NO_X & PM_{10} EMISSIONS FROM INDUSTRIAL-SCALE COMBUSTION IN THE UK

NAEI Methodology Report

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1. FOREWORD

The work described in this report was done in 2020, and the methodology proposed was then used in the NAEI for the first time in NAEI19, published in February 2021. Where the text in this report refers to current/latest data, this relates to NAEI18, published in February 2020. Since February 2021, the methodology has been further developed and these developments are described in the final section of the report, added in 2024. The revised method was used starting with the NAEI22, published in February 2024.

2. EXECUTIVE SUMMARY

The version of the NAEI published in February 2020 (NAEI18) uses EMEP/EEA Emission Inventory Guidebook Tier 1 emission factors to estimate emissions of NO_X and PM_{10} from industrial-scale combustion plant used within the energy, industry, commercial, agricultural and public sectors. This means that the NAEI cannot reflect all of the impacts of regulation, and also does not provide policymakers with the level of detail they need.

Therefore, we have developed a new method that:

- Separates large and larger-medium sized plant from other installations within each sector;
- Uses appropriate NO_X and PM_{10} factors for the different size and sector categories.

In our view, this new approach fulfils the requirements for a Tier 2 method for a key emission inventory category, and so represents an improvement on the existing NAEI method. It also provides more detail in the NAEI, for example allowing large combustion plant (LCPs) in industry to be separately reported by the NAEI for the first time. Further development would be needed before the NAEI could provide separate emission estimates for medium combustion plant (MCPs) as defined in Directive 2015/2193, but this method represents an important first step towards that objective. The proposed method also allows combustion by economic sectors including glassmaking and brickmaking to be separately estimated in the NAEI for the first time.

The new method, like the existing NAEI18 method, relies upon the EMEP/EEA Guidebook for emission factors. However, operator-reported emission estimates are used too, for both LCPs and for some MCPs. This means that the proposed method would reflect the impact of regulation for these sites; something the current NAEI approach does not.

Overall emissions estimated using the new method are summarised below and are broadly similar to those using the existing NAEI18 model, particularly for NO_X. While the PM_{10} emissions estimates are also broadly similar, the new method does indicate a different trend between 2005 and 2018, with emissions increasing by 18% with the new method compared with 51% with the existing method. This would have an impact on UK progress towards emission reduction targets which are measured as a percentage reduction from 2005.

	2005 emission / ktonnes	2018 emission / ktonnes	% change between 2005 & 2018
NO_X:			
Proposed method	127.3	85.6	-33%
Current method	132.5	85.0	-36%
PM_{10}:			
Proposed method	11.5	13.6	+18%
Current method	10.4	15.6	+51%

We recommend adoption of the new method as it is a higher tier approach than used currently in the NAEI for several activities including key categories and therefore provides an improvement in uncertainty. The new method provides more detail of stationary combustion activities than can be provided by the current method.

The new method is suitable for use in the forthcoming version (the 2021 submission) and if used in that version, could subsequently be updated on an annual basis using any new EU ETS-type data, as well as by periodically revisiting the analysis of LCP data.

This study has highlighted areas where data is uncertain in existing LCP datasets and in allocation of fuel use to economic sectors in national energy statistics. The study also identifies where the new method could be further improved. The approach could be extended to other pollutants if there was a need to move to a higher tier. More UK-specific data could be collected and would allow the selection of Guidebook emission factors to be refined or for those factors to be replaced with UK-specific factors that accurately reflect the UK situation. Permitting of MCPs and specified generators will increase in future and this represents an opportunity to improve both the detail and the accuracy of the proposed method.

The methodology described in Section 4 of this report was introduced into the NAEI for the 2021 submission. For the 2024 submission, the methodology was transposed into an R based model, and extended to also cover NMVOCs, CO, PM2.5, Black Carbon, and a range of POPs/PAHs. Some of the emission factors selected for use within the methodology were also revised for combustion of biomass. Details of these are presented in Section 8.

3. INTRODUCTION

The NAEI currently uses EMEP/EEA Emission Inventory Guidebook Tier 1 emission factors to estimate emissions from industrial-scale combustion plant used within the energy, industry, commercial, agricultural and public sectors (reported in 1A1c, 1A2, 1A4a, and 1A4c). This means that emissions for all sizes and types of these combustion installation are estimated using the same emission factor for all historic and projected years (from 1970 until 2030). The Tier 1 method cannot take any account of changes in abatement due to regulation, or changes in technology over the 1970-2030 period. This simple method has been used due to a lack of data to allow different types of combustion plant to be separated out.

The NAEI uses UK energy statistics taken from the Digest of UK Energy Statistics (DUKES), and these differentiate fuel use by economic sector only. The statistics provide no split of fuel use by size or type of combustion plant, nor any division by regulatory regime, so there are no separate figures for large combustion plant (LCP), medium combustion plant (MCP) etc. As a result, the NAEI also only includes differentiation into economic sectors and no detail on different types of regulated plant.

The current NAEI is structured according to international reporting requirements which stipulate this division by very broad economic sector. This is less helpful for policy makers, who may need to understand emissions within specific industries, as well as understanding both the impact of existing measures to reduce emissions (e.g. for LCPs) but also the potential for further reductions (e.g. for MCPs).

To meet the requirements of policy makers, we need to revise the NAEI in two ways:

1. To change the NAEI structure: by separating out different sizes/types of combustion installation, so that estimates can be made for different types of regulated plant e.g. LCPs, MCPs, and regulated furnaces, driers and similar plant, as well as providing finer detail on industry sector where possible.
2. To change the NAEI methodology: to derive UK-specific emission factors that take account of historical control measures, such as LCPD & IED, and also future control measures, such as those for existing MCPs.

The changes to the NAEI need to be such that they can be implemented over both the historical (1990-2018) and projected (2020-2030) parts of the inventory, as well as continuing to meet international reporting requirements. This report describes an initial phase of work to split out those larger types of plant that can much more easily be disaggregated, and to replace the current method of estimating emissions for those plant with methods that reflect the technologies and emission controls in place.

The proposed method was further developed for the NAEI22 and details of these improvements are given in Section 8.

4. METHODOLOGY

4.1 GENERAL APPROACH

As mentioned previously, a lack of detail in UK energy statistics has hitherto been a barrier to separating out different types of combustion plant in the NAEI. Therefore, we have considered what other datasets are available that would allow at least some differentiation. We have identified two datasets that provide fuel consumption data for individual installations:

- Fuel use data reported by operators of LCPs, which are regulated under Chapter III of the Industrial Emissions Directive (IED);
- Fuel use reported for installations covered by the EU ETS (these will include LCPs, larger MCPs, and other large combustion plant such as offshore combustion plant, kilns, furnaces, driers etc).

The LCP dataset[1] also includes emissions data for NO_X, SO_2 and dust. Installation-specific emissions data are also available from the following emission inventories:

Pollution Inventory for England (PI);
Scottish Pollutant Release Inventory (SPRI);
Welsh Emission Inventory (WEI);
Northern Ireland Pollution Inventory (NIPI)
Environmental Emissions Monitoring System (EEMS) for offshore industry
European Pollutant Release & Transfer Register (E-PRTR)[2]

The emission inventories are largely maintained by national regulatory authorities for environmental regulation of industry. The emissions data in these five datasets relates to regulated installations in general i.e. it isn't limited to just emissions from fuel combustion and so has to be used with care. For example, emissions reported for installations that use furnaces and driers could include dust from materials being heated.

The EMEP/EEA Emission Inventory Guidebook[3] gives default emission factors for use in emission inventories including factors for specific sizes of plant and specific technologies.

We have used these various datasets to:

- Make separate estimates of fuel use by i) LCPs and ii) larger MCPs and large & medium sized furnaces/kilns/driers, broken down also by economic sector;
- Developed a set of emission factors to use with those estimates of fuel use.

This new method therefore allows us to use UK-specific data, supplemented with Guidebook default factors, to estimate emissions from larger combustion plant. Emissions from smaller plant (SCPs and small MCPs) will still need to be estimated using the existing NAEI method. However, the new method is an improvement in that it allows us to estimate emissions more reliably for those plant that are most subject to regulation, and in a way that will at least partially reflect changes in control over time. The approach is described in more detail below.

4.2 PROCESSING OF THE LCP DATASET

The LCP dataset consists of fuel use and emissions for each LCP installation for the years 2004-2017. Fuel use is given in TJ (net), separated into the following fuel types:

- Biomass
- Coal
- Other solid fuel

[1] Available from https://www.eea.europa.eu/data-and-maps/data/lcp-9 . The current work used LCP_database_v5.2.
[2] Accessed from https://prtr.eea.europa.eu/#/home during August 2020.
[3] Available from https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

- Oils
- Natural gas
- Blast furnace gas
- Coke oven gas
- Basic oxygen steel gas
- LPG
- Refinery gas
- Other gases

Many of these categories can be matched up with a single fuel category from the NAEI, the exceptions being ‘other solid fuel’, ‘oils’ and ‘other gases’. The ‘other solid fuel’ category could in theory cover coal plus additional fuels such as manufactured smokeless solid fuels and coke produced by coke ovens and possibly even petroleum coke which is coke produced at crude oil refineries. However, in the case of data for UK installations, all entries for this ‘other solid fuel’ category are just duplicates of the entries for coal and can therefore be ignored.

Allocation of the data for ‘other gases’ and ‘oils’ is more difficult and has been done on a case by case basis. There were over a thousand instances where consumption of other gases was recorded, and in most cases, the installation was one of the following:

- A gas terminal or gas compressor, in which case the fuel was assumed to be a process off-gas (treated as natural gas in the NAEI);
- an oil terminal, oil refinery or a petrochemicals manufacturing site, such that the gas could be assumed to be a petroleum-based off-gas (so OPG in the NAEI);
- a site processing organic matter (wood, paper, food) such that the gas could be assumed to be biogas;
- an integrated steelworks, so the gas can be assumed to be a process off-gas such as coke oven gas, blast furnace gas or possibly a mixture of those gases. For simplicity, we assumed the gas was blast furnace gas, this being the most abundantly available gas on these sites.

There were also a small number of instances where installations that report use of other gases do not fit into either of these four categories, and comparison with EU ETS data for these few sites suggests that natural gas is the only fuel used, so we assumed that this ‘other gas’ was in fact natural gas.

The LCP data for ‘oils’ could be assigned as any one of three NAEI fuels – fuel oil, gas oil, burning oil – or even a mixture of these fuels. Oil was burnt at 91 sites out of 223 and these oils represent about 1% of the energy input at LCPs and only about 0.2% of total energy consumption within the sectors studied. So, while some sites do use a mixture of these oils, we decided to just assign fuel at each site to a single type of oil in order to keep subsequent processing simple for these relatively minor fuels. A case-by-case examination was then carried out to judge which of the three oils was most likely the main oil being used at that site. Comparison with EU ETS data was used to help make these judgements, although this was not always clear-cut, and so some expert judgements were necessary for some sites. However the fuel at these sites will be a trivial component of overall fuel use so we do not consider that these expert judgements will have any significant impact on the overall results. The mapping between the LCP data and NAEI fuel types is therefore as shown in Table 1.

Table 1. Mapping of LCP database fuel types to NAEI fuels

LCP Data fuel	NAEI fuel
Biomass	Biomass
Coal	Coal
Other solid fuel	Ignored (duplication of coal)
Oils	Fuel oil, gas oil, or burning oil allocated on a case by case basis
Natural gas	Natural gas
Blast furnace gas	Blast furnace gas
Coke oven gas	Coke oven gas
Oxygen steel gas	Blast furnace gas[a]
LPG	LPG
Refinery gas	OPG
Other gases	Natural gas, blast furnace gas, OPG or biogas, being allocated on a case by case basis

[a] In DUKES & the NAEI, blast furnace gas covers gases from blast furnaces and basic oxygen furnaces at steelworks

Activity data for some sites in the LCP inventory appeared unusual – for example, a number of gas compressor sites each reported the same extremely high fuel consumption in both 2013 and 2014. Therefore, the LCP dataset was compared with EU ETS data, in order to try to identify any major outliers.

In order to make these checks, it was first necessary to establish which records in EU ETS corresponded broadly to the installations listed in the LCP dataset. In most cases, this was straightforward. However, there are some locations where there are multiple installations, and where it was more difficult to be completely certain that installations in the LCP & EU ETS datasets had been correctly matched. Comparison of the types and quantities of fuel reported in both LCP and EU ETS data could be used to help match up sites, but it was also important to bear in mind that there might be differences in the scope of the installations in the two datasets. Thus, even though a particular installation might appear in both data sets, the exact scope might be slightly different and so fuel use might also be different. Despite these complications, the comparison of LCP and EU ETS datasets was valuable in that it did allow a large number of outliers to be identified. In some cases, such as the gas compressor sites mentioned above, the disparity between LCP and EU ETS data was only seen in certain years and was in those years so extreme that the EU ETS data could be adopted with a high confidence that it was more reliable. At most sites, however, there was either:

- a fairly constant relationship between the EU ETS and LCP data such that the EU ETS data can be said to confirm the LCP data;
- a varying relationship between the EU ETS and LCP data. Sometimes, this variation could be explained by factors such as the changing scope of EU ETS, but in other cases it was impossible to make any judgement why the relationship changed in different years. In the absence of any compelling reason to trust EU ETS data over LCP data, we used the latter, assuming that the differences were due to factors that we did not know about. For example, it is possible that some installations in EU ETS consist of a mixture of LCP and non-LCP devices (such as other large combustion plant, furnaces, kilns, MCPs etc.) and that these non-LCP devices are only used periodically. That would lead to fuel use reported in EU ETS being higher than fuel reported in the LCP dataset, but by a varying degree, depending on how often the non-LCP devices were used.

We recommend that further investigation would be needed to better understand the differences in fuel use reported in the EU ETS and LCP datasets, however the age of the LCP data may make this difficult.

The LCP dataset suggests that there are large changes in fuel use at some sites from year to year. It also indicates very different trends in fuel use at some sites compared to EU ETS. These features could indicate errors in the LCP dataset or errors in our matching of EU ETS & LCP installations. Any errors will impact on the final emission factors we calculate (and therefore emission estimates as well).

