, Combined Oil and Gas). The TERT agreed with the explanation. The TERT recommends that the United Kingdom includes in the IIR information regarding the most relevant factors influencing the trend and for the dips and jumps in the time series.			
GB-2A1-2017-0001	No	2A1 Cement production, $PM_{2.5}$, 1990-2015	For category 2A1 Cement Production and $PM_{2.5}$, the TERT noted that the time series showed that the annual emissions reported are the same for all the years covered. In response to a question raised during the review, the United Kingdom pointed out that 2A1 comprises emissions from the manufacture of cementitious materials from blast furnace slag, whilst those from Portland cement had been allocated within NFR 1A2f Stationary Combustion in Manufacturing Industries and Construction: Non-metallic Minerals. The United Kingdom explained that evolution of emissions from slag grinding sites reflected the evolution of overall plant capacities (number of plants). The TERT noted that the issue is below the threshold of significance for a technical correction. The TERT recommends that the United Kingdom enhances the transparency in the IIR,	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			including a detailed description of emission sources, activity data and emission factors in the next submission.			
GB-2A6-2017-0001	Yes	2A6 Other mineral products (please specify in the IIR), SO_2, NMVOC, $PM_{2.5}$, 1990-2015	For category 2A6 Other Mineral Products and SO_X, NMVOC and $PM_{2.5}$ the TERT noted a lack of transparency in the IIR on the mapping of the NAEI Source Categories to the NFR category 2A Mineral Industry regarding the emission sources covered (NAEI coal tar and bitumen processes) and the allocation of NAEI categories (NAEI bitumen use) within multiple NFR categories. In response to a question raised during the review, the United Kingdom explained that emissions reported in 2A6 due to bitumen use excluded NMVOC and PM emissions from roadstone coating and NMVOC emissions from road construction. The United Kingdom stated that these latter emissions were reported under the category NFR 2D3 Solvent Use. The TERT notes that this issue does not relate to an over- or under-estimate. The TERT recommends that the United Kingdom enhances the transparency of the IIR regarding the emission sources covered within these NFR categories.	no		
GB-2B1-2017-0001	No	2B1 Ammonia production, NO_X, NH_3, NMVOC, 2005-2015	For 2B1 Ammonia Production for NO_X, NH_3 and NMVOC the TERT noted that in response to a question raised during the review the United Kingdom explained that no process emissions were reported under category 2B1 separately. The reason for this was that the United Kingdom has no data for chemicals production in the public domain and based its inventory for chemicals on site-specific emission data provided by individual companies that provide only totals of pollutant emissions to the regulator and these totals are reported under 2B10a Storage,	no	Yes. The IIR text has been revised to give further information on the estimates for chemical processes. Notation key 'IE' is used for 2B1 and 2B2 for the relevant pollutants	1.8.2; 4.6

