IMPROVEMENTS TO THE NATIONAL ATMOSPHERIC EMISSIONS INVENTORY FOR NRMM - NON-AGRICULTURAL MACHINERY

Methodology Report

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National Atmospheric Emissions Inventory

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FOREWORD

This work on Improvements to the Emission Inventory for Non-Agriculture Non-Road Mobile Machinery was conducted in 2019-2021 and was first used in the 2023 submission of the National Atmospheric Emissions Inventory (NAEI) and was published in the Informative Inventory Report (1990 to 2021), Section 3.3.9.2[1] and is available on the NAEI website. Any future development to the NRMM model will be documented in the latest UK Informative Inventory Report.

EXECUTIVE SUMMARY

Between 2019 to 2021, Defra commissioned Ricardo to undertake a research project to inform policy development to address emissions from non-agricultural Non-Road Mobile Machinery (NRMM).

A broad definition of NRMM (from EU Regulation 2016/1628) is any mobile machine, transportable equipment or vehicle (with or without bodywork or wheels), not intended for the transport of passengers or goods on the road, and includes machinery installed on the chassis of vehicles intended for the transport of passengers or goods on roads. It should be noted that the scope of this research project does not cover stationary equipment, agricultural & forestry machinery, grounds care/gardening machinery, railway vehicles or watercrafts.

As part of this research, the project team has collated updated activity data and developed a new NRMM emissions calculation model which underpins the current National Atmospheric Emissions Inventory (NAEI).

The focus of the Defra research project was towards NRMM's relevance to urban air quality where the greatest population exposure will occur, and thus the following industry sectors where the use of NRMM applied have been considered:

- Construction
- Mining/Quarrying
- Waste
- Other industry (e.g. warehousing, logistics, supermarkets, road surface treatment)
- Machineries used in airports and seaports, and
- Transport refrigeration units.

This report summarises the research approach and process in gathering the updated NRMM activity data (Chapter 2), and the current methodology and input assumptions for estimating NRMM emissions for the aforementioned industry sectors (Chapter 3).

Details of the methodology relating to agriculture mobile machinery can be found in the "Improvements to the Emission Inventory for NRMM – Agricultural Machinery" report (2025), while further information relating to domestic house and garden machinery (1A4bii) are described in the latest UK Informative Inventory Report[2].

It should be noted that a further step in the existing NAEI inventory calculation involves reconciling overall bottom-up estimates of gas oil used by diesel NRMM with total UK gas oil consumption figures presented in the Digest of UK Energy Statistics (DUKES). This ensures an overall energy balance is maintained, a requirement in national inventory reporting. The current fuel reconciliation approach is summarised in the latest UK Greenhouse Gas Inventory: Annexes report (Annex 4, Section A4.2.1.4)[1].

[1] UK_IIR_2023_Submission

[2] Reports - NAEI, UK (naei.energysecurity.gov.uk)

1. INTRODUCTION

Non-Road Mobile Machinery (NRMM) covers a very wide range of machinery, which spans from very small machinery (e.g. household generators, lawnmowers and chainsaws) to heavy machinery (e.g. excavators, cranes, large generators, off-road trucks, mining and drilling machinery). Due to its diverse nature of use, it represents an uncertain and challenging emission source to characterise.

During 2019 to 2021, Defra commissioned Ricardo to undertake a research project to inform policy development to address emissions from non-agricultural Non-Road Mobile Machinery (NRMM). As part of this research, the project team has collated updated activity data and developed a new NRMM emissions calculation model to improve the current National Atmospheric Emissions Inventory (NAEI).

The previous NAEI NRMM inventory model was based on a detailed bottom-up approach, taking into account the power of the engine, estimates of the UK population and annual hours of use of each type of machinery. It included a simple fleet turnover calculation used to characterise the population of each machinery type by age (year of manufacture/sale) each year and hence emission standard. Emission factors are largely taken from the EMEP/EEA Emissions Inventory Guidebook which provides g/kWh factors for different legislative classes of machinery and engine and fuel types. The population, usage and lifetime of different types of off-road machinery were based on a detailed study carried out in 2004[3,4], with some further updates in 2014. However, because of the sparsity of NRMM activity data, the lack of centralised reporting to a regulatory agency, and the resource-intensive nature of capturing further information through dialogue with potential stakeholders, the NAEI does not routinely update the NRMM activity data used in the compilation of the inventory each year.