The LCP dataset also includes emissions reported for NO_X and dust (not explicitly PM10). These were cross-checked against emissions reported in the various regulator inventories, such as the Pollution Inventory (PI) for processes regulated by the Environment Agency (EA), and the Scottish Pollutant Release Inventory (SPRI) for processes regulated by Scottish Environment Protection Agency (SEPA). As with the EU ETS, it is first necessary to match installations listed in the LCP dataset, with processes permitted by the regulators and included in the PI, SPRI etc. As with the process of matching sites in EU ETS, this is mostly but not always straightforward, and as with EU ETS it is important to remember that the scope of permitted processes will sometimes be wider than just LCPs. Emissions reported in the PI/SPRI etc will therefore sometimes be higher than emissions reported in the LCP dataset. This is especially so in the case of emissions of dust, since permitted installations can emit particulate matter from manufacturing processes as well as from combustion devices.

The LCP dataset we used only extended to 2017 and later data may become available subsequently. However, processing of the LCP dataset was very time-consuming and so while incorporating later data would be an 'improvement' it is unlikely to be an especially cost-effective improvement compared with some others that will be recommended in this report. This is because LCPs consume only a relatively small proportion of the total quantity of fuel burnt by industrial-scale plant, and emit an even smaller proportion of the emissions from those plant (see Section 5 for details).

4.3 GENERATION OF FUEL SPLITS

The EU ETS dataset includes fuel usage data for the period from 2005 onwards, although there have been three phases of the EU ETS with changes in the coverage of UK installations in each phase. EU ETS will cover all fuel used in LCPs but will additionally cover fuels used in larger MCPs and large furnaces, kilns, ovens, driers and other devices that use heat from fuel combustion directly. Therefore, by comparing fuel consumption given in the LCP dataset and EU ETS, one can generate separate estimates of fuel consumed in LCPs and non-LCP devices (MCPs and furnaces/driers etc.) Many installations appear in EU ETS only, so these installations only use fuels in MCPs and/or furnaces/driers etc.

EU ETS data covers a wide range of fuels and some of these fuels are used in quantities that are relatively small relative to total UK consumption. Therefore, to ensure that the new method focussed on the main fuels used, we excluded fuels where use across all sites in the EU ETS was less than 0.5% of fuel use (in other words, fuels where >99.5% of consumption must be in smaller sites). So, for example, this meant that we excluded all use of kerosene and LPG, and so the current Tier 1 approach will continue to be used for these fuels. This should be reasonable in any case – the near absence of these fuels in the LCP and EU ETS datasets confirms that they are almost exclusively burnt in smaller plant, for which the Tier 1 factors should be fairly realistic. Note that EU ETS is designed to reduce emissions of fossil CO_2 so the scheme does not include many sites that burn biofuels – only those that also burn significant quantities of fossil fuels are likely to be covered.

The installations in the LCP and EU ETS datasets were allocated to the sectors listed below. This will allow a greater level of detail in the NAEI than is currently possible. In theory, further sub-sectors could have been split out from sectors such as the "other industry" category, however this would be unlikely to have much impact on emission estimates and indeed probably would have introduced uncertainties or other complications, due to a lack of comprehensive data.

Gas distribution	Chipboard
Gas terminals	Glass
Oil terminals	Plaster
Offshore oil & gas	Roadstone coating
Gas separation (use of OPG)	Minor power producers
Steelworks	Autogeneration

Other steel	Other industry
Non-ferrous metals	Data centres
Chemicals	Commercial
Paper	Public
Food & drink	Railways
Brickmaking	Agriculture

Fuel consumption for LCPs, and for large MCPs/furnaces etc.,as derived from the process above, could then be compared with total UK fuel consumption for the related category in the NAEI. By difference, one could then infer the quantity of fuel used in small MCPs/small furnaces/SCPs. This could be done for all years from 2005 to 2018. As mentioned above, the scope of EU ETS has changed across three phases: phase I (2005-2007); phase II (2008-2012); phase III (2013-2018) and therefore this has an impact on the estimates we make for fuel consumed in large MCPs/furnaces. Many furnaces and similar devices were not included in the scope of EU ETS until phase III, therefore EU ETS-based estimates for 2005-2012 will underestimate the fuel used in these types of devices. As a result, we decided that some of the early EU ETS data was too incomplete to be used in the analysis, and instead we used the phase III data as the basis of estimates for earlier years. This was done for the following sectors:

- Other steel
- Non-ferrous metals
- Chemicals (for gas and gas oil)
- Food & drink (for gas)
- Chipboard
- Roadstone coating

All of these sectors will use a high proportion of fuel in furnaces and similar devices and so there is a large increase in fuel reported in EU ETS between 2012 and 2013.

There were also some noticeable step-changes in the EU ETS data between 2007 and 2008 (Phase 1/2), for the following sectors:

- Steelworks (for gas)
- Chemicals (for OPG)
- Paper (for gas and gas oil)
- Food & drink (for gas oil)
- Bricks
- Glass
- Plaster

These step-changes are due to the opting-out of various installations during phase I and/or changes in scope between phases I and II. We therefore used the phase II/III data as the basis of estimates for 2005-2007 for these sectors.

The need for the various adjustments for 2005-2007 or 2005-2012 for some sector/fuel combinations mean that the fuel splits are more uncertain for the earlier years.

The final output for these calculations is a set of assumptions on how to split each fuel use category into three components:

1. LCPs
2. Large MCPs and larger furnaces/kilns/driers
3. Small MCPs, smaller furnaces/kilns/driers, and SCPs

Some examples of these splits are given in Table 2, for a selection of years.

Table 2. Examples of fuel splits

Sector/fuel	Plant Type	2005	2008	2012	2015	2018
Gas distribution / natural gas	LCPs	78%	55%	43%	41%	56%
	Large MCPs etc	22%	25%	53%	47%	38%
	Small MCPs / SCPs etc.	0%	20%	5%	12%	6%
Chemicals / coal	LCPs	12%	12%	14%	54%	76%
	Large MCPs etc	0%	1%	0%	0%	0%
	Small MCPs / SCPs etc.	88%	86%	86%	46%	24%
Public sector / fuel oil	LCPs	0%	0%	0%	0%	0%
	Large MCPs etc	49%	9%	16%	9%	5%
	Small MCPs / SCPs etc.	51%	91%	84%	91%	95%

There were occasional instances where the raw data for LCPs and large MCPs together exceeded the fuel consumption given in DUKES and used in the NAEI. For example, in the case of gas distribution/natural gas given in Table 2, the original data for 2005 summed to 101% of the NAEI (fuel reported in LCP was 79% of the NAEI fuel use, while fuel reported in EU ETS for medium plant was 22%). This is a known issue in the NAEI (it is apparent from analysis we do for outputs from the GHG side of the NAEI programme, for example) and there are various possible explanations for these differences. But, for the sake of simplicity, in all such cases such as this we applied a correction to both large and medium plant sufficient to bring total fuel use down to 100% of the NAEI figure.

The fuel splits such as shown in Table 2 can be combined with suitable emission factors to create a Tier 2 methodology. The following sections describe the ways that emission factors were generated/selected.

4.4 EMISSION FACTORS FOR LARGE COMBUSTION PLANT

Emission factors for large combustion plant were generated using emissions reported by operators, as recorded in the LCP database. Operators report NO_X and dust, although there are gaps. Across the data set as a whole, so also including sites such as power stations that are outside the scope of this current work, there are 4002 instances of NO_X emissions being reported, but only 2226 instances of dust emissions being reported (and 4017 instances of fuel use being reported). So, NO_X is reported in practically all instances but dust in only in 55% of instances. Many of the instances with no reporting of dust emissions relate to installations burning gaseous fuels and it appears that dust emissions were assumed by the operators and regulators to be zero (or sufficiently trivial that could be assumed to be zero). We assume also that operators of gas-fired plant will not have any emission limit value to comply with and will not therefore need to monitor dust to demonstrate compliance. However, the EMEP/EEA Emission Inventory Guidebook provides particulate matter emission factors for all types of fossil fuels, so it is necessary for the NAEI to include emission estimates for all sites and all fuels. There are relatively few gaps in NO_X reporting, but all fossil fuel combustion will result in NO_X emissions, so the NAEI does need to include emission estimates for these sites also.

As with fuel consumption data, we were able to cross-check emissions data in the LCP database with another dataset – emissions reported in the various inventories compiled by the UK regulators. As mentioned above, there is the potential for the scope of emission estimates to differ in the two datasets, therefore the cross-check could only be used to identify potential errors, or to help fill gaps in reporting for dust. We made a small number of revisions on the basis of the cross-checks, but most of the gaps in reporting of emissions remained. Therefore, in these cases we generated emission estimates by applying Guidebook factors to the reported fuel. Since these installations are large combustion plant, we used Tier 2 factors given in the 1A1a chapter of the Guidebook: while we are here interested in 1A2 & 1A4 processes, rather than 1A1a, that chapter of the Guidebook is recommended as being potentially appropriate for NFR sectors where large combustion plant are used. The factors for 1A1a are therefore the most appropriate choice. UK-specific factors would be an improvement but would require consultation with regulators and operators to establish suitable values.

Annex A lists the derived factors for LCPs, while Annex B lists the Guidebook factors used for gap-filling at LCP sites.

4.5 EMISSION FACTORS FOR LARGER MEDIUM COMBUSTION PLANT / LARGE FURNACES ETC, BASED ON SITE-SPECIFIC EMISSIONS DATA

We identified a small number of sectors for which we had access to emissions data for all or most installations, either direct from operators or from E-PRTR. These sectors were:

- Rolling-mill furnaces at the UK's three oxygen steelworks (at Port Talbot, Scunthorpe & Teesside)
- Glassworks
- Plants manufacturing wood products such as chipboard, particleboard and oriented strand board

For these sectors it is therefore feasible to use reported emissions as the basis of emission factors, and these have therefore been generated. The NAEI already contains PM_{10} & $PM_{2.5}$ emission estimates for wood product manufacturing based on E-PRTR data, so for this sector we needed only include new estimates for NO_X. Similarly, the NAEI also includes estimates for PM from glassworks, based on data from industry, so again we only need generate a factor for NO_X.

Other sectors were also evaluated:

- Brickworks
- Plaster furnaces
- Animal rendering plants
- Car manufacturing plants

However, the extent of emissions data was lower and considerable work would have been necessary to take account of the non-reporting sites. Further research (and perhaps consultation with operators and regulators) might allow factors to be ultimately developed for these sectors.

4.6 GUIDEBOOK EMISSION FACTORS FOR LARGER MEDIUM COMBUSTION PLANT / LARGER FURNACES

For most of the larger MCPs and furnaces/kilns etc. in the EU ETS, we do not have site-specific emissions data. Therefore, it is necessary to use literature emission factors to generate emission estimates. We have chosen to use emission factors from the latest (2019) edition of the EMEP/EEA Emission Inventory Guidebook as the most defensible approach.[4] The Guidebook offers both Tier 1 and Tier 2 factors: the former are fuel-specific only so are applicable regardless of the combustion technology in use, whereas the latter are higher quality factors that reflect both the fuel and the technology in use. Wherever possible, we have used Tier 2 factors.

One important distinction should be noted: we have generated estimates of fuel use by fuel type and <u>economic sector</u>. Whereas Guidebook factors relate to fuel type and <u>combustion technology</u>. Therefore, in order to decide which Guidebook factor should be used, one has to make a judgement about the types of combustion technology in use in each sector. The Guidebook recognises four basic types of technology: boilers, furnaces, gas turbines and engines. So, for each sector / fuel, we need to decide which of those four types of technology is typically used. In a small number of sectors, we have decided that there is likely to be a sufficiently mixed population of devices in use so that we should

[4] The 2019 Gudebook was the latest guidance at the time of the project, the model now implements the 2023 EMEP/EEA Guidebook.

instead assume a combination of technologies. But this approach is used sparingly, since we have no data to allow us to quantify the usage of the different technologies, and we can therefore only make expert judgements. We recommend that future work could establish the technologies used with greater certainty. For example, the EU ETS dataset or, better still, EU ETS permit documents could be analysed more deeply in order to estimate the split in boilers/furnaces/gas turbines/engines at each site, and from that we could then estimate the split also at sectoral level.

Some fuels will only be used with certain technologies – coal and fuel oil will only be used in boilers and furnaces, and coke oven coke will only be used in furnaces. But natural gas and gas oil can be used in the full range of technologies, and the choice of factor can have a big impact on emission estimates. For example, Table 3 shows the factors relating to use of oil.

Table 3 Guidebook emission factors for combustion of oils in small & medium sized plant

Device Type	Tier	GB Table[a]	NOx, g/GJ
Boiler, < 1 MW_{th}	2	T3-24	100
Boiler, > 1 MW_{th}	2	T3-25	100
Gas turbine	2	T3-29	83
Engine	2	T3-31	942
All types	1	T3-9	306

[a] Refers to the table numbers in the 1A4 chapter of the 2019 edition of the Guidebook

Since the factor for engines is more than 11 times higher than the factor for gas turbines, the choice of factor is critically important. Many sectors are actually likely to use both types of technology, so the choice is actually difficult. As mentioned above, we have occasionally assumed a combination of technologies (a 50/50 split of two technologies) but for most sectors we select the most 'typical' technology. A more in-depth analysis of technologies, as recommended previously, would help refine emission estimates for gas oil in particular, as well as the various gaseous fuels. Note also that the emission factors for the two classes of boiler take the same value – this is perhaps counter-intuitive given that the larger class will include at least some boilers that are regulated whereas the < 1 MWth class is much less likely to. However this is a good example of the limitations of the Guidebook, which in turn probably reflects a paucity of good data on emission factors for these plant.

The Guidebook does not have factors for every combination of fuel and technology. In particular, there will be use of fuels in furnaces, kilns, driers and other devices where the heat of combustion is used in-situ, and the Guidebook does not always have factors that are specific for this type of fuel use. There are factors for certain important industrial processes where there is contact between the combusted fuel and the material being heated e.g. furnaces used in ferrous and non-ferrous metal processes, and in the minerals sector. These factors encompass both combustion and process emissions and, in any case, require production data rather than fuel use. There are no specific factors for devices that use heat directly in sectors such as the chemical, paper, and food & drink sectors. Devices in these sectors will generally burn fuel such that there is no contact between the combusted fuel and the materials being heated. In these cases, we consider it reasonable to apply emission factors for boilers, on the basis that burner technology in a furnace is similar to that applied in a boiler. Clearly there will be exceptions including direct contact drying and, use of combined heat and power (CHP) plant with engine or gas turbines to provide heat.