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			Handling and Transport of Chemical Products. These totals could also include sources like combustion, which are already included in 1A2c Stationary Combustion in Manufacturing Industries and Construction: Chemicals, and therefore the United Kingdom states that its methodology is conservative and it is likely that there is an overestimate of emissions. The United Kingdom also explained that it reports separate emission estimates for a very small number of individual chemicals (such as NO_X from nitric acid production), where data specific to individual processes could be obtained from operators. The TERT noted that activity data on 2B1 and 2B2 Nitric Acid Production are reported in CRF tables. The TERT noted that the issue is below the threshold of significance for a technical correction. The TERT recommends that the United Kingdom investigates to report emissions from categories 2B1 and 2B2 separately in its next submission in order to assure comparability and transparency and in order to avoid over-estimation and that the United Kingdom reports on the results of this investigation in its IIR. If this is not possible, the TERT recommends that the United Kingdom includes a clear explanation of the emission estimates in its IIR and uses the proper notation keys for 2B1 and 2B2 in its NFR table, i.e. 'IE' for the emissions of pollutants that are included in 2B10a Storage, Handling and Transport of Chemical Products, and a reference to this category in the column 'notes' of the NFR table.			
GB-2B6-2017-0001	No	2B6 Titanium dioxide production,	For NO_X and SO_2 emissions from 2B6 Titanium Dioxide Production the TERT noted that in response to questions raised during the review the United Kingdom explained that	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
		SO_2, NO_X, 2005-2015	emissions are derived from site-specific emissions data provided by each operator to the regulators and that there are no data for chemicals production in the public domain. The United Kingdom also explained that the fact that NO_X and SO_2 emissions are not reported separately for this category while emissions from PM are reported separately, reflects the assumption that in the case of particles, one can assume that all or nearly all of the reported emissions derive from the titanium dioxide process. Whereas in the case of NO_X, the sites involved have very large combustion plant (boilers, CHP) and perhaps other types of furnaces, as well as the titanium dioxide process. For SO_2 the situation is also complicated by the presence of sulphuric acid manufacture at some of the sites. The United Kingdom explained that rather than trying to arbitrarily split emissions between the source categories the United Kingdom reports all emissions in a single category (1A2c for NO_X, 2B10a for SO_2) and that re-allocation would add complexity to the inventory compilation process without changing national totals and with probably only trivial changes at NFR category level. The United Kingdom also explained that the activity data reported in the NFR (a constant of 200 kt for the time series) are not the actual production, but an estimate of the production capacity in 1991, which is the closest estimate to actual production. The United Kingdom further explained that the figure has not been updated to reflect closure of some sites, or changes in capacity since 1991 at the sites that remain in operation, since the United Kingdom does not have any data relating to this. The TERT noted that the issue is below the threshold of significance for a			

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			technical correction. The TERT recommends that the United Kingdom includes this explanation in its next inventory to increase transparency in its inventory.			
GB-2B7-2017-0001	No	2B7 Soda ash production, NH_3, 2005-2015	For NH_3 emissions from 2B7 Soda Ash Production for 2005-2015, the TERT noted that in response to questions raised during the review the United Kingdom explained that emissions from NH_3 are not reported separately in this category but all in 2B10a Storage, Handling and Transport of Chemical Products. This reflects longstanding practice in the United Kingdom emission inventory where NH_3 emissions from the soda ash production sites are reported with all other chemical processes. The TERT noted that, emissions are provided separately for $PM_{2.5}$, PM_{10} and TSP for 2B7. The TERT recommends that, since emissions could be split for $PM_{2.5}$, PM_{10} and TSP, the United Kingdom also includes a separate estimate of NH_3 emissions from soda ash production in its next inventory.	no	Yes. NH_3 emissions from sites with soda ash production have been re-allocated from 2B10a to 2B7	4.6
GB-2D-2017-0001	Yes	2D Non-energy products from fuels and solvent uses, NMVOC, 2000-2015	For category 2D Non-energy Products from Fuels and Solvent Uses and pollutant NMVOC for all years, the TERT noted that the United Kingdom's solvent sector data are largely based on the activity data and EF estimates that are gathered in some cases 10 years ago. This means that NMVOC emissions are calculated on data that is extrapolated from increasingly old activity data where uncertainty is becoming larger every year and therefore may not present the actual situation. The TERT notes that this issue has been raised previously under the UNECE review process. In response to a question raised during the review, the United Kingdom explained that no data are readily available and any improvements depend on cooperation with industry and/or	no		