This report summarises the approach and process in gathering the updated NRMM activity data as part of the 2019-2021 Defra research, and subsequently the model development which underpins the current NAEI NRMM emission inventory.

It should be noted that the focus of the 2019-2021 Defra research was towards NRMM's relevance to urban air quality where the greatest population exposure will occur. As a result, agricultural machinery is not considered except for where specific machinery types may be used for non-agricultural purposes, as in the case of industrial tractors. Table 1-1 summarises which industry sectors where the use of NRMM have been considered as part of the research project.

Table 1-1 Scope of industry sector (of which the use of machinery) considered.

Industry Sector	Within scope:	Priority:	Notes:
Construction	Yes	High	-
Roadworks	Yes	High	-
Transport refrigeration units	Yes	High	-
Airports/Ports	Yes	Medium/High	-
Permitted sites (large industrial complexes)	Yes	Medium/High	Those close to an urban population are relevant.
Sites not subject to permitting (warehousing/storage)	Yes	Low/Medium	-
Mining and quarrying	Yes	Low	Most operational sites are in rural areas.
Rail vehicles, agricultural machinery, fishing vessels and other marine vessels, smaller domestic NRMM	No	-	For agriculture machinery, please refer to "Improvements to the Emission Inventory for NRMM – Agricultural Machinery" report (2025)

[3] https://uk-air.defra.gov.uk/assets/documents/reports/cat15/0502141215_NRMM_report_Final_November_2004_3.pdf
[4] Emission factor programme Task 8c - emissions from non-road machinery in the lawn and garden sector (defra.gov.uk)

2. RESEARCH APPROACH

The 2019/2020 Defra research project approach focused efforts towards a framework of actors within the NRMM market:

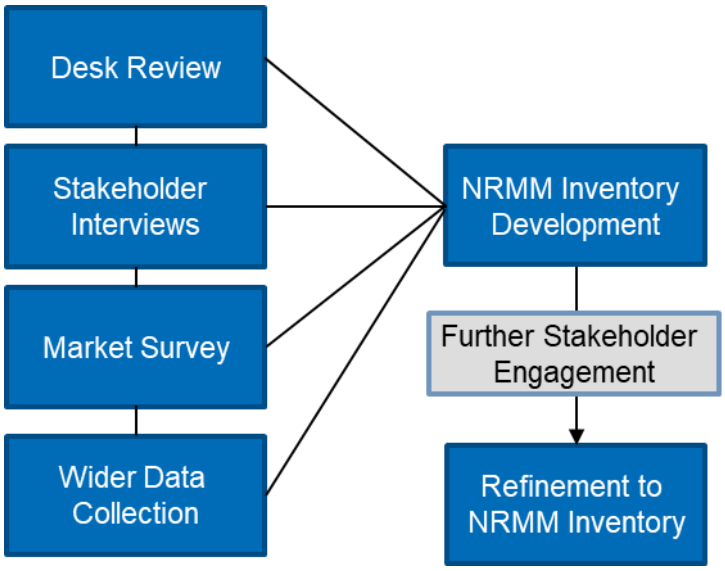
- Operators – Organisation or company that hires or owns NRMM to operate in one or many commercial applications.
- Hire companies – Organisation that hires or leases NRMM to operators.
- Manufacturers, dealers, and distributors – Organisation that manufacturers NRMM, or has a role within the market that results in an understanding of NRMM at the point of sale.

It is considered that each type of actor would be knowledgeable towards different aspects of NRMM operation. For example, operators are directly involved in the use of NRMM within specific applications, they therefore understand aspects such as the location of use, hours of use, fuel used. Whereas manufacturers, dealers and distributors tend to understand more readily the anticipated lifetime of a specific machine.

Note that, whiles this framework generally applies across industry sectors, there are specific examples of where this framework may not hold true. The project team understand that for industrial trucks (forklifts) it may be common for the manufacturer to hire units directly to operators. Such examples were identified during engagement with stakeholders, however, the framework remained applicable to the majority of sectors.

The research project involved a number of tasks as shown in Figure 1, which resulted in the collation of updated NRMM activity data, and eventually the model development which underpins the current NAEI NRMM emission inventory. Each of these tasks are discussed in more detail in section 2.1 to 2.6.

Figure 1 Overview of key tasks involved.



2.1 DESK REVIEW

As an initial step, a desk review was undertaken to establish the current state of the NRMM market, from literature within the public domain. To facilitate the desk review, multiple research questions were formulated and placed into a review template. Research questions were phrased around four key aspects:

- The ownership structure of NRMM;
- Operational/population data;
- Stakeholder input; and
- Policy responses.