In the longer-term it is conceivable that the Guidebook might be expanded so as to increase the choice of emission factors but in the short-term, the only alternative would be to develop UK-specific factors that distinguish between technologies and size of plant at a more detailed level. It would perhaps be difficult to demonstrate that UK-specific factors were an improvement on Guidebook factors unless it could be demonstrated that the UK-specific factors were based on good evidence. Developing UK-specific factors might therefore be difficult, at least without input from UK regulators and/or industry.

The proposed method currently assumes the same technology or technology split is used in each sector across the 2005-2018 time-series. The more in-depth analysis mentioned above would allow this to be tested and changes in technology over time could also be examined in future in order to improve estimates for earlier years back to 1990, and also for projections to 2030.

Table B.2 in Annex B lists the Guidebook factors used for large MCPs and large furnaces/kilns.

4.7 GUIDEBOOK EMISSION FACTORS FOR SMALLER PLANT

Our final categories of fuel use – smaller MCPs, smaller furnaces/kilns etc., and SCPs – often cover a wide range of installation types and sizes. For offshore oil & gas and autogeneration, we have assumed that certain appliance types dominate for each fuel. For example, engines for offshore gas oil use and boilers/furnaces for offshore gas use, engines for autogeneration gas oil and gas use. For fuel oil generally, we have assumed that the fuel is used in boilers or furnaces and used factors for boilers. For coal use, we have adopted factors for small (<1 MWth) boilers. For the remaining sectors and fuels, we have used the same Tier 1 factors for combustion in industry as are used in the current NAEI.

As with Guidebook factors for medium-sized plant, there is a limited choice of factors available for smaller-plant and, again, the only short-term alternative would be to develop UK-specific factors that distinguish between technologies and size of plant at a more detailed level. Given the large number of installations and the fact that many will be unregulated, it would be challenging to develop UK-specific factors. We recommend that it would be a better priority to first split the fuel used in these smaller plant, so that we can distinguish between regulated plant (such as small MCPs and small furnaces etc., regulated as Part A2 and Part B processes) and unregulated plant. Guidebook factors are likely to always be the best option for unregulated plant, whereas it should be possible to collect data for regulated plant, especially as MCPs are brought into environmental permitting.

Annex B lists the Guidebook factors used for small MCPs, small furnaces/kilns and SCPs.

5. RESULTS

5.1 INTRODUCTION

Results are summarised in the following sections, for the three size-categories that we have developed:

Large combustion plant	Onshore combustion plant covered by Chapter III of the Industrial Emissions Directive (2010/75/EU) but excluding those sectors where the NAEI already has a higher tier method (so power stations, refineries, processes at steelworks, cement kilns, lime kilns). Fuel use and emissions are generated from operator-returns which have been collated into a database by the European Environment Agency.
Medium-sized plant	All plant included in EU ETS except for large combustion plant. In practice this means combustion plant with a total rated thermal input of between 20 and 50 MW, as well as fuel use associated with certain industrial processes such as production of metals, glass, bricks and plaster. This category will therefore include some (but not all) installations that are within the scope of the Medium Combustion Plant Directive (2015/2193/EU) and have either already been permitted or will be permitted by 1 January 2024. But it will also cover other medium-sized plant that are outside the scope of MCPD, such as furnaces or kilns. Fuel use estimates are derived from the EU ETS dataset and emissions are then estimated using a combination of operator-reported emissions (from the E-PRTR) and emission factors from the EMEP/EEA Guidebook.
Smaller-plant	All other plant, so plant that do not exceed a total rated thermal input of 20 MW, as well as fuel use associated with industrial processes such as production of metals, glass, bricks and plaster but where the process

does not meet the threshold for inclusion within EU ETS. This category will therefore include large numbers of installations that fall within the scope of the MCPD, including a proportion of those already permitted and to be permitted by 1 January 2024, and all of those MCPs to be permitted by 1 January 2029. Fuel use estimates are derived by subtracting fuel use for large combustion plant and medium-sized plant from UK fuel consumption statistics i.e. for fuel data covering all sizes of plant. Emissions are then estimated using emission factors from the EMEP/EEA Guidebook.

It is important to stress that these categories reflect the available data but do not provide us with a single category that covers installations that are within the scope of the MCPD. That would require further sub-division of two of the categories, since MCPs make up a proportion of both the 'medium-sized plant category, and a proportion of the 'smaller-plant' category.

The proposed method allows us to estimate emissions for about 40 sector/fuel categories but for the sake of simplicity, the following sections of the report present summary results by NFR category. These categories, which are used for international inventory-reporting systems, are described below:

1A1c	This NFR covers manufacture of solid fuels and other energy industries but for this study we are only concerned with gas distribution (in the case of NO_X) and gas distribution and offshore oil and gas platforms (in the case of PM_{10}). For other sectors covered by NFR 1A1c, such as coke ovens, the NAEI already uses a higher-tier method and so there is no need to consider those sectors in the current work.
1A2a	Stationary combustion in the iron & steel sector. Figures below will exclude sub-sectors where we already use a higher-tier method, such as combustion in steelmaking processes.
1A2b	Stationary combustion in the non-ferrous metal sector.
1A2c	Stationary combustion in the chemicals sector.
1A2d	Stationary combustion in the pulp, paper and print sector.
1A2e	Stationary combustion in the food processing, beverages and tobacco sectors.
1A2f	Stationary combustion in the non-metallic minerals sector. Emissions are reported as zero for this sector, but some of the sub-sectors that are split out for the first time using the proposed methodology e.g. glass, bricks, could be reported here instead of in 1A2g, which is where they are currently reported. However, this would then mean that there was a difference in reporting for NO_x/PM_{10} and other AQ and GHG pollutants.
1A2g	Covers 1A2gviii only, which is stationary combustion in other industry sectors (so any industry sub-sectors not included in 1A2a-1A2f.
1A4a	Stationary combustion in the commercial/institutional sectors.
1A4c	Stationary combustion in the agricultural sector e.g. combustion plant used to provide heating for greenhouses

Note that for some NFR categories (1A1c & 1A2a), the current study only covers part of the category. This is because the NAEI already uses a higher tier method to estimate emissions. The study also only considers those fuels that are used in significant quantities by large or medium plant i.e. where more than 0.5% of that fuel is used in these large and medium-sized plant (see section 4.3 for further information). To put the results we present into context, the 2020 NAEI submission (covering up to the year 2018) had the following figures for NO_X and PM_{10} in 2018 :

For NO_X:

All UK emissions	843 ktonnes
All emissions in 1A1c, 1A2a-f, 1A2gviii, 1A4a, 1A4c	194 ktonnes (23% of UK total)
Emissions in sectors covered by this study	85 ktonnes (10% of UK total)

For PM_{10}:

All UK emissions	176.4 ktonnes
All emissions in 1A1c, 1A2a-f, 1A2gviii, 1A4a, 1A4c	17.8 ktonnes (10% of UK total)
Emissions in sectors covered by this study	15.6 ktonnes (9% of UK total)

So this study proposes a new method for sources and fuels that were responsible for about 10% of total UK emissions of both NO_X and PM_{10} in 2018. A further 13% of the UK national total for NO_X was reported in the nine NFR categories listed above but is outside the scope of this study for the reasons given above. This includes emissions from offshore oil & gas installations, steelmaking processes, coke ovens and emissions from the use of burning oil and LPG by small plant.

5.2 EMISSIONS FROM LARGE COMBUSTION PLANT

Emission estimates for large combustion plant are summarised in Table 4 by NFR category for NO_X and Table 5 for PM_{10}.

Table 4. NO_X emissions from large combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	1482	1124	0	5529	1845	941	0	1028	213	0	12163
2006	1172	1110	0	5430	1943	546	0	868	193	0	11261
2007	2440	1121	0	5103	1599	552	0	982	190	0	11987
2008	1589	1138	0	5170	2022	486	0	576	180	0	11162
2009	926	1315	0	3697	1774	441	0	538	175	0	8866
2010	1323	884	0	3873	1505	379	0	946	204	0	9113
2011	678	723	0	4258	1441	453	0	844	225	0	8622
2012	705	849	0	3812	870	500	0	841	164	0	7742
2013	1549	1781	0	2756	692	728	0	1551	150	0	9207
2014	1471	1435	0	2304	832	748	0	1468	130	0	8387
2015	897	1418	0	2558	535	597	0	192	131	0	6327
2016	522	562	0	1938	627	503	0	338	28	0	4519
2017	815	719	0	1782	712	496	0	325	26	0	4875
2018	517	667	0	1734	796	534	0	238	29	0	4514

Table 5. PM_{10} emissions from large combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	8	120	0	139	204	10	0	23	0	0	505
2006	4	139	0	256	103	14	0	34	0	0	550
2007	105	92	0	240	146	12	0	17	1	0	612
2008	9	266	0	159	188	2	0	13	0	0	637
2009	7	295	0	76	166	4	0	12	0	0	560
2010	10	152	0	79	117	10	0	13	0	0	381
2011	10	94	0	74	96	10	0	10	0	0	294
2012	17	64	0	70	86	10	0	11	0	0	259
2013	10	204	0	60	45	15	0	30	0	0	364
2014	15	279	0	53	9	15	0	30	0	0	400
2015	11	195	0	71	4	10	0	7	0	0	297
2016	8	101	0	22	3	7	0	3	0	0	143
2017	16	158	0	20	3	8	0	1	0	0	205
2018	14	154	0	20	3	8	0	1	0	0	202

There is an overall reduction in emissions of both pollutants between 2005 and 2018, with emissions in the latter year being 63% lower for NO_X and 60% lower for PM_{10}. This reduction does not occur at a uniform rate over the 2005-2018 period and there are some reversals in the downward trend for some years. For example, total NO_X emissions increase in 2007, 2010, 2013 and 2017. There is also a reduction in emissions of NO_X for each of the NFR categories between 2005 and 2018 though again with some short-term reversals in this trend in the intervening years.

The NO_X figures also include some notable step changes which may indicate data quality issues. For example, the emissions from 1A1c are highly variable, and there is a large step-change in the figures for 1A2g between 2012 and 2015. It must be stressed that these emission estimates are based on reported data, often for only a relatively small number of sites, therefore even a single outlier in the data can have a marked impact on the numbers given in these tables. In the case of 1A1c, it has already been remarked (in Section 4.3) that some of the LCP data for gas compressors is questionable and although it has been possible to substitute alternative fuel use data, we have left emissions data unchanged in the absence of any alternative figures. It is certainly possible that the high emissions for 1A1c in 2013 and 2014 are unrealistic and should be lower. The step-change in 1A2g between 2014 and 2015 would have been even greater had we used the LCP database values for emissions from one site in 2014. It gave NO_X emissions for this site as 3455 tonnes compared with 203 tonnes reported in the PI for the same site. The PI figure is used instead, but the data from this and other sites still contribute to higher emissions in 2014 than in the subsequent year.

In the case of PM10, there is far more variability in the trends at NFR level and emissions are higher in 2018 than in 2005 in two cases (1A1c, 1A2a). As with NO_X, a single outlier can have a big impact on the derived emission estimates.

Further development of the LCP emission estimates is recommended. We recommend that priorities would be to:

- Consult with regulators and possibly operators in order to understand outliers and other features in the fuel use and emissions data and to identify any errors in the data;
- Further develop methods for gap-filling in instances where operators haven't supplied emissions data (e.g. for gas-burning sites where there is no ELV set for particulate matter.)

However, emissions from large-sized plant are relatively small and so the actions listed above are therefore arguably far less important than those that are recommended in the subsequent sections for medium and smaller plant.

5.3 EMISSIONS FROM MEDIUM-SIZED PLANT

Emission estimates for medium-sized plant are summarised in Table 6 by NFR category for NO_X and Table 7 for PM_{10}.

Table 6. NO_X emissions from medium-sized combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	818	3094	129	5579	1112	1821	0	28,101	5211	343	46,209
2006	927	2904	118	5359	971	1516	0	24,350	4921	316	41,381
2007	747	2624	109	4824	946	1354	0	24,398	4811	345	40,176
2008	784	1883	96	4802	671	1447	0	22,292	3971	327	36,273
2009	1216	1710	76	3902	573	1242	0	17,765	3796	333	30,614
2010	1834	1721	78	4045	625	1326	0	18,398	4085	365	32,478
2011	2112	1841	79	3384	622	1314	0	19,292	3618	300	32,561
2012	1471	1678	82	3408	727	1315	0	19,599	3838	262	32,382
2013	1264	1676	89	4067	610	1284	0	17,028	4077	192	30,288
2014	1404	1058	93	3431	482	1245	0	16.053	3791	193	27,749
2015	1405	1718	100	3752	377	1174	0	17,116	3941	195	29,776
2016	1236	1518	97	3993	340	1098	0	16,698	3915	220	29,116
2017	903	1489	99	4251	343	1087	0	18.114	3808	246	30,340
2018	809	1352	95	3942	328	1113	0	18,721	4025	233	30,617

Table 7. PM_{10} emissions from medium-sized combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	397	101	8	101	21	203	0	488	197	5	1520
2006	356	111	4	85	12	97	0	313	185	5	1167
2007	332	131	4	75	19	80	0	396	169	5	1210
2008	377	145	1	74	57	116	0	367	133	5	1275
2009	383	139	1	64	48	106	0	581	125	5	1452
2010	411	125	1	55	39	100	0	574	128	5	1438
2011	437	100	1	41	40	91	0	443	102	4	1259
2012	472	108	1	41	105	86	0	503	99	4	1420
2013	506	510	1	53	59	95	0	467	99	3	1792
2014	480	517	1	46	6	71	0	552	96	3	1772
2015	446	424	1	51	5	53	0	769	97	3	1849
2016	445	127	1	50	5	24	0	692	98	3	1446
2017	460	99	2	58	4	23	0	697	80	4	1427
2018	471	66	2	53	4	24	0	754	81	3	1458

Emissions from medium-sized plant are mostly estimated using Guidebook factors which are constant across the time-series. This means that the trends shown in Tables 6 & 7 are largely a reflection of trends in the consumption of fuels. Thus, for example, the decrease in emissions of both pollutants for NFR 1A2b is simply a reflection of the decreasing use fuels in this sector. The trends for NFRs 1A1c, 1A2c, 1A2d, 1A2e, 1A4a & 1A4c are similarly linked to the changes in fuel use in those sectors. In the case of 1A4c, the trend for both NO_X and PM_{10} emissions is the same because only one fuel is included in the calculations (natural gas) so, for both pollutants, the emission trend is identical to the natural gas consumption trend. For all other NFR codes, the emission trends will be different because of the differing contributions of fuels to emissions. NO_X is emitted at an approximately similar rate when all fuels are burnt so contributions to NO_X emissions are roughly in line with consumption of fuels. In most sectors, the main fuel will be natural gas so, for NO_X, the trend in natural gas consumption strongly influences the overall emission trend. But in the case of PM_{10}, emission rates are much higher for solid fuels such as coal, coke, pet coke and biomass, and for heavy fuel oil. So, trends in PM_{10} emissions are much more closely linked to trends in use of these fuels.