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			trade associations. The United Kingdom provided a brief update on the most recent interactions. The TERT acknowledges that any improvements will require cooperation, but notes that this sector is very important for the total emissions of NMVOC and as such should be prioritised. The TERT therefore recommends the United Kingdom to continue and strengthen the work on updating key data for the solvents inventory.			
GB-2D3a-2017-0001	Yes	2D3a Domestic solvent use including fungicides, NMVOC, 2005, 2010, 2015	For category 2D3a Domestic Solvent Use Including Fungicides and NMVOC for all years, the TERT noted that the NMVOC emissions reported were higher than the activity data reported, which is usually impossible. In response to a question raised during the review, the United Kingdom explained that there is an error in the activity data reported in the NFR, but that emissions are calculated and reported correctly. The TERT agreed with the explanation provided by the United Kingdom. The TERT recommends that the United Kingdom corrects the activity data reported in the NFR in its next submission.	no	Yes	(See Annex I submission Excel file)
GB-3B1a-2017-0001	No	3B Manure management - $PM_{2.5}$, 2000-2015	For category 3B1a Manure Management - Dairy Cattle and $PM_{2.5}$ for years 1990-2015, the TERT noted that the IEF was high given that dairy calves are also included in this category in the NFR and that cattle are grazing more than half of the year. In response to a question raised during the review, the United Kingdom explained that the default EF for Dairy cattle was also used for dairy calves. In addition, the TERT noted that the total number of cattle had been used as AD, instead of the proportion of housed animals (in line with the 2016 EMEP/EEA Guidebook) and suspected this could have been the case in the estimates for other animal	RE	Yes	5

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			categories. The TERT asked for revised estimates, AD and EF used for all animal categories. The United Kingdom provided final estimates for the category 3B, but it did not include AD, EF or emissions split by animal category. The TERT agreed with the revised estimate. The TERT recommends that the United Kingdom includes revised estimates in its next submission in line with the 2016 EMEP/EEA Guidebook, and inform in the IIR of AD (livestock numbers) and EF by animal category used in the estimates.			
GB-3B1a-2017-0002	Yes	3B1a Manure management - Dairy cattle, NH_3, NMVOC, 1990-2015	For category 3B1a Manure Management - Dairy Cattle the TERT notes that the numbers reported include dairy replacements, calves and heifers. The TERT notes this was already highlighted in the last CLRTAP review and that the United Kingdom is aware that activity data for 3B1a Manure Management - Dairy Cattle should only include dairy cows. In response to a question raised during the review week, the United Kingdom acknowledged the issue and indicated that the reporting will be changed in the next submission. The TERT recommends that activity data reporting is modified in the next submission.	no	Yes	5
GB-3B-2017-0001	No	3B Manure management, NO_X, 1990-2015	For category 3B Manure Management and pollutant NO_X for years 1990-2015 the TERT noted that emissions are not reported. In response to a question raised during the review, the United Kingdom indicated that these estimates will be included in the next submission. The TERT recommends that the 2016 EMEP/EEA Guidebook methodology is used to estimate and report these emissions in the next submission.	no	Yes	5
GB-3B-2017-0002	Yes	3B Manure manageme	For category 3B1a Manure Management - Dairy Cattle and	no	This should be implemented based on the use of the same,	5

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
		nt, NH_3, NMVOC, 1990-2015	pollutants NH_3 and NO_X for years 1990-2015, the TERT noted a potential inconsistency between values reported in the IIR and the NIR. In response to a question raised during the review, the United Kingdom explained that N excretion rates for all cattle types are currently being revised, calculated according to diet and production characteristics, and revised values will be used consistently across the GHG and AQ inventories in the 2018 submission. The TERT recommends that the same N excretion rates are used for GHG and air pollutants estimates in its next submission. For category 3B2 Manure Management - Sheep and pollutants NH_3 and NO_X for years 1990-2015 the TERT noted a potential inconsistency between values reported in the IIR and the NIR. In response to a question raised during the review, the United Kingdom explained that values in the NIR are annual N excretion while in the IIR the total N excretion is presented for the 8 months that the lambs are estimated to be alive in any year. The TERT recommends that N excretion values and other parameters are presented in a consistent manner in the next submission of IIR and NIR.		new agriculture model (for AQ and GHGs).	
GB-3B-2017-0003	Yes	3B Manure management, NH_3, 1990-2015	For category 3B Manure Management and categories related (3Da2a Animal Manure Applied to Soils and 3Da3 Urine and Dung Deposited by Grazing Animals), the TERT noted a lack of transparency in the reporting. In response to a question raised during the review, the United Kingdom sent information about abatement techniques and references and indicated that the reporting will be made consistent between the IIR and NIR/CRF. The TERT recommends that the United Kingdom enhances the	no	Yes – see above and a reference is provided	5