The questions were based on both the practical considerations towards the emissions calculation methodology and considerations towards understanding the structure of the NRMM market.

Relevant literature was identified through a literature search as well as existing documents through known and recognised schemes (e.g. HS2 and the London NRMM LEZ) and research sent directly for review by known stakeholders. In addition, specific responses from the Defra's 2018 Call for Evidence on NRMM and red diesel were reviewed. A summary table can be found in Appendix 1, detailing each item reviewed.

Literature reviewed was not as informative as initially anticipated and the ability to answer research questions was limited. However, the desk review did identify multiple lines of enquiry that were subsequently followed as part of wider data collection and helped to premise stakeholder interviews. For example, reviewing the work of the Construction Low Emission Partnership (CLEP) and the London NRMM register furthered stakeholder interviews with King's College London, the institution contracted to manage and maintain these initiatives. Similarly, such research proved useful in discussion with the Greater London Authority (GLA), who provided the data behind the London NRMM Register. These are further discussed in Section 2.4. Similarly, the desk review aided the development of the market survey template detailed in Section 2.3.

2.2 STAKEHOLDER INTERVIEWS AND ENGAGEMENT

The information collected in the desk review informed the approach to stakeholder engagement. Interviews were planned to explore the gaps identified in desk research and establish other potential information or data sources. Information from the desk review influenced the interview question structure and the interview process.

A set of 'interview checklists' was developed, a summary of questions and prompts for the interviewer and interviewee to help structure and facilitate the interview. These checklists were circulated to the stakeholder in the days prior to the interview to enable the stakeholder time to prepare should they need to pool any internal resources or raise any issues internally.

A 'stakeholder list' was also developed through, for example, the stakeholders identified through the desk review, those stakeholders contacted through the earlier Defra's 2018 Call for Evidence, and a wider internet search. Potential stakeholders were mapped to the categories of actors described at the beginning of Section 2. In addition, multiple trade bodies were targeted but typically acted as a professional body for one of the three categories (e.g. the plant hire market, or construction contractors).

Nine interviews were conducted in total. This included one hire company, one operator, three trade bodies and four specialist sector organisations. The organisations interviewed, alongside the dates of interviews were held are detailed in Table 2-1 below.

Table 2-1 List of interviews conducted

Market actor category	Organisation	Date held	Method
Hire company	Select Plant Hire	05/11/2019	Phone interview
Operator	HS2	23/10/2019	Phone interview
Specialist sector organisation	Off Highway Engine and Equipment Group (OHEEG)	31/10/2019	In person meeting
Specialist sector organisation	King's College London (KCL)	04/11/2019	Phone interview

Market actor category	Organisation	Date held	Method
Specialist sector organisation	Cold Chain Federation (CCF)	05/11/2019	Phone interview
Trade body	Civil Engineering Contractors Association (CECA)	05/11/2019	Phone interview
Specialist sector organisation	Mineral Products Association (MPA)	08/11/2019	Phone interview
Trade body	Construction Plant Hire Association (CPA)	15/11/2019	Phone interview
Trade body	Road Haulage Association (RHA)	16/12/2019	Phone interview

Through the interviews conducted, it became apparent that the detailed data required from stakeholders was not easy to communicate within an hour interview. Often the contacts did not have the information required available or indicated they would prefer to submit it in a different form. As agreed with Defra, it was therefore deemed appropriate to focus more resource into developing and distributing a detailed market survey to these same stakeholders (see Section 2.3). Though the stakeholder interviews were not suited to obtaining quantitative information, they remained valuable with regards to further understanding the views and perspectives of market actors towards their own industry and potential policy measures.

2.3 MARKET SURVEY

Whilst stakeholders were responsive during stakeholder interviews, many felt they were not in a position to provide quantitative data in an interview setting, typically because gathering such data requires the input of multiple employees, or queries to multiple company-held databases and or business practices. As a result, further emphasis was placed on developing and circulating a market survey amongst stakeholders and trade bodies. To maximise response rates, the survey was developed in conjunction with industry stakeholders whilst also retaining the parameters necessary for the emissions calculation methodology.