This difference in the way the various fuels affect the totals is seen most clearly in the figures for 1A2e where there is a 39% decrease in emissions of NO_X between 2005 and 2018 but an 88% decrease in emissions of PM_{10}. Over that time period there is only a 20% decrease in the consumption of natural gas which is the main fuel used by the sector and represents 90% or more of the energy input each year. In comparison, coal use is phased out completely by 2018, and use of gas oil and fuel oil decreases by 96% and 80% respectively by 2018. The trend in NO_X emissions is strongly influenced by the consumption of natural gas, so there is a more modest reduction in emissions. Whereas coal and oil combustion are the dominant sources of PM_{10} emissions from the sector and so emissions decline sharply in line with consumption of these fuels. There are somewhat similar trends in other sectors such as 1A4a due also to declining use of coal and oils, and more stable consumption of natural gas.

Emission estimates for 1A2a and 1A2gviii are somewhat different in that these rely only partly on the Guidebook factors used elsewhere. Instead, emissions data reported by operators are used for some sub-sectors within these NFR categories, and so emission factors are to some extent year-specific and should reflect any changes in these sub-sectors due to regulation (providing that is reflected in the emissions reported by operators). These sub-sectors actually dominate emissions of NO_X within these two NFR categories, so the trends shown in Table 7 for 1A2a and 1A2g are largely a reflection of the changes in reported emissions for these sub-sectors (steelworks, glass, chipboard). Section 4.5 mentions that there is the potential for further site-specific and operator-reported emissions data to be incorporated into the methodology. Given the small selection of Guidebook factors available, use of operator-reported emissions should yield more reliable UK emission estimates, particularly for sectors where combustion devices might deviate most from the technology (and fuel) represented by the Guidebook factors. Examples might include sectors using furnaces or kilns (so ferrous & non-ferrous metals, plaster, bricks) and sectors where devices are especially modern (for example data centres or upgraded manufacturing plant) or especially old. Emission factors for these sectors could not be developed as part of the current work because emissions were not available for sufficient numbers of plant. Further research and probably consultation with sectors would be needed to develop emission factors but is recommended.

As well as developing emission factors based on site-specific emissions data, one other potential improvement would be to develop country-specific factors that could be used in place of the Guidebook factors. For example, one could perhaps derive UK-specific factors for sectors where there was a paucity of reported emissions data but where there was a reasonably good understanding of the technologies in use and the regulatory framework. The various Guidebook factors for medium-sized plant seem to relate either to studies undertaken outside the UK (so may not represent UK technology) or, to fairly basic equipment (with limited abatement). For example, particulate matter emission factors for biomass combustion in the Guidebook imply relatively low levels of abatement – this may be reasonable for historic years but is not consistent with achievable emission levels or, for regulated activities, emission limits for new plant. Use of UK-specific factors in the NAEI are therefore likely to be increasingly necessary as regulation of medium-sized plant proceeds. The permitting of MCPs (all UK) and specified generators (in England, Wales & Northern Ireland) should bring with it the opportunity to collect data on the numbers of plant, the installed technologies, and emission limit values (ELVs), and from that, it should be possible to estimate emissions. The potential for collecting this information could be investigated through discussions with regulators.

5.4 EMISSIONS FROM SMALLER PLANT

Emission estimates for smaller plant are summarised in Table 8 by NFR category for NO_X and Table 9 for PM_{10}.

Table 8. NO_X emissions from smaller combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	0	1102	657	2155	1562	3043	0	30,377	29,725	356	68,977
2006	0	1037	617	2166	1349	2963	0	24,895	26,081	311	59,419
2007	70	1351	572	2183	1410	2849	0	22,818	24,340	292	55,883
2008	339	1138	513	1920	1119	2797	0	19,039	27,971	161	54,995
2009	248	843	405	2059	848	2450	0	17,794	23,490	170	48,307
2010	366	865	418	2418	800	2675	0	21,303	25,509	129	54,483
2011	274	691	420	2721	665	2715	0	18,595	21,630	160	47,871
2012	74	598	438	2305	998	2706	0	18,047	24,838	136	50,140
2013	272	472	410	900	1480	2863	0	20,129	25,583	159	52,268
2014	165	571	378	633	1612	2763	0	21,119	21,854	152	49,248
2015	194	632	613	278	644	2321	0	20,366	23,217	129	48,395
2016	135	591	614	267	751	2391	0	20,424	23,759	122	49,054
2017	47	403	623	201	583	2585	0	20,664	23,100	110	48,317
2018	73	394	650	768	482	2757	0	21,294	23,959	123	50,499

Table 9. PM_{10} emissions from smaller combustion plant, in tonnes

NFR	1A1c	1A2a	1A2b	1A2c	1A2d	1A2e	1A2f	1A2g	1A4a	1A4c	Total
2005	141	200	8	1704	220	206	0	5785	1230	4	9499
2006	135	180	7	1678	154	329	0	5622	1060	3	9169
2007	126	541	7	1735	291	419	0	4081	995	3	8197
2008	143	492	5	1718	65	345	0	4294	1047	2	8111
2009	134	444	4	1604	124	405	0	5047	1012	2	8776
2010	154	404	4	1712	268	415	0	7559	1050	1	11,569
2011	165	321	4	2055	273	442	0	6643	1064	2	10,969
2012	187	317	5	1467	523	427	0	7217	996	1	11,141
2013	142	311	4	1006	666	497	0	9991	1052	2	13,670
2014	184	316	4	686	919	580	0	11,406	1022	2	15,117
2015	220	266	7	250	738	508	0	10,067	409	1	12,467
2016	196	221	7	231	722	383	0	9120	417	1	11,298
2017	148	182	7	159	585	433	0	9796	435	1	11,746
2018	157	137	7	120	538	419	0	10,105	463	1	11,946

Emissions from smaller plant are entirely estimated using Guidebook factors which are constant across the time-series. This means that the trends shown in Tables 8 & 9 will just reflect trends in the consumption of fuels. However, as with medium-sized plant, the overall trends at sector level will be different for NO_X and PM_{10}, due to the much greater contribution of solid fuels and fuel oil to emissions of the latter.

One notable feature of the data for smaller plant is that for NO_X, emissions generally fall slightly between 2005 and 2018 (true for 8 out of 9 sectors) whereas for PM_{10} there are some sectors with big percentage reductions in emissions over the time period (1A2a, 1A2c, 1A4a, 1A4c) but other sectors with big percentage increases (1A2d, 1A2e, 1A2g).

The modest downward trend for NO_X seen for most sectors is largely due to an overall decline in fuel use in each sector – often this decline is seen in the natural gas consumption, sometimes it is other fuels that have been used less. But because there are broadly similar levels of NO_X emitted when all fuels are burnt, less fuel generally translates into less NO_X.

The different picture seen for PM10 is, as with medium-sized plant, a reflection of the fact that solid fuels and fuel oil generate much more particulate matter than gases or lighter oils do, so the trend in emissions depends very much on the use of those particular fuels. There are two trends that are driving increases in PM_{10} in some of the sectors:

1. Increasing use of biomass as a fuel. Biomass use in smaller plant increased threefold between 2005 and 2018 and all of this fuel is reported in 1A2gviii, which is the part of 1A2g relating to stationary combustion. The increasing consumption is the primary reason for the big increase in PM_{10} emissions in that NFR category. By 2018, biomass combustion accounts for almost two thirds of the PM_{10} emitted from 1A2g.
2. Our analysis of 2005-2018 EU ETS data suggests that coal use is increasing in smaller plant over that time period, at least for some sectors (1A2a, 1A2d, 1A2e, 1A2g). This conclusion is reached because the quantity of coal reported in EU ETS (for large and medium-sized plant) declines sharply over the period from 2005 to 2018 and at a faster rate than suggested in UK energy statistics for industry as a whole. If large and medium plant are using an increasingly small percentage of UK industrial coal consumption, then it follows that small plant must be using an increasingly large percentage. For the four sectors listed above, the increase in the smaller plant's share of coal is sufficiently large that there is also an increase in the quantity of coal used. For example, our analysis suggests that 27% of coal supplied to the paper sector is used in smaller plant in 2005 (so, 27% of 4070 TJ_{net} which is 1080 TJ_{net}). But there is no coal use in large/medium plant by 2018 so all of the coal then used by the sector must be in smaller plant (so, 100% of 2820 TJ_{net}). Thus, consumption of coal in smaller plant in this sector appears to have increased by 160% between 2005 and 2018.

Of these two trends, the first is expected. UK energy statistics indicate strong growth in the use of biomass fuels, and we expected that this would show up in the data for smaller plant. It should be noted that in this current study we have relied on EU ETS as a source of information on medium-sized plant. But many plant burning biomass will not appear in the EU ETS dataset, regardless of whether they are large, medium, or small – dedicated biomass plant are outside the scope. Because of this, our approach does almost certainly understate the percentage of biomass burnt in medium-sized plant. This is an important issue because we apply quite different PM_{10} emission factors for medium and small plant. Emission factors for smaller plant are higher so, if we overestimate biomass use in smaller plant and underestimate biomass use in medium-sized plant, we then overestimate PM_{10} emissions. Further work would be necessary in order to generate a more reliable split of biomass use between medium and small plant. For example, the Renewable Heat Incentive has three bands of tariff for the non-domestic scheme (<200kWth, between 200kWth and 1MWth and ≥1MWth) which may provide data to help establish a more accurate activity split.

The second issue, that of an apparent increase in the use of coal in smaller industrial plant, is surprising, since it implies that either new coal-fired devices are being commissioned, or that existing plant with the capacity to burn coal are being used increasingly. Neither of those scenarios seems likely. One important consideration is that whereas the fuel use estimates for large and medium plant are based on potentially very reliable data (LCP returns, EU ETS), the estimates for smaller plant are simply the difference between those estimates for large/medium plant and UK consumption totals (given in

DUKES). Thus the accuracy of the estimates for smaller plant is dependent on the accuracy of the UK totals in DUKES. We believe that DUKES' figures for UK demand as a whole i.e. across all sectors are highly reliable. Data can be collected on the total production of fuels and on imports and exports. However, it is more difficult to establish exactly where all of the produced and imported fuel ends up being used. We therefore believe that DUKES' estimates of fuel consumed by individual economic sectors are more uncertain than the total demand figures. It is therefore conceivable that DUKES may be overstating the use of coal in the economic sectors that contribute to 1A2a, 1A2d, 1A2e, 1A2g. Interestingly, our analysis suggests that use of coal in smaller plant in 1A2c and 1A4a has fallen dramatically over the period 2005-2018, and this could also be the result of inaccuracies in the sectoral fuel use figures in DUKES. If DUKES was assigning too much coal to sectors such as iron & steel, paper, food & drink and not enough to chemicals and public sector then that would help to explain the features seen in our estimates.

It is important to stress that this issue of coal allocation does not necessarily imply that UK emission estimates are wrong. Since the proposed method uses the same emission factor for smaller plant in each of the NFR categories shown in Tables 8 & 9, it follows that if DUKES overstates coal use in 1A2a and understates coal use in 1A2c by the same amount, then correcting that would only lead to a re-allocation of emissions. The emission estimate for 1A2a would decrease and the estimate for 1A2c would increase by the same amount so there would be no net change in UK emission totals.

However, this would not be not true if, for example, DUKES was overestimating industrial coal use but underestimating coal usage in the domestic sector. In this case, different emission factors are used so re-allocating coal between industrial sectors and domestic (1A4b) would result in changes to UK emission totals. In theory this would also be true if DUKES was overestimating industrial coal use but underestimating coal usage in power stations, but analysis of EU ETS data that we do as part of the GHGI programme suggests that DUKES figures for power station coal use are very accurate.

Further work is recommended to examine this coal issue from two directions: firstly, consultation with the DUKES team to help understand the scale of uncertainty associated with the sectoral fuel use estimates, which could perhaps lead to adjustment of our estimates; and secondly, work to build up estimates of fuel use in smaller plant that are independent of DUKES. This is described in more detail in section 5.5.

5.5 OVERALL EMISSIONS

Estimates of NO_X for the period 2005-2018 using both the existing NAEI method and the proposed method are shown in Figure 1, with a breakdown of the new estimates into large, medium and smaller plant shown in Figure 2. Corresponding figures for PM_{10} are shown in Figures 3 and 4. These graphs only include emissions for sources covered by the current work, so NFR 1A1c, 1A2a-f, 1A2gviii, 1A4a and 1A4c.