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			transparency of its next submission by including the most relevant parameters/factors that affect the estimates: such as consistent livestock numbers, N excretion rates and use of MMS, and a detailed justification of any reduction in emissions (EFs) caused by mitigation measures/national policies. All country specific EFs should also be documented including references and all assumptions should be accompanied by a clear justification of the applicability.			
GB-3D-2017-0001	No	3D Crop production and agricultural soils, NO_X, 1990-2015	For category 3D Crop Production and Agricultural Soils and NO_X for years 1990-2015, the TERT noted that emissions are not reported. In response to a question raised during the review, the United Kingdom indicated that these estimates will be included in the next submission. The TERT recommends that the 2016 EMEP/EEA Guidebook methodology is used to estimate and report emissions under sub-categories in 3D Crop Production and Agricultural Soils in the next submission.	no	Yes	5.4
GB-3Da1-2017-0001	No	3Da1 Inorganic N-fertilizers (includes also urea application), NH_3, 1990-2015	For category 3Da1 Inorganic N-fertilizers (Includes also Urea Application) and NH_3 for years 1990-2015, the TERT noted that the United Kingdom uses a Tier 3 methodology for these estimates and that there is a lack of transparency regarding the AD and EF used. In response to a question raised during the review, the United Kingdom indicated that the “Other” category in Table 5-7 includes fertiliser compounds and blends containing N, but not urea-based and it is assumed to have the same EF as ammonium nitrate. The TERT recommends that the United Kingdom presents in its IIR further information on the methodology applied, including the assumptions, justifications and	no	There is no longer an “other” category in Table 5-7	5

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			methodology used to derive the "modifiers" included in the IIR as well as the amount of N to which the modifiers apply.			
GB-3Da2b-2017-0001	No	3Da2b Sewage sludge applied to soils, NO_X, NH_3, 1990-2015	For category 3Da2b Sewage Sludge Applied to Soils and pollutants NH_3 and NO_X for years 1990-2015, the TERT noted that NH_3 is reported as 'IE'. In response to a question raised during the review, the United Kingdom explained that NH_3 emissions from sewage sludge applied to land are reported under NFR category 5D1 Domestic Wastewater Handling. Regarding NO_X, the TERT noted that emissions are reported as 'NA'. The TERT recommends that the 2016 EMEP/EEA Guidebook methodology is applied for the estimation and reporting of NH_3 and NO_X emissions from 3Da2b Sewage Sludge Applied to Soils in the next submission.	no	Yes	5.5
GB-3Da2c-2017-0001	No	3Da2c Other organic fertilisers applied to soils (including compost), NO_X, NH_3, 1990-2015	For category 3Da2c Other Organic Fertilisers Applied to Soils (Including Compost) and pollutants NH_3 and NO_X for years 1990-2015, the TERT noted that there may be an under-estimate. In response to a question raised during the review, the United Kingdom explained that on the one hand, the emissions from land spreading of non-animal-manure digestate is currently reported under 5E Other Waste. On the other hand, a small percentage of livestock manure is processed through Anaerobic Digestion and the digestate is subsequently applied to soils. This proportion of manure is not included in the estimates of emissions from digestate applied to land under 5E (Other waste) as it is already included as manure applied to land under Agriculture. However, a footnote in the IIR states: "Manure sources are assumed to be mostly included in the agricultural inventory already in terms of land spreading	no	Yes. Emissions from spreading of non-manure digestates to land are now reported under 3Da2c, as recommended. At this stage, emissions from manure digestates are not differentiated from emissions from manure spreading and are reported under 3Da2a. It is intended to report emissions from manure (3Da2a) and manure digestate (3Da2c) separately in the next submission.	5.6