The survey was reviewed by the Off-Highway Engine and Equipment Group (OHEEG), one of the technical committees under the Society of Motor Manufactures and Traders (SMMT), with the feedback received discussed and incorporated into the survey's design. OHEEG represent a key stakeholder due to their technical nature and extensive knowledge of the NRMM market. As a committee they represent multiple market sectors and operate across market actors and therefore their feedback accounts for multiple perspectives. The survey was also reviewed by the Cold Chain Federation, a trade association representing refrigerated transport and therefore TRUs.

In total, 22 survey responses were received by the project team, these varied by company size, industry sector and the extent to which they were detailed.

An R script was written that batched the data into a central file once all survey returns were received. During this script, a series of additional variables are added to the output based on the population of other cells within the survey return, encoding metadata of the company into the centralised output. Variables such as company revenue, number of employees and the self-assessed market share, when paired with the company name and iterated across the rows of the return enabled the application of national statistics to help derive a national estimate, by resolving the data to the national level based on the metadata.

2.4 WIDER DATA COLLECTION

To complement and validate the analysis of data collated through the market survey, a wider data collection exercise was carried out to identify and evaluate further sources of data. Multiple data sources were scoped out during the initial desk review, whereas other data sources were identified through interaction with stakeholders or required extensive negotiation and/or separate agreements in order to gain access to. Table 2-2 shows all wider data sources considered.

Table 2-2 Wider data sources identified

Data source:	Comments:	Applicability:
CESAR (Construction and Agriculture Equipment Security and Registration scheme)	The Construction Equipment Association (CEA) is the owner of the CESAR scheme, which was initiated in 2007 with the support of the Home Office used to deter plant theft and for insurance purposes [5]. The scheme has also been extended to cover agricultural plant with the support of the Agricultural Engineers Association (AEA). It covers a database of plant machinery within the construction and agricultural sectors. It constitutes the largest database of NRMM in the UK.	Applicable
Defra 2018 Call for Evidence on Red Diesel	Defra's 2018 Call for Evidence included a basic template for respondents to collate data on the characteristics of their NRMM. Copies of written responses were also supplied, redacted where necessary, which may include further data. Select responses for market sectors lacking in the responses to the market survey were reviewed.	Applicable
Eurostat/ONS Prodcom statistics	Data regarding sales from PRODCOM statistics. Data is summarised by codified categories. 13 types of machinery were identified from a review of the data during the initial desk review. The data only describes a broad classification of machinery and summarised by propulsion type, not by fuel type (e.g. 'Self-propelled boring or sinking machinery').	Partially Applicable (as proxy data for trend in sales data)
DfT/DVLA licensing data	The DVLA as part of their licensing activities, include a suite of machinery within their licensing statistics. Contacts within the DfT were able to send data on the number of these machines once the project team had evaluated their list of vehicle classifications, to identify those of interest.	Partially Applicable (as proxy data for trend in sales data)
DESNZ Digest of UK Energy Statistics (DUKES)	Total gas oil consumption	Partially Applicable (for validation purpose)
London NRMM Register	London's NRMM register represents the database populated from the operation of London's NRMM scheme. Supplied via correspondence with the GLA, the data is subject to multiple caveats, including concerns regarding completeness and the accuracy of specific variables such as the duration of deployment on site. The data was processed to align with the machinery types classification used within this project.	Partially Applicable (to inform machinery types and power rating band used in construction sector)
Non-agricultural use of red diesel for non-road mobile machinery – HMRC and the Treasury	In 2018, a research agency, IFF Research, conducted a series of quantitative interviews	Partially applicable (as proxy data for sector split)