Figure 1. Comparison of NO_X emission estimates using the existing (NAEI18) and proposed methods (in ktonnes)

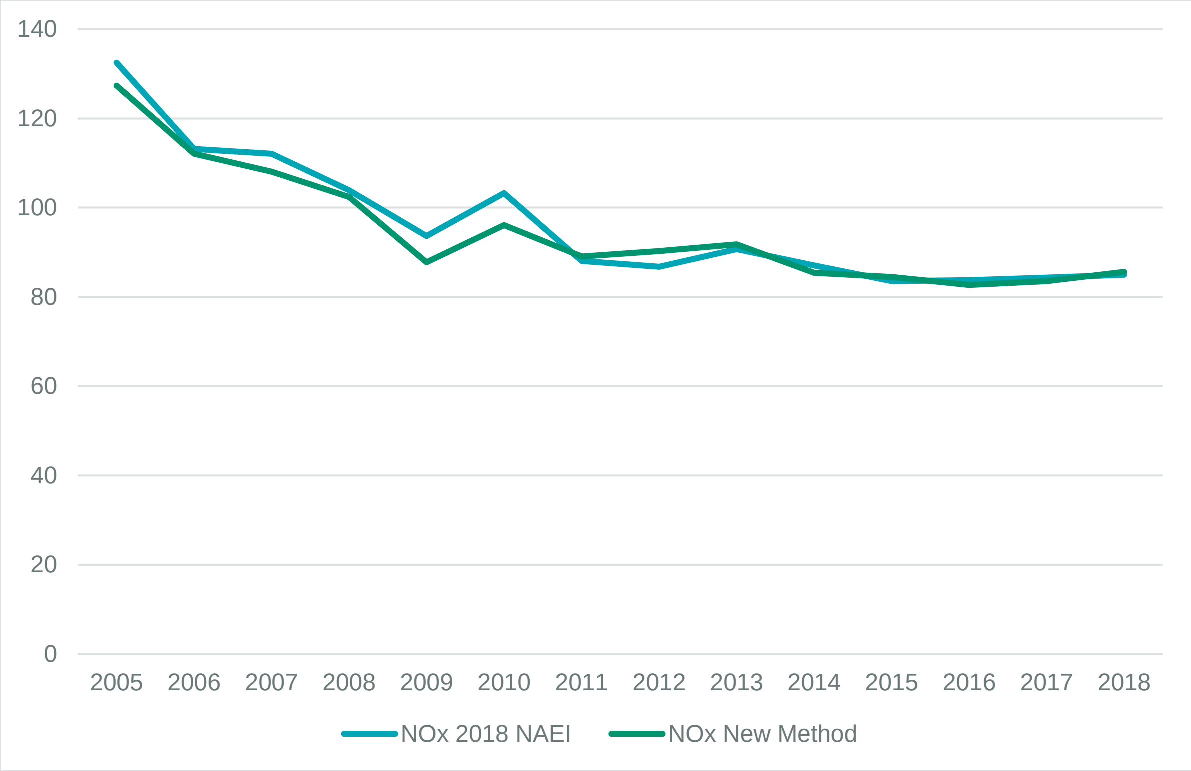

Figure 2. NO_X emission estimates for large, medium and smaller plants using the proposed method, in ktonnes

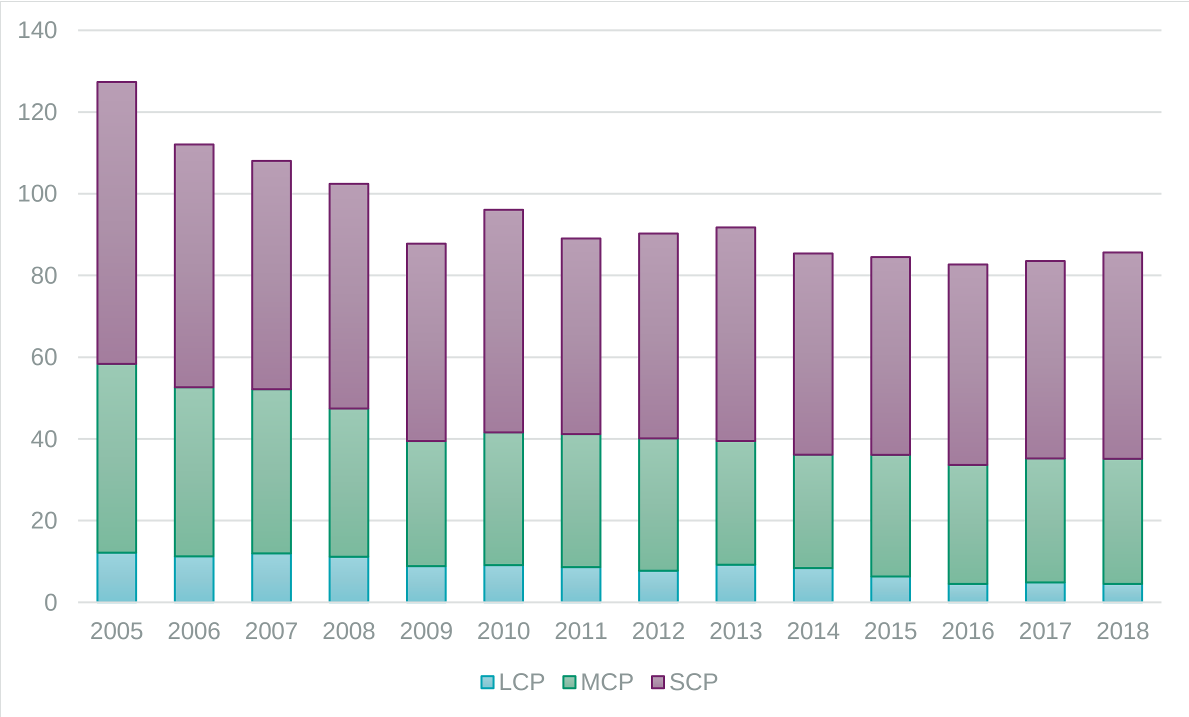

Figure 3. Comparison of PM_{10} emission estimates using the existing (NAEI18) and proposed methods (in ktonnes)

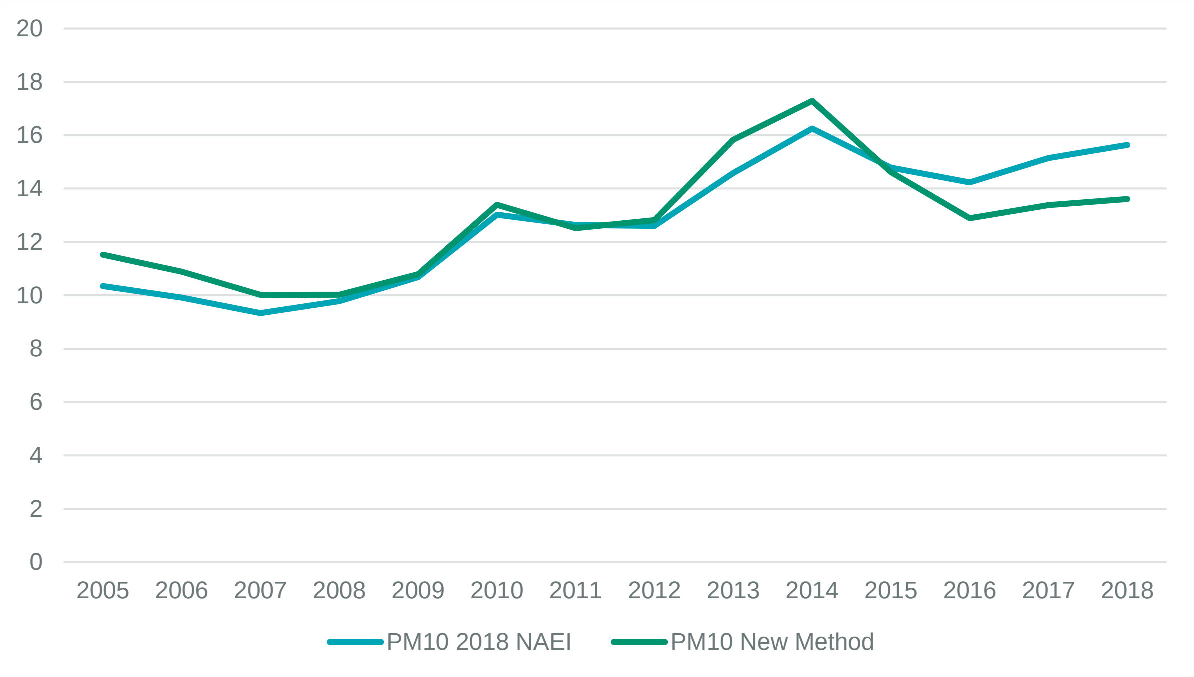

Figure 4. PM_{10} emission estimates for large, medium and smaller plants using the proposed method, in ktonnes

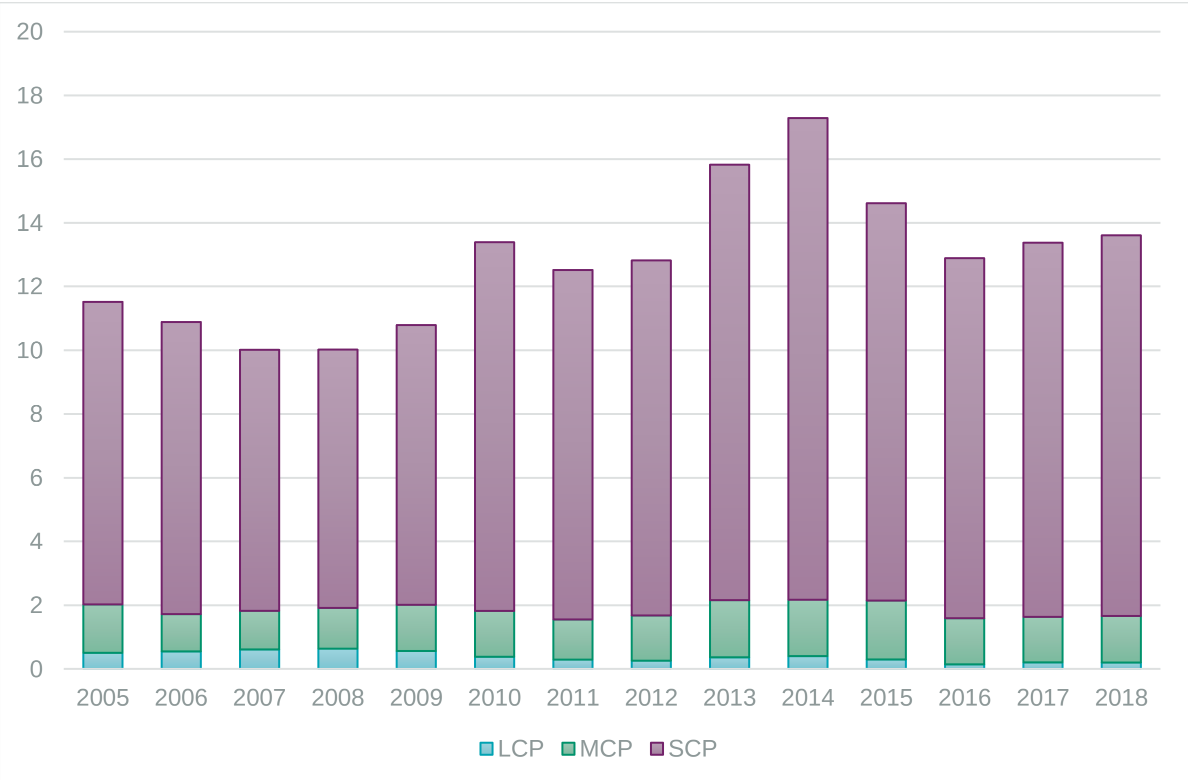

Figure 1 indicates that the NO_X estimates are similar for both methods. While this might seem surprising, it must be remembered that both approaches rely heavily on Guidebook emission factors (Tier 1 in the existing method, Tier 2 in the proposed method). The Guidebook Tier 1 factors for stationary combustion seem to generally be just the mean value of various Tier 2 factors, so it is not that surprising that moving from use of Tier 1 to use of Tier 2 factors should not alter the emission estimates much. However, it is an upgrade to the tier used i.e. it is an improvement in the method according to the guidance given in the Guidebook. During the 2020 NECD Review, there was examination of the fact that the UK uses a Tier 1 method for one of the NFR categories that are the subject of this work. Reviewers considered if there was a case for a potential technical correction. We would argue that the proposed method is Tier 2, albeit a relatively simple one, and would therefore probably have satisfied the reviewers if it had been the method used in the NAEI at the time of the review.

Figure 2 summarises the contributions of the three size classes to NO_X emissions. It shows that emissions from both LCPs and the larger medium-sized plant are estimated to have fallen. By 2018, we estimate that LCPs are responsible for only 5% of NO_X from the nine NFR categories that are studied in this work, compared with 9% in 2005. Emissions from smaller plant also decline but this group is the dominant source of NO_X in all years, our estimates suggesting that their contribution is between 50% and 60% of emissions each year.

Reductions in NO_X emissions between 2005 and 2018 are 63% for large plant, 34% for the medium plant and 28% for smaller plant. This pattern seems reasonable given that all large plant are regulated under IED, and that a proportion of medium plant will be too (this group contains many regulated furnaces and kilns, for example). The trend in emissions from medium plant is also a reflection of trends in fuel use and this will be a major contributor to the emission reductions seen. As discussed in Section 5.2, the proposed method is only able to fully take account of regulation for some types of medium plant. Regulation can lead to changes in the quantities and types of fuel used (e.g. because an operator decides to buy a new gas-fired CHP plant rather than to upgrade an old coal-fired boiler) and the proposed method will of course reflect these types of changes. But it can also lead to emission reductions through modifications to combustion technology or use of add-on abatement and that cannot be reflected in the new method except in those cases where we use operator-reported emissions, such as rolling mill furnaces and glass kilns. Expansion of the method to include further operator-reported data would increase the extent to which regulation could be reflected in the inventory and might cause a greater reduction in emission estimates across the 2005-2018 period.

Some smaller plant will be regulated, but the proposed method uses fixed emission factors across the time-series and so will not be able to reflect any changes in, for example, levels of abatement. It will, of course, be able to reflect any changes in the quantities and types of fuel used that result from regulation. The smaller plant category will still include many installations that could be regulated under the Medium Combustion Plant Directive (MCPD), or even under the Industrial Emissions Directive (IED) or UK legislation (some smaller furnaces and similar plant could well be regulated as Part B processes). Incorporating the impact of regulation is therefore still a worthwhile long-term objective and with this in mind, we recommend that:

- Further work is needed to split the smaller plant category into:
    - Smaller installations within the scope of the MCPD;
    - Smaller furnaces and similar plant, regulated under IED or UK legislation;
    - Small unregulated plant.
- In tandem with the above, consultation is needed with regulators and industry to establish appropriate emission factors for the different categories of fuel use.