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			emissions, and were omitted here, to avoid potential double-counting." The TERT disagreed with the explanation provided by the United Kingdom, since it is not clear whether these estimates are reported or not. The TERT notes that the issue is below the threshold of significance for a technical correction. The TERT recommends that the United Kingdom follows the 2016 EMEP/EEA Guidebook to estimate and report NH_3 and NO_X emissions from 3Da2c Other Organic Fertilisers Applied to Soils (Including Compost) and includes further information on the method, activity data used and the completeness of the reporting in the next submission.			
GB-3De-2017-0001	No	3De Cultivated crops, NMVOC, 1990-2015	For category 3De Cultivated Crops and NMVOC for years 1990-2015, the TERT noted that emissions are reported as 'NA'. In response to questions raised during the review, the United Kingdom indicated that emissions would be estimated in the next submission. The TERT recommends that the United Kingdom estimates and reports these emissions in the next submission.	no	Yes	5
GB-3F-2017-0001	No	3F Field burning of agricultural residues, SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$, 2005-2015	For category 3F Field Burning of Agricultural Residues and pollutants SO_2, NO_X, NH_3, NMVOC, $PM_{2.5}$ for years 1994-2015, the TERT noted that emissions are reported as 'NO'. In response to a question raised during the review, the United Kingdom explained that legislation within the EU has largely outlawed the practice of field burning agricultural wastes, but that the burning of linseed residues is exempted from the ban. However, any emissions will be extremely small and hence it may be considered that 'relevant emissions are considered never to occur'. Nonetheless, the United Kingdom did not provide	no	Yes – notation key NE is used post 1993	(See Annex I submission Excel file)

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			estimates. The TERT agreed with the explanation provided by the United Kingdom. However, the TERT recommends that emissions are estimated and reported in the next submission using Tier 1, if activity data are available; or emissions are reported as 'NE' if activity data are not available and further explanations (e.g. those sent to the TERT during the review week) are included in the next IIR.			
GB-5D-2017-0001	No	5D Wastewater handling, NMVOC, 2005, 2010, 2015	For 5D Wastewater Handling, pollutant NMVOC, years 2005, 2010, 2015 the TERT noted that the United Kingdom reported 'NA'. In response to a question raised during the review, the United Kingdom provided a first estimate showing that the emissions were far below the threshold of significance. The TERT recommends that the United Kingdom includes an emission estimate in its next submission.	no	Yes	6
GB-5E-2017-0001	No	5E Other Waste (please specify in IIR), SO_2, NO_x, NMVOC, $PM_{2.5}$, 2005, 2010, 2015	For 5E Other Waste, pollutant $PM_{2.5}$, years 2005, 2010, 2015 the TERT noted that the United Kingdom does not report emissions from that sector from car and building fires. In response to a question raised during the review, the United Kingdom explained that these emissions are reported in sector 6A Other Sources. The TERT notes that this issue does not relate to an over- or under-estimate and recommends that the United Kingdom reports these emissions in 5E in the next submission.	no	Yes	6
GB-6A-2017-0001	No	6A Other Sources, SO_2, NO_x, NH_3, NMVOC, $PM_{2.5}$, 2005-2015	For category 6A Other Sources and all pollutants for all years, the TERT noted that the description in the IIR is very short and does not contain any substantial information on the methodologies, activity data and emission factors used. Also, the TERT noted that emissions from accidental fires were allocated to this category rather than in category 5E Other	no	Yes	7

Observation	Key Category	NFR, Pollutant(s), Year(s)	Recommendation	RE or TC	Implemented	Section in IIR covered in
			Waste as per the 2016 EMEP/EEA Guidebook. In response to a question raised during the review, the United Kingdom provided detailed information on the methodology and data applied for accidental fires and also stated its intention to reallocate the emissions from accidental fires in the next submission. The TERT recommends that the United Kingdom reallocates emissions from accidental fires to category 5E in the next submission and includes a description of the methodology, activity data and emission factors along with their references in the IIR. Furthermore, the TERT recommends that the United Kingdom for the other activities included under category 6A (Bonfire night, infant emissions from nappies, domestic pets, non-agriculture livestock - horse wastes, professional horse wastes, park and garden fertiliser application) includes a description of the methodology used, the activity data with references, and the emission factors used with references.			