[5] https://www.thecea.org.uk/cesar/

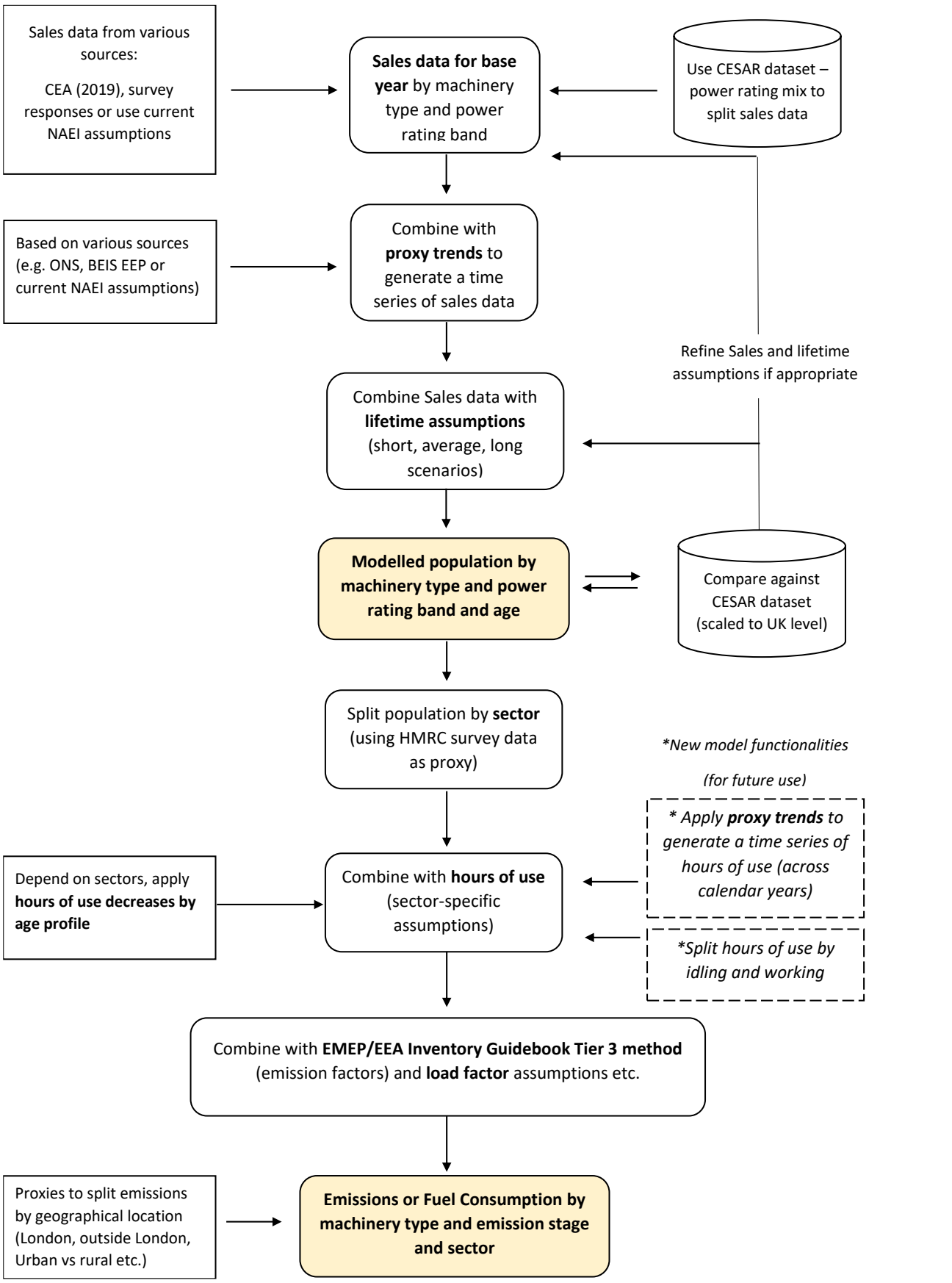
2.5 NRMM INVENTORY DEVELOPMENT

A number of improvement and new features have been made to the NRMM emission calculation method and model (hereafter referred to as the NAEI NRMM model). The main changes include:

- **Update of EMEP/EEA Emissions Inventory Guidebook method version**. The old NAEI NRMM model is based on the 2009 EMEP/EEA Guidebook version. The current NAEI NRMM model is based on emission factors and algorithms provided in the 2019 EMEP/EEA Guidebook version. Both the old and current NRMM model are regarded as Tier 3 methodologies.
- **Power rating bands.** The old NAEI NRMM model assumed a single average power rating (in kW) for each machinery type. However, the survey responses show that some machinery types do span across several power rating bands and will have an implication of the associated emission stage. Thus the current NAEI NRMM model now has a provision of eight power rating bands for each machinery type: “P < 8 kW”, “8 <= P < 19 kW”, “19 <= P < 37 kW”, “37 <= P < 56 kW”, “56 <= P < 75 kW”, “75 <= P < 130 kW”, “130 <= P < 560 kW”, “P > 560 kW”.
- **Hours of use**. The old NAEI NRMM model assumed a single and constant profile of hours of use for each machinery type and across its lifetime. The current NAEI NRMM model considers hours of use in two ways. Firstly, it allows hours of use assumptions for a given machinery type to vary by the sector in which it is used. This is to recognise that different sectors may have different hours of use for the same machinery type. Secondly, it also has the provision to adjust for decreasing operating hours with increasing age. This incorporates feedback given by the stakeholders (and also recognised by the European Commission Joint Research Centre (JRC) and Swedish inventory studies). It highlights the importance of considering annual hours of use as a function of machinery age and if not taken into account it will overestimate the emission contribution of older machines.
- **New machinery types**. This includes transport refrigeration units (TRUs), machineries used in ports (rubber tyred gantry cranes, reachstackers, straddle carriers or shuttle carriers), road surface treatment (bitumen and aggregate applicators) and LPG forklifts used in warehousing/logistics. Regarding TRUs, the UK refrigerated fleet can be considered as comprising: i) van derived trucks below 7.5 tonnes (these are predominantly powered by the vehicles’ main engines running on road diesel, and thus their emissions are already included in the road transport inventory); ii) 7.5 tonnes to 26 tonnes refrigerated trucks; and ii) refrigerated trailers. Thus, the latter two types, where the refrigeration unit is powered by a separate engine, are covered in the Defra research project and their input assumptions are provided in Appendix 2.
- **Sector and geographic disaggregation**. The old NAEI NRMM model reports emissions by four NFR source sectors: 1A2gvii Mobile combustion in manufacturing industries and construction, 1A3eii Other (airport support vehicles), 1A4bii Residential: Household and gardening (mobile), and 1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery. It should be noted that the latter two categories were not within the scope of the Defra research project. The current NAEI NRMM model now calculates bottom-up emissions and fuel consumption for the following sectors: construction, mining & quarrying, waste operations, airports, ports, and other. Depending on the machinery type, the ‘other’ category may cover industrial sectors, warehousing, logistics, supermarkets, road surface treatment, etc. In addition, the current NAEI NRMM model has the capability to disaggregate emissions by geographic location: within London, England (outside London) urban vs rural, and the rest of the UK (Scotland, Wales, and Northern Ireland) if suitable bottom up or proxy data can be made available in the future.
- **Other provisions for future use**. The current NAEI NRMM model now include provisions to vary hour of use assumptions across years. This is to recognise that for any given year, the hours of use (i.e. level of activity) may be affected by circumstances such as economic downturn (while the total number of machines might not be changed). Moreover, the model also has a provision to split the hours of use and the corresponding load factor by idling and working modes. The load factor assumptions should represent engine run time, i.e., the entire period from engine start to engine stop, inclusive of both loaded operation and idle time. Thus, currently, there is no need to proportion the hours of use by idling and working modes; but the current NAEI NRMM model will have the means to incorporate such a working/idling split with representative load factors for each mode if data are made available.

Figure 2 2 provides a schematic diagram of data flow how the current NAEI NRMM model were developed from the Defra research project.

Figure 2 Data flow for the development of the current NAEI NRMM model



2.6 FURTHER STAKEHOLDER ENGAGEMENT

A series of further stakeholder engagement, feedback, and data collation were commissioned by Defra in November 2020 as part of an extension improvement task. This further engagement was aimed towards providing the opportunity for stakeholders to provide feedback on the NRMM inventory development as discussed in Section 2.5. The focus of this engagement was a Non-Road Mobile Machinery (NRMM) Technical Stakeholder Workshop, held by Defra and Ricardo on the 26th January 2021. Stakeholders from across NRMM sectors were invited to attend and readily provide feedback via interactive polling. Polling was used to guide follow-up engagement via email or further meetings, creating an 'action items list', coordinated with Defra.

Through this 'action items list' a series of coordinated stakeholder engagement was agreed upon, resulting in a number of revisions to the input data to the NAEI NRMM model. The most significant revisions, in terms of overall magnitude of emissions, were:

- **Revision of Stage V emission factors** - Stage V emission factors, stated in the 2019 EMEP/EEA Guidebook, are based upon the limit value within the Stage V legislation. This is 0.015 g/kWh for Stage V engine categories 19 – 560 kW. However, for Stage V there is additionally a PN (number) limit of 1 x 10^{12} #/kWh. This PN limit requires the use of a high-efficiency wall-flow particulate filter, the consequence of which is that the actual mass significantly lower than the particulate matter (PM) limit would suggest. To adjust for this, the US EPA's certification test database for NRMM was consulted, averaging those values for the comparable US standard with diesel particulate filter (DPFs) fitted. All machines certified after 2019 with DPFs fitted, for the power band ranges in which Stage V apply were assessed, with a value of 0, replaced with the detection limit, of 0.005 g/kWh.
- **Revision of Stage IIIB and Stage IV emission factors** - A number of manufacturers fitted DPFs for certification purposes from Stage IIIB onwards, though this is not total, thought to be between 20-30% of engines. A weighted average of 20% DPF fitted was calculated using the same US EPA database for the power band ranges that apply to Stage IV. As the same limit value is used for Stage IIIB and Stage IV, this was also applied to Stage IIIB.
- **Revision to emission factors for low and high power bands** - Although NRMM in certain power bands were unregulated in Europe prior to Stage V, nevertheless it was common for machines in these size classes to be fitted with engines suitable for the US market, with the exception of > 560 kW gensets. A significant proportion, therefore, will have lower emissions than might be assumed for 'unregulated' engines. The most common > 560 kW engines prior to Stage V were those of US Tier 2. Those < 19 kW engines often complied with US Tier 4 limits. Emission Factors were changed to reflect US Tier 2 or Tier 4 prior to Stage V. Tier 2 machines were phased into the market from 2006 onwards for machinery for >560 kW. Tier 4 as phased in from 2008 onwards for those machines <19 kW. This essentially reflects 'cross-market integration', by assuming that manufacturers will comply with regulations outside of the EU market.

In addition to these main 'cross-cutting' revisions, a number of sector specific revisions were made to input parameters such as annual hours of use, working lifetime and sector distribution. These were agreed amongst key stakeholders from construction, warehousing, and refrigerated transport sectors. Owing to market circumstances surrounding the COVID-19 pandemic, Ricardo were unable to consult stakeholders from airports and ports sectors but would advocate that these sectors be consulted should resources be made available in future.

3. NRMM METHODOLOGY

This chapter summarises the input assumptions and methodology currently used in the NAEI NRMM model for the following type of machineries, listed by NFR category (which are the focus of this report):

- 1A2gvii Mobile Combustion in manufacturing industries and construction
  - Construction
  - Mining/Quarrying
  - Waste
  - Other industry (e.g. road surface treatment)
- 1A4aii Commercial /institutional: Mobile
  - Forklifts
- 1A3eii Other
  - Machineries used in airports and ports, and transport refrigeration units (TRU)

For methodology relating to agriculture mobile machinery (1A4cii), please refer to the "Improvements to the Emission Inventory for NRMM – Agricultural Machinery" report (2025).

For methodology relating to domestic house and garden mobile machinery (1A4bii), please refer to the latest UK Informative Inventory Report[6].

A further step in the existing NAEI inventory calculation involves reconciling overall bottom-up estimates of gas oil used by diesel NRMM with total UK gas oil consumption figures presented in the Digest of UK Energy Statistics (DUKES). This ensures an overall energy balance is maintained, a requirement in national inventory reporting. However, DUKES has not thus far been able to differentiate fuel used for NRMM compared with other, stationary combustion sources for a given industry sector. The current NAEI approach is summarised in latest UK Greenhouse Gas Inventory: Annexes report (Annex 4, section A4.2.1.4)[7].

3.1 INPUT ASSUMPTIONS

The emissions model is based on the Tier 3 methodology given in section 3.4 of the EMEP/EEA 2019 Guidebook. The equation to calculate the emissions is given below:

$$E = N \; x \; HRS \; x \; P \; x \; LF \; x \; (1 + DFA) \; x \; LFA \; x \; EF_{Base}$$

where:

E = mass of emissions of pollutant during inventory period (g),

N = number of engines (units),

HRS = annual hours of use,

P = engine size (kW),

LF = load factor,

DFA = deterioration factor adjustment,

LFA = load factor adjustment,

EF_{Base} = Base emission factor (g/kWh).

The following sub-sections provide further descriptions to how the equation parameters were derived. Appendix 3 provides a summary table of the input assumptions for the following parameters: load factors, hours of use and lifetime assumptions.

[6] NAEI Informative Inventory Report for Air Pollutant Emissions; please refer to the latest version
[7] NAEI National Inventory Report for Greenhouse Gases; please refer to the latest version

3.1.1 Number of Engines *(N)*

The total UK number of NRMM machineries are modelled using data on the:

- sales of the machinery in a base year (number of units),
- a sales index to estimate the sales across the time series (unitless), and the
- useful working lifetime of the machinery (years).

This represents a simple fleet turnover calculation used to characterise the population of each machinery type by age (year of manufacture/sale) each year and hence emission standard. The current NAEI NRMM model has flexibility to calibrate to a given population if such information is made available.

The sales data for the base year are based on various sources including survey data, CEA (2019) report, expert judgment or previous NAEI assumptions. The base year is chosen to be year 2018 for ease of comparison with the latest NAEI inventory year that was available at the time when the Defra research project was undertaken (i.e. which was the calendar year 2018). The sales index data are taken from a number of sources including ONS Prodcom data, ONS construction output statistics, DESNZ energy and emissions projections (EEP) drivers and DfT's DVLA statistics. This enables the model to derive sales (and thus population) going backward and forward in time.

The lifetime of the machinery is based on survey responses, age range informed by CESAR dataset, expert judgment or previous NAEI assumptions. It should be noted that the current NAEI NRMM model has the flexibility to add lifetime scenarios so that multiple lifetime assumptions can be considered for each machinery to test the sensitivity of the model results.

3.1.2 Annual Hours of Use *(HRS)*

The annual hours of use data by sector is based on survey data, information on approximate correlation between engine power and operating hours, expert judgment or previous NAEI assumptions. It should be noted that this parameter is one of the most uncertain ones, due to very limited information available. Moreover, assumptions have been applied as to which machinery type is used by which sector according to survey data and expert judgement.

3.1.3 Engine Size *(kW)*

The engine size or fleet weighted power rating assumptions are taken from various sources including the CESAR dataset, London NRMM registry, personal communication with stakeholders or based on previous NAEI assumptions. Where the engine size data is not available for a particular power rating band, the engine size is assumed to be the midpoint of that power rating band. For example, in the " 19 <= P < 37 kW" power rating band, the assumed engine size is 28 kW.

3.1.4 Load Factor *(LF)*

A load factor is a unitless value ranging between 0 and 1 to express at what fraction of the power rating does the engine actually work most of the time. For example, a bulldozer may be rated at 100kW power, but it may actually only work at a small fraction of this power rating most of the time. The current NAEI NRMM model is set up to accept different load factor values for whether the engine is working or idling. Currently, all engines are assumed to be working rather than idling because the load factor assumptions should represent engine run time, i.e. entire period from engine start to engine stop, inclusive of both loaded operation and idle time. The input assumptions are taken from previous NAEI assumptions or updated assumptions provided by stakeholders (personal communication).

3.1.5 Deterioration Factor Adjustment *(DFA)*

The deterioration factor adjustment value is used to account for deterioration of the machine that affects the emission factor. The deterioration factor affects emissions of nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and Total Suspended Particulates (TSP) or Particulate Matter (PM). Values of factors and equations for deterioration from the "Deterioration factor adjustments" section of the 2019 EMEP/EEA Guidebook are used. In the current NAEI NRMM model, the deterioration factor for TSP is used for PM_{10}. For 2-stroke and 4-stroke engines, deterioration factor for the engine size class "100 <=S <225 cc" (or referred to as size code "SN3" in the Guidebook) has been used, as this is the most conservative assumption.

3.1.6 Load Aactor Adjustment *(LFA)*

These adjustment factors are applied to the base emission factors and are to account for changes in the g/kWh emission factors due to engines operating under different load factors and are provided in Table 3-14 of the 2019 EMEP/EEA Guidebook. It varies by pollutant, emission stage, and the load factor of the machinery. Load factor adjustment values provided by the Guidebook are only relevant for engines running on diesel/gas oil.

3.1.7 Base Emission Factor *(EF_{Base})*

For gas oil-fuelled engines, the base emission factors used are the Tier 3 emission factors from Table 3-6 of the 2019 EMEP/EEA Guidebook.

For LPG-fuelled forklifts, the base emission factors used are the Tier 1 emission factors from Table 3-9 of the EMEP/EEA Guidebook. Higher tier emission factors are not available in the 2019 EMEP/EEA Guidebook for LPG.

For 2-stroke and 4-stroke petrol-fuelled engines, the base emission factors used are the Tier 3 emission factors from Table 3-7 and Table 3-8 respectively of the 2019 EMEP/EEA Guidebook. Base emission factors for the engine size class “100 <=S <225 cc” (or referred to as size code “SN3” in the Guidebook) have been used, as this is the most conservative assumption.

3.2 FURTHER MODEL PARAMETERS

This section details functionality in the current NAEI NRMM model that extends beyond the Tier 3 2019 EMEP/EEA Guidebook method.

3.2.1 Usage by Age

The current NAEI NRMM