Figure 3 indicates that, like for NO_X, existing and proposed emission estimates for PM_{10} are broadly similar, however there is an important difference in that the existing NAEI estimates increase by 51% between 2005 and 2018, whereas the proposed method yields estimates that grow only by 18%. Changing to the proposed method would therefore make it easier for the UK to reach emission reduction targets, as well as improving the quality of the estimates. Figure 4 shows that more than 80% of PM_{10} each year is some smaller plant – figures range from 81% to 88%. Most of the rest is from the medium-sized plant while LCP contribute no more than 6% of emissions in any year and 2% or less in each year since 2011. As with NO_X, there are the same considerations regarding the inability of the proposed method to take account of regulation. In the case of PM_{10}, the fact that smaller installations dominate emissions so much means that the further disaggregation of the smaller plant category is especially important for the further development of emission estimates.

It is also worth pointing out that, as well as regulation, the PM_{10} emission estimates in particular could be improved by better modelling of any distinctive aspects of the industrial combustion sector in the UK. This could include the very strong growth in biomass use in the UK in recent years. That implies that combustion devices used to burn biomass will typically be of modern design and might therefore have very different emission characteristics to the 'typical' plant which should be the basis of Guidebook default factors.

5.6 USE OF THE METHOD IN THE NAEI

The current Tier 1 approach used in the NAEI has one great virtue – it is very simple and therefore easy to calculate and update. However, it is not consistent with methodology guidance for a key category in the emission inventory (such as 1A4ai in the case of NO_X and 1A2gviii for both pollutants). We consider that the proposed method meets the requirements of a Tier 2 approach, albeit a fairly simple one, and therefore would allow the UK to comply with this guidance. The proposed method is more complex and updating it on an annual basis would be very time-consuming if all of the underlying analysis were to be re-done each year. Therefore, should Defra wish to use the new method in the NAEI, we propose that a more pragmatic approach should be taken to annual updates. This should ensure that the estimates can be updated in a timely manner and using resources in proportion to the importance of the sector.

The processing/interpretation of the LCP returns is very time-consuming and yet Figures 2 and 4 show that LCPs make only a relatively small contribution to emissions. Therefore, we propose that, for the purposes of updating the method on an annual basis, a simple analysis of the EU ETS dataset (which already has to be thoroughly processed for the GHGI) will suffice to give a reliable set of estimates for total use of fuels in LCPs & MCPs. This analysis could be used for short-term extrapolation of the assumptions generated during this research project, with a full analysis of LCP returns carried out periodically (say every 3-5 years) in order to establish a new baseline for the next period of extrapolation. This slightly simplified way of updating the estimates each year would not prevent the method being described as Tier 2.

The work has established a set of default (Guidebook) emission factors to use for large, medium, and smaller plant. Any annual update of the method would of course need to take account of any revisions that are made to the chosen emission factors. But there should also be periodic review of the choices themselves, particularly should the Guidebook include more detailed factors, change the categories for emission factors, or make some other adjustment to recommended methods in a future edition.

The periodic analysis of LCP returns, and periodic reviews of emission factors are perhaps of less importance than other one-off research and development to extend and improve the methodology. Emission estimates for medium and smaller plant in particular are still likely to be quite uncertain even with the proposed method, and more reliable methods for those types of plant would probably constitute a bigger improvement in quality than re-visiting the full analysis done as part of the current study. We give more details of potential improvements in Section 7 below.

Currently, we can apply the method to emission sources that are reported in the following NFR categories: 1A1c, 1A2a, 1A2b, 1A2c, 1A2d, 1A2e, 1A2gviii, 1A4i and 1A4ci. In each case, we are only currently using the method for those fuels where there is significant use of that fuel in larger and medium plant (greater than 0.5% of sectoral fuel demand). The reasoning behind this is simple – we wanted to prioritize effort where it would make the biggest impact on the quality of the NAEI. And, since we are largely proposing using the same emission factors for smaller plant as are currently used for all processes, the new method will not generate different emission estimates for sectors where practically all fuel use is in smaller plant. For this reason, we have not considered fuels such as LPG and burning oil. These fuels are largely absent from EU ETS and so must be almost exclusively used in smaller plant. It would be possible to adapt the proposed method to cover these and other fuels, however it would require additional work and would be unlikely to change emission estimates. However, it might at some point be worth consideration simply because it would allow the UK to report the use of a Tier 2 approach for all of the emissions in the previously listed NFR categories, rather than just for the majority.

The LCP dataset also includes SO_2 emissions and so it would in theory be possible to generate SO_2 emission estimates in a similar way as for NOx and PM_{10}. This has not been done because it is assumed that the current NAEI methodology is relatively high quality and that any alternative estimates would therefore not represent an improvement in quality. Similarly, it would be possible to take the fuel splits generated by the proposed method and to combine them with Tier 2 Guidebook factors for other pollutants. For many pollutants, this would be fairly pointless: Guidebook factors for pollutants such as metals are likely to often be the same or very similar, regardless of whether they are for large, medium or small plant. The main advantage for the UK would perhaps be that we could claim to be using a higher tier method. For some pollutants such as CO and NMVOC, Guidebook emission factors will sometimes be different for the various types of plant and so adopting a Tier 2 approach might then lead to noticeable changes in emission estimates, at least at sectoral level. But stationary combustion is a relatively minor source for NMVOC, so any changes to emission estimates would be unlikely to have much impact on national totals. UK emissions from the nine NFR categories covered by this study were just 1% of 2018 national totals for NMVOC and NH_3, whereas for CO and SO_2 the figures were 16% and 28% respectively. As with NO_X and PM_{10}, it would actually not be appropriate to use the proposed method for all emissions within the nine NFR categories of these four pollutants – sometimes we are already using a higher tier method so the proposed method would not be an improvement. The percentages given above are therefore maximum values for the proportion of the UK inventory for which we could use the method. For SO_2 in particular, this will probably greatly overstate the potential for improvement due to the relatively high quality of the existing estimates.

Therefore, we suggest that while extending the method to other pollutants is possible, it shouldn't be considered an especially high priority.

5.7 UNCERTAINTY

A quantitative assessment of uncertainty is outside the scope of the current work however it is possible to make some qualitative judgements. The proposed method improves on the existing NAEI method in two ways: 1) it uses UK-specific and site-specific data to a greater extent; and 2) where it continues the use of Guidebook factors, it applies these factors within a Tier 2 approach rather than Tier 1.

The use of UK-specific data will lower uncertainty since it allows the NAEI to reflect the actual use of fuel in larger installations (through use of LCP & EU ETS data) and to reflect actual emissions (through use of LCP & PRTR data). The operator-reported emissions data should, in many cases be based on continuous emissions monitoring (CEMS). The EMEP/EEA Guidebook refers to the 2019 Refinement to the 2006 IPCC Guidelines[5] for guidance on reducing uncertainty and these IPCC Guidelines state that improving the representativeness of estimates is one strategy for reducing uncertainty, and gives the use of reported emissions based on CEMS as an example of this.

The existing NAEI method relies on Tier 1 emission factors which should be representative of a 'typical' European combustion plant, but which may not be so representative of UK plant. The proposed method does still use Guidebook factors, but these are used in a Tier 2 method, whereby technology-specific factors are chosen, rather than a generic factor for each fuel type. This ability to select factors that better reflect the type of combustion in each sector mean that the proposed method should give emission estimates that are more certain. Both the EMEP/EEA Guidebook and the IPCC guidelines on reducing uncertainty indicate that uncertainty can be reduced by moving to a higher tier method.

[5] https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol1.html

6. CONCLUSIONS

We can draw the following conclusions from the work:

1. It has been possible to develop an improved method for estimating emissions from industrial-scale combustion plant, which makes separate emission estimates for large, medium and smaller plant.
2. This methodology can be applied to emissions reported in NFR 1A1c, 1A2a, 1A2b, 1A2c, 1A2d, 1A2e, 1A2gviii, 1A4i and 1A4ci. Currently we have generated estimates for all important fuels used in larger and medium-sized plant.
3. As well as allowing separate estimates for different sizes of plant, the method also allows the separate reporting of emissions for some economic sub-sectors within the above listed NFR categories, such as glassworks, brickworks, plaster furnaces and chipboard plant, all of which are part of 1A2gviii in the existing NAEI. Further sub-division of NFR sectors may be possible but hasn't been done for the current work due to the requirement for further data.
4. The method is limited to those fuels that are burnt in significant quantities by large and medium-sized plant (greater than 0.5% of total fuel use in all sizes of plant). The method could be applied also to other fuels such as LPG and burning oil, but since these fuels are burnt almost exclusively in smaller plant, their inclusion in the method would likely have little or no impact on UK emission estimates.
5. The proposed method can be described as a Tier 2 approach, so is a more appropriate methodology for NFR categories such as 1A4ai, which are key sources. The NECD review team flagged the lack of a Tier 2 methodology for that NFR category during the 2020 technical review.
6. The method could be used in the NAEI and updated on an annual basis however some simplification has been suggested to avoid such updates requiring excessive resources.
7. The method requires us to split fuel use into consumption in each of three categories (broadly speaking, these are large, medium and smaller plant). These fuel splits are more uncertain for the earlier years, due to the more limited data available via EU ETS.
8. The method extends back to 2005 only, whereas the NAEI reports emissions from 1970 onwards. We recommend that the emission factors generated for 2005 be used for all earlier years. It would be possible to do research with the aim of generating more considered estimates for earlier years, but these would always be very uncertain due to the lack of data.
9. Using the method would have implications for other deliverables which use the historic NAEI time-series as an input dataset, for example emission projections, point and emission maps. These implications need to be evaluated fully and we can evaluate the additional work to apply the new methodology to these areas of the NAEI if required.
10. In some cases, the quantities of fuel reported in the LCP & EU ETS datasets i.e. for large and medium plant, exceed the fuel consumption reported in DUKES and used in the NAEI for all plant. In all such cases such as this we normalised the data by applying a correction to both large and medium plant sufficient to ensure total fuel use was equal to the NAEI figure.
11. Some of the fuel splits lead to the conclusion that quantities of coal burnt in smaller plant are increasing. This conclusion is counter-intuitive, and discussions with energy statisticians may help our understanding of uncertainty in UK statistics and therefore, how likely this increase in consumption is.
12. The LCP data used in the study contains outliers, some of which appear to be errors (e.g. for certain gas compressor sites in 2013-2014). We have made expert judgements on which outliers should be excluded from the analysis, but it would be an improvement to discuss these outliers with the UK regulators so as to get a better understanding of if any are indeed erroneous.
13. Dust emissions are only reported for LCPs in about 55% of cases. This is because operators of LCPs burning only gaseous fuels have generally not reported dust emissions. While emissions from such plant will likely be small in comparison with other LCPs, inventory guidance suggests emissions won't be zero so we have had to estimate these emissions using Guidebook emission factors. The absence of operator-reported emission data for these sites and the use of simple Guidebook factors instead does add uncertainty to the overall estimates.

14. Emissions data reported in the PRTR, or in the emission inventories maintained by UK regulators can be used to generate UK-specific factors for some medium-sized plant, improving the quality of the estimates. There is some scope to extend the existing work further.
15. The relatively small number of different emission factors available in the Guidebook is a limiting factor for the proposed method. In the short-term, the only way to overcome this would be to develop UK-specific factors though this would be resource-intensive.
16. There are instances where the choice of Guidebook emission factor has a particularly large impact on emission estimates, for example for use of natural gas where NO_X factors are much higher for engines. More analysis of the type of combustion plant on EU ETS installations would allow the selection of factors to be made with more confidence.
17. Emission estimates generated using the proposed method are similar to those generated using the existing NAEI method and this is due to the common source of emission factors for much of the fuel use. Though the existing method relies on Guidebook Tier 1 factors and the proposed method uses Tier 2 factors wherever possible, these factors are very similar. In many cases, the Tier 1 factors are often the mean of selected Tier 2 factors.
18. There are some differences in the emission estimates, however. In particular, the proposed method suggests a lower growth in PM_{10} emissions between 2005 and 2018 compared with the existing method (18% compared with 51%). Use of the proposed method in the NAEI could therefore have a noticeable impact on UK progress against emission reduction targets.
19. The proposed method would, for the first time, allow the NAEI to generate separate emission estimates for large, medium and smaller plant. The definition of large plant would be consistent with large combustion plant as defined in Chapter III of the IED. The definition of medium plant would not be consistent with the scope of the MCPD since it includes installations that are outside the scope of MCPD (e.g. furnaces) and exclude smaller plant which are within the scope of MCPD. Nevertheless, it would be an important first step towards an NAEI that could provide emission estimates for combustion processes, disaggregated by size of plant and regulatory regime.
20. The proposed method suggests that the majority of emissions reported in the nine NFR categories come from smaller plants – over 50% of NO_X and over 80% of PM_{10}. Much of the remaining emissions are generated from medium plant so large combustion plant are responsible for only a very small percentage of total emissions from all industrial-scale combustion plant.
21. Emissions of both NO_X and PM_{10} have fallen from large combustion plant. This may reflect the requirement for process operators to have abated emissions and/or to upgrade or replace combustion plant in response to regulation.
22. The new estimates suggest that NO_X emissions from medium and smaller plant are declining. For medium plant this is partly a reflection of the use of operator-reported emissions data i.e. it is likely to reflect site-specific changes at regulated sites, that could include abatement or other improvements. The decrease in emissions from smaller plant is solely due to changes in UK fuel consumption – modest decreases in natural gas use and generally larger reduction in use of solid mineral fuels and heavy oils.
23. For PM_{10}, the estimates suggest that emissions from medium and smaller plant are not falling. The figures for medium plant indicate very little net change between 2005 and 2018 and though the figure in 2018 is 4% lower than that in 2005, there is no suggestion of a sustained reduction over the period. Estimates for smaller plant indicate an increase in PM_{10} from this type of plant between 2005 and 2018, almost exclusively due to an increased use of solid fuels (so biomass and coal).
24. Because our method utilises data collected for the purposes of EU ETS, we are likely to underestimate the use of biomass fuels in medium-sized plant. This may lead to the method overestimating emissions of PM_{10} from this fuel. Further research would be needed to address this issue however it is likely that our estimates for biomass fuels would still be more uncertain than those for fossil fuels (because of the absence of high-quality data such as is available for fossil fuels in the EU ETS dataset.
25. The proposed method should reduce uncertainty in emission estimates through increased use of UK-specific data and use of a higher tier method.

7. RECOMMENDATIONS

We make the following recommendations:

Adoption of the method in the NAEI

- The method should be adopted for the 2019 version of the NAEI, published in February 2021, replacing the current Tier 1 approach which is not consistent with emission inventory guidance for a key category
- To minimise resource impacts, annual updates for future versions of the NAEI should be made using a simplified analysis of EU ETS-type data each year, with more detailed analyses, including of LCP returns, made periodically to verify assumptions.
- The method could be extended to other, minor fuels. This could improve consistency and accuracy of the inventory in this area for relatively little resource however it would be unlikely to have much impact on emission estimates. It would mean, however, that the UK was using a higher tier method for these minor fuels.
- It would be possible to extend the method to other pollutants but for the most part this is unlikely to have much impact on emission estimates or UK emission totals. However, it would mean that the UK was using a higher tier method for these pollutants.

Improvement of the method and estimates for large plant

- The LCP dataset included some outlier values, and some of these could be the result of error. Consultation with regulators would help to identify any errors, and where values are correct, explain the context.
- Only 55% of LCP returns report dust emissions. While this is explainable, it does add uncertainty to the emission estimates. Further analysis and consultation with regulators could identify ways to improve the gap-filling process used to generate dust emission estimates for these sites.

Improvement of the method for medium plant

- Further analysis of the types of combustion devices used at medium plant and small plant would help improve the confidence in emission factors. Permit documents, if available could be analysed so that the selection of emission factors could be better-informed and be made at the level of individual sites. Such an analysis is recommended for sites using natural gas and gas oil but is less important for solid fuels or fuel oil because of the more limited range of technologies used for those fuels.
- Consultation with industry could help to improve the assumptions used to address changes in the scope of EU ETS. However, this would be quite resource-intensive and may yield a limited improvement in the quality of estimates.
- Further analysis of regulators' emission inventories (PRTR, PI, SPRI etc.) and consultation with regulators and industry could allow more site-specific emissions data to be included in the method. This is turn could improve the sensitivity of the method to changes in industry caused by regulation.
- For some sectors, there is currently no likelihood of collecting sufficient site-specific emissions data to generate Tier 3 UK emission factors. As an alternative, we recommend that consultation with regulators and industry could be used to establish if other approaches could be used to generate UK-specific emission factors, such as the use of emission limit values (ELVs) that installations across a sector might be expected to comply with.
- Permitting of MCPs and specified generators means that information on these installations should become available. This information could be used to improve the emission estimates and we recommend that regulators are contacted to understand the progress on permitting and

to obtain information on the numbers of plant, installed technologies, fuels ELVs and emission data. Early discussion with the regulators is recommended to establish the available data and to enable simple and robust reporting systems for key data.

Improvement of the method for smaller plant

- Further analysis is needed to split the fuel estimates for smaller plant into at least 3 categories: i) small MCPs; ii) small furnaces and similar plant regulated under IED or UK regulations; iii) small, unregulated plant. We suggest this is the highest priority for further work, although it will also be challenging and might also need to be a long-term task to reflect the phased permitting of installations under MCPD.
- Consultation with regulators and industry could be used to establish UK-specific emission factors for smaller (but regulated) plant. Factors could be based on emission limit values (ELVs) or other conditions of operation for installations. In some limited cases, it might be possible to collect site-specific emissions data and to generate a UK-specific and sector-specific emission factor in that way. However, generation of UK-specific factors would likely require a more detailed understanding of the make-up of the smaller plant category, so this current recommendation would probably be dependent on the previous recommendation having been carried out.

8. UPDATES TO THE METHOD IN 2023-2024

Sections 3-7 of this report detail the work carried out in 2020 to develop a new method for estimating emissions from selected parts of 1A2, 1A4ai & 1A4ci. This new method was subsequently accepted for use in the 2021 submission of the NAEI. In the 2024 submission, covering up to the year 2022, further refinements have been made to the method and these are detailed here. The changes can be summarised as follows:

1. Extension of the method to also generate emission estimates for NMVOC, CO, $PM_{2.5}$, Black Carbon, and a range of POPs/PAHs
2. Changes to the choice of emission factors selected for particular sectors and classes of combustion device, particularly in the case of biomass/biofuel combustion.
3. Conversion of the main compilation model from Excel to R

Further details of the changes in each of these areas is given below.

The extension of the method to cover additional pollutants was a significant change but relatively easy to implement. The existing method for PM_{10} and NO_X made heavy use of emission factors taken from the EMEP/EEA Guidebook and this reference also provides factors for many other pollutants. The Guidebook defines various classes of combustion device and then provides emission factors for the same set of pollutants for each of those classes of combustion device. Since we had already assigned NAEI activity data to these classes for the purposes of estimating PM_{10} and NO_X, it was a simple task to also use the relevant factors for other pollutants, thus generating Tier 2 estimates for those pollutants as well. In theory, one could also have treated further pollutants in the same way – metals, for example – however the NAEI already uses methods for these pollutants that are considered more reliable than the Guidebook factors. Previous versions of the NAEI had used emission factors from a range of literature sources including the US EPA's compilation of emission factors known as AP-42, and revising to use Guidebook factors did result in some notable changes in UK emission estimates e.g. for estimates for NMVOC from gas combustion, where EMEP/EEA factors are higher than the US EPA factors which they replace. However, industrial-scale combustion remains a relatively trivial source of NMVOC emissions despite this revision.

Emission factors for NO_X and PM_{10} were reviewed at the same time as the scope of the method was increased. In most cases, we considered that no change was required however there were two areas where changes were deemed necessary. The first of these relates to the burning of wood/biomass, and the second area relates to the burning of gaseous fuels.

The changes for the burning of wood/biomass were especially significant. The work described in the rest of this report used LCP data and ETS data to identify large and large/medium sites burning fossil fuels but these two datasets contain relatively little information on sites burning biomass (although they do contain data on sites burning waste wood). Therefore practically all biomass combustion is by default allocated to the smallest size category in the resulting emission estimation model. Originally, emissions from this 'small' category of biomass use had then been calculated using Tier 1 emission factors taken from the EMEP/EEA Guidebook. The values for PM_{10} were 143 g/GJ(net) for combustion in NFR 1A2 and 163 g/GJ(net) for combustion in NFR 1A4a/c. These T1 factors were used in the versions of the NAEI submitted in 2021 to 2023.

The 2023 review of factors considered all of the available Guidebook options for solid biomass/wood, which are shown below in Table 9:

Table 9. $PM_{2.5}$ factors from the 2019 edition of the EMEP/EEA Emission Inventory Guidebook

NFR	GB 2019 Table	Tier	Scope	PM_{10}, g/GJ net
1A4a/c	3.10	1	All sectoral combustion	163
1A2	3.5	1	All sectoral combustion	143
1A4a/c	3.45	2	>1 MW boilers	38
1A4a/c	3.46	2	<1 MW boilers (unknown type)	100.5
1A4a/c	3.47	2	1 MW boilers (manual)	163
1A4a/c	3.48	2	1 MW boilers (automatic)	38

This table shows clearly how the T1 factors are relatively high/conservative compared to some of the Tier 2 emission factors. The Tier 1 emission factors for 1A4a/c are identical to those presented for **manually-stoked** biomass boilers <1MW (both 163 g/GJ). The Tier 1 factors for 1A2 (143 g/GJ) are slightly lower but still very much closer to the manual boiler factor than the automatic boiler factor (38 g/GJ). Both of the T1 factors, the T2 factors for manually-stoked boilers, and the factor for 'unknown' types (100.5 g/GJ) appear to us to be quite conservative for modern boilers which likely dominate UK stock and operation. The growth in use of biomass for heat in recent years has been driven by various decarbonising policies which means that the UK stock of such boilers is relatively new and this implies automatic operation and relatively low emissions compared to manual boilers. For example:

- The Renewable Heat Incentive (RHI) drove recent installation of many non-domestic boilers and included a 30g/GJ threshold for PM (TSP) emissions.
- For boilers up to 500 kW output the maximum allowed TSP concentration for type-approval under EN303-5:2012[6] was about 72 g/GJ but automatic Class 5 biogenic boilers achieve 20 g/GJ (and Ecodesign requirements[7] in place since January. 2020 are about 30 g/GJ and 20g/GJ for manual and automatic boilers respectively).
- Burning of waste wood has been a regulated activity for many years and emission limits (applicable since 2013) for EPR small waste incineration plant are lower than 40 g/GJ (the EPR Schedule 13 emission limit for treated waste wood and the BAT requirements for larger plant are lower).

Until introduction of MCP controls (which do not fully apply to existing MCP yet) burning of wood below 20MWth was covered by Clean Air Act either through the relatively relaxed Grit and Dust

[6] BS EN 303-5:2012 Heating Boilers, Part 5 : Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500kW – Terminology, requirements, testing and marking (since replaced by the 2021 version but classes of dust emission unchanged)

[7] COMMISSION REGULATION (EU) 2015/1189 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1189

regulations or additional requirements in Smoke Control Area which sets an emission limit[8] of 150 mg/m^3 for a dry gas at 0°C, 101.3 kPa and stack O_2 (72 g/GJ assuming 10% O_2). Boiler and air heater appliances approved (Exempted) for use in Smoke Control Areas are predominantly automatic devices (both at residential and non-residential scale).

Although use of older technologies including manual-stoking cannot be ruled out, we consider that wood-burning in the industrial and commercial sectors has been predominantly from use of automatic boilers. Therefore, we revised the emission calculations for the 2024 submission of the NAEI to use the 38 g/GJ factors from Tables 3.45 and 3.48 for medium-sized and small-sized biomass combustion respectively. The switch from T1 to T2 factors was replicated for other pollutants too, but has no impact on NO_X since both T1 & T2 factors are the same. However, In the case of NMVOC & CO, the decision to use T2 factors is significant because the T2 factors are lower: 12 g/GJ NMVOC & 300 g/GJ CO, compared with factors of 300 g/GJ NMVOC & 570 g/GJ CO had the calculations been made using the T1 factors for biomass. As with $PM_{2.5}$, the much higher T1 factors for NMVOC & CO are the same as the T2 factors for manually-stoked boilers and do not seem appropriate for the UK's relatively modern stock of combustion plant, so the use of T2 factors seems right for these pollutants as well.

In the case of gaseous fuels, the change was less significant in terms of the percentage change to emission factors but was introduced to improve the quality of the method for NO_X emissions from the most commonly used fuels in the UK. In the 2019-2021 submissions, many sectors burning gaseous fuels had their emissions calculated using a T1 factor published in the NFR 1A2 section of the 2019 Guidebook. The T1 factor for NO_X (74 g/GJ net) seems to have been calculated as the average of four T2 factors – for gas use in medium boilers (40 g/GJ net), small boilers (73 g/GJ net), gas turbines (48 g/GJ net), and engines (135 g/GJ net) respectively. Since the T1 factor is equal to the average of these four factors, it is equivalent to assuming that one quarter of the gas is burnt in each type of appliance. Because the factor for engines is much higher than the factors for the other types of appliance, we wanted to test whether this assumption of one quarter of gas burnt in engines was reasonable for the UK. We therefore used data on CHP plant technologies contained in DUKES to generate an estimate and found that the actual figure was more likely to be about 5%. Therefore, the T1 factor, since it assumed 25% use of gas in engines, would overestimate emissions in the UK where usage in engines was more likely 5%. We therefore calculated a new composite factor using the four T2 factors mentioned above, but with engines assumed to represent 5% of gas use i.e. the new factor was:

5% x (135 g/GJ) + 95% x (average of 40 g/GJ, 48 g/GJ & 73 g/GJ)

The new composite NO_X factor was 57.7 g/GJ, so 22% lower than the T1 factor, and for the 2023 submission it was applied in all cases where the T1 factor had previously been used. We did not have sufficient information to generate a robust split for the other three types, which is why the composite factor assumed an equal share of gas turbines, small boilers and medium boilers. The composite factor could be further refined in future if an accurate split within these three categories could also be generated. Note that a similar calculation was performed for other pollutants, again leading to a lower factor than the T1, although the emissions of these other pollutants are relatively trivial within a UK context both before and after the improvement.

[8] As described here : https://assets.publishing.service.gov.uk/media/5dc176d540f0b63796dc4c3b/hetas-appliance-exemption-app-guidance.pdf

9. APPENDICES

Appendix A: Emission factors derived for LCPs

Appendix B: Guidebook factors used in the proposed method

APPENDIX A – EMISSION FACTORS DERIVED FOR LCPS

Emission factors are summarised in Table A1 for NO_X and Table A.2 for PM_{10}.

Table A.1 Derived NO_X factors for UK large combustion plant, in g/GJ (net)

Sector	Fuel	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gas distribution	Natural gas	69	65	164	125	90	96	74	80	229	219	98	46	59
Steelworks	Fuel oil	90	75	93	110	116	77	96	85	144	148	112	62	90
Steelworks	Natural gas	34	34	39	39	50	41	33	43	38	37	44	25	38
Steelworks	Blast furnace gas	29	29	30	33	42	32	23	30	55	50	46	23	36
Steelworks	Coke oven gas	0	0	0	0	0	47	53	0	0	0	0	25	0
Oil terminals	Gas oil	390	400	218	345	345	325	300	982	716	325	353	685	350
Oil terminals	Natural gas	69	69	75	89	80	85	62	98	95	58	47	47	118
Other industry	Gas oil	1751	1597	1565	919	838	651	1369	673	535	812	314	0	0
Other industry	Natural gas	92	77	77	44	38	40	47	50	57	62	50	53	64
Other industry	Biomass	59	68	85	73	64	159	87	140	178	187	84	41	40
Public	Natural gas	398	379	342	330	384	424	386	288	291	294	241	48	48
Railways	Natural gas	116	95	111	105	106	203	352	96	90	96	1889	203	144
Oil & gas	OPG	72	56	86	252	118	144	148	187	180	164	163	74	81
Gas terminals	Gas oil	0	0	0	0	2055	0	0	0	494	474	670	1153	1476
Gas terminals	Natural gas	51	83	139	141	120	41	82	78	57	67	83	51	60
Chemicals	Fuel oil	184	135	172	171	279	341	298	133	142	0	0	0	0
Chemicals	Gas oil	532	621	483	530	590	507	448	395	323	303	1043	174	520
Chemicals	Natural gas	70	72	54	63	53	55	63	69	46	42	56	40	38
Chemicals	OPG	108	120	155	106	79	97	118	101	100	84	93	68	50
Chemicals	Coal	344	221	173	200	219	214	224	224	221	226	217	177	166
Paper	Gas oil	464	700	611	382	337	340	99	522	691	571	281	567	0
Paper	Natural gas	55	56	55	48	51	50	48	48	42	54	49	62	64
Paper	Coal	235	245	251	268	278	279	286	0	0	0	0	0	0
Food & drink	Natural gas	61	39	31	33	30	25	31	36	50	51	45	41	40

Note: zero values indicate that a fuel was not burnt in LCPs for that year

Table A.2 Derived PM_{10} factors for UK large combustion plant, in g/GJ (net)

Sector	Fuel	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gas distribution	Natural gas	0.20	0.15	5.49	0.05	0.25	0.27	0.33	0.41	0.32	0.33	0.20	0.19	0.15
Steelworks	Fuel oil	121.84	131.02	59.84	126.43	111.48	279.74	179.33	131.43	404.40	499.29	224.80	291.09	494.17
Steelworks	Natural gas	1.08	1.43	0.69	1.01	1.02	1.09	0.60	0.37	0.57	80.60	0.43	0.58	0.53
Steelworks	Blast furnace gas	1.02	1.08	0.66	1.11	0.98	1.69	1.16	1.12	2.97	3.29	1.49	1.15	1.62
Steelworks	Coke oven gas	0.00	0.00	0.00	0.00	0.00	3.54	1.47	0.00	0.00	0.00	0.00	0.58	0.00
Oil terminals	Gas oil	12.18	12.18	12.18	12.18	12.18	12.18	12.18	12.18	1.53	2.62	2.86	0.27	0.06
Oil terminals	Natural gas	0.20	0.20	0.20	0.64	0.20	0.53	0.49	0.21	0.22	0.08	0.19	0.13	0.24
Other industry	Gas oil	16.19	25.84	50.11	34.23	23.11	30.74	41.98	44.37	12.18	47.38	38.73	0.00	0.00
Other industry	Natural gas	1.50	2.70	0.72	0.47	0.75	0.54	0.57	0.74	0.48	0.67	0.45	0.71	0.38
Other industry	Biomass	28.27	20.31	23.65	31.24	30.11	2.25	0.98	1.53	4.18	4.46	155.00	0.20	0.12
Public	Natural gas	0.87	0.90	0.81	0.80	0.81	0.94	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Railways	Natural gas	0.20	0.20	1.19	1.02	0.95	0.20	0.20	0.20	0.20	0.20	9.97	1.22	1.50
Oil & gas	OPG	0.20	0.20	1.05	1.71	0.77	0.74	0.88	1.13	1.18	1.07	0.92	0.50	0.30
Gas terminals	Gas oil	0.00	0.00	0.00	0.00	12.18	0.00	0.00	0.00	12.18	12.18	12.18	12.18	148.66
Gas terminals	Natural gas	0.20	0.20	1.77	0.20	0.20	0.18	0.17	0.50	0.31	0.30	0.20	0.21	0.67
Chemicals	Fuel oil	9.64	30.95	37.19	15.45	12.95	15.99	14.04	19.64	109.45	0.00	0.00	0.00	0.00
Chemicals	Gas oil	13.76	29.45	25.89	10.18	25.42	17.96	18.89	14.18	14.95	12.95	11.43	3.56	29.86
Chemicals	Natural gas	1.56	2.17	1.70	1.16	1.01	1.00	0.93	1.18	1.16	0.89	1.49	0.29	0.27
Chemicals	OPG	2.48	4.01	0.98	2.93	1.40	1.99	2.19	2.68	1.90	1.70	2.48	0.45	0.27
Chemicals	Coal	0.69	0.63	0.30	0.26	0.23	0.58	0.49	0.70	1.18	7.70	7.70	7.70	7.70
Paper	Gas oil	15.80	23.83	19.44	30.80	24.03	45.89	3.33	22.48	58.45	41.98	13.34	12.18	0.00
Paper	Natural gas	0.31	0.43	0.82	0.68	0.76	0.50	0.56	4.75	2.70	0.56	0.36	0.30	0.28
Paper	Coal	65.21	27.37	48.85	50.31	58.60	55.03	48.62	0.00	0.00	0.00	0.00	0.00	0.00
Food & drink	Natural gas	0.65	0.98	0.65	0.16	0.26	0.70	0.67	0.75	1.01	1.00	0.78	0.61	0.61

Note: zero values indicate that a fuel was not burnt in LCPs for that year

APPENDIX B – GUIDEBOOK AND RELATED FACTORS USED IN THE METHOD

Table B.1 presents Guidebook factors used to fill gaps in emission reporting for large combustion plant.

Tables B.2 to B.10 show the factors used for medium and small plant, with the tables grouping factors by broad economic sector. In these tables, the following codes are used for the class of installation:

M	refers to large MCPs and large furnaces/kilns/driers etc.
S	refers to small MCPs, SCPs and small furnaces/kilns/driers etc.

Table B.1 Guidebook factors for large combustion plant

Economic sector	Fuel	Guidebook Details				Factor, g/GJ (net)		
		Chapter	Table	Factor description	Tier	NO_X	PM_{10}	$PM_{2.5}$
All sectors	Coal	1A1	3-9	Hard coal, dry bottom boiler	2	209	7.7	3.4
All sectors	Fuel oil	1A1	3-11	Residual oil, dry bottom boiler	2	142	25.2	19.3
All sectors	Gas oil	1A1	3-18, 3-19	Gas oil, gas turbine and gas oil, engine (mean used)	2	670	12.2	11.8
All sectors	Natural gas; OPG; coke oven gas; blast furnace gas	1A1	3-17	Gaseous fuels – gas turbines	2	48	0.2	0.2
All sectors	Biomass	1A1	3-13	Wood, dry bottom boilers	2	81	155	133

Note: These emission factors have been applied where plant-specific emission data have not been reported and gap-filling is needed to develop a time series.

Table B.2 Guidebook Factors for oil & gas industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_x	PM_{10}	$PM_{2.5}$	
Offshore oil	M	Gas oil	1A4	3-9	Liquid fuels	1	306	21	18	Mixed technology
Offshore oil	S	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Offshore oil	M	Natural gas	1A4	3-28	Natural gas, gas turbines	2	48	0.2	0.2	Gas turbine
Offshore oil	S	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler
Offshore gas	M	Gas oil	1A4	3-9	Liquid fuels	1	306	21	18	Mixed technology
Offshore gas	S	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Offshore gas	M	Natural gas	1A4	3-28	Natural gas, gas turbines	2	48	0.2	0.2	Gas turbine
Offshore gas	S	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler
Oil terminals	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnaces
Oil terminals	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnaces
Gas terminals	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnaces
Gas terminals	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnaces
Terminals	M	OPG	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnaces
Terminals	S	OPG	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Terminals	S	OPG	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Gas distribution	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Gas distribution	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Gas distribution	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Gas distribution	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.3 Guidebook Factors for iron and steel industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_x	PM_{10}	$PM_{2.5}$	
Steelworks	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Steelworks	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Steelworks	M	Coke oven gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Steelworks	M	Blast furnace gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Steelworks	S	Blast furnace gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Steelworks	S	Blast furnace gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Other steel	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Furnace
Other steel	S	Coal	1A4	3-20	Coal, 50kWth – 1 MWth boilers	2	160	76	72	Furnace
Other steel	M	Coke	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Furnace
Other steel	S	Coke	1A2	3-2	Solid fuels	1	40	0.45	0.45	No specific technology 1A2 used as not coal fuel.
Other steel	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Other steel	S	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Other steel	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Other steel	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	No specific technology, 1A2 used as more conservative than 1A4
Other steel	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler or furnace
Other steel	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Other steel	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Other steel	M	Coke oven gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Other steel	S	Coke oven gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Other steel	S	Coke oven gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.4 Guidebook Factors for non-ferrous metal industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_X	PM_{10}	$PM_{2.5}$	
Non-ferrous	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Non-ferrous	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	No specific technology,.1A2 used as most appropriate for sector.
Non-ferrous	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler or furnace
Non-ferrous	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Non-ferrous	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.5 Guidebook Factors for chemical industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_X	PM_{10}	$PM_{2.5}$	
Chemicals	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Boiler
Chemicals	S	Coal	1A4	3-20	Coal, 50kWth – 1 MWth boilers	2	160	76	72	Boiler
Chemicals	M	Waste oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Chemicals	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Chemicals	S	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Chemicals	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Chemicals	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	No specific technology,.1A2 used as most appropriate for sector.
Chemicals	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler or furnace
Chemicals	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Chemicals	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Chemicals	M	OPG	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler
Chemicals	S	OPG	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Chemicals	S	OPG	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.6 Guidebook Factors for paper industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_x	PM_{10}	$PM_{2.5}$	
Paper	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Boiler
Paper	S	Coal	1A4	3-20	Coal, 50kWth – 1 MWth boilers	2	160	76	72	Boiler
Paper	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Paper	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	No specific technology,.1A2 used as most appropriate for sector.
Paper	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler
Paper	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Paper	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.7 Guidebook Factors for food & drink industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_x	PM_{10}	$PM_{2.5}$	
Food & drink	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Boiler
Food & drink	S	Coal	1A4	3-20	Coal, 50kWth – 1 MWth boilers	2	160	76	72	Boiler
Food & drink	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Food & drink	S	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Food & drink	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Food & drink	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	No specific technology,.1A2 used as most appropriate for sector.
Food & drink	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler or furnace
Food & drink	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Food & drink	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.8 Guidebook Factors for mineral industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_x	PM_{10}	$PM_{2.5}$	
Bricks	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Bricks	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Glass	M	Petroleum coke	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Furnace
Glass	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Glass	M	Waste oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Glass	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Glass	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Plaster	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Plaster	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace
Roadstone	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Roadstone	M	Waste oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Roadstone	M	Gas oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Furnace
Roadstone	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Furnace

Table B.9 Guidebook Factors for other industry installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_X	PM_{10}	$PM_{2.5}$	
Autogeneration	M	Natural gas	1A4	3-28	Natural gas, gas turbines	2	48	0.2	0.2	Gas turbine
Autogeneration	S	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Car manufacture	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler
Chipboard	S	Waste wood	1A2	3-5	Biomass fuels	1	91	143	140	Mixed technology
Minor power	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Minor power	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Other industry	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Boiler
Other industry	S	Coal	1A4	3-20	Coal, 50kWth–1 MWth boilers	2	160	76	72	Mixed technology
Other industry	M	Biomass	1A4	3-45	Wood, 1-50 MW_{th} boilers	2	210	38	37	Boiler
Other industry	S	Biomass	1A2	3-5	Biomass	1	91	143	140	Mixed technology
Other industry	S	Biomass	1A4	3-48	Wood, <1MWth automatic boilers	2	91	38	37	Automatically-stoked boiler
Other industry	S	Petroleum coke	1A2	3-2	Solid fuels	1	173	117	108	Mixed technology
Other industry	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Other industry	S	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Other industry	M	Waste oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Other industry	S	Waste oil	1A2	3-4	Liquid fuels	1	513	20	20	Mixed technology
Other industry	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Other industry	S	Gas oil	1A2	3-4	Liquid fuels	1	513	20	20	Mixed technology
Other industry	M	Natural gas	1A4	3-27	Natural gas, 1-50 MW_{th} boilers	2	40	0.45	0.45	Boiler or furnace
Other industry	S	Natural gas	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Other industry	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Other industry	M	Colliery methane	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Other industry	S	Colliery methane	1A2	3-3	Gaseous fuels	1	74	0.78	0.78	Mixed technology
Other industry	S	Colliery methane	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table.

Table B.10 Guidebook Factors for agricultural, commercial & public sector installations

Subsector	Class	Fuel	Guidebook Details				Factor, g/GJ (net)			Assumed technology
			Chapter	Table	Factor description	Tier	NO_X	PM_{10}	$PM_{2.5}$	
Agriculture	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Agriculture	S	Natural gas	1A4	3-8	Gaseous fuels	1	74	0.78	0.78	No technology assumption
Agriculture	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Data centres	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Data centres	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Other commercial	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Other commercial	S	Gas oil	1A4	3-9	Liquid fuels	1	306	21	18	No technology assumption
Other commercial	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Other commercial	S	Natural gas	1A4	3-8	Gaseous fuels	1	74	0.78	0.78	No technology assumption
Other commercial	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Public	M	Coal	1A4	3-21	Coal, 1-50 MW_{th} boilers	2	180	76	72	Boiler
Public	S	Coal	1A4	3-20	Coal, 50kWth–1 MWth boilers	2	160	76	72	Boiler
Public	M	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Public	S	Fuel oil	1A4	3-25	Fuel oil, 1-50 MW_{th} boilers	2	100	40	30	Boiler
Public	M	Gas oil	1A4	3-31	Gas oil, reciprocating engines	2	942	30	30	Engine
Public	S	Gas oil	1A4	3-9	Liquid fuels	1	306	21	18	No technology assumption
Public	M	Natural gas	1A4	3-30	Natural gas, reciprocating engines	2	135	2	2	Engine
Public	S	Natural gas	1A4	3-8	Gaseous fuels	1	74	0.78	0.78	No technology assumption
Public	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines
Railways	M	Natural gas	1A4	3-28	Natural gas, gas turbines	2	48	0.2	0.2	Gas turbine
Railways	S	Natural gas	1A4	3-8	Gaseous fuels	1	74	0.78	0.78	No technology assumption
Railways	S	Natural gas	1A4	NA	Gaseous fuels	2	57.7	0.4	0.4	Mixed technology, 5% engines

Entries in red refer to changes introduced in the 2023 submission with these factors replacing the previous entry in the table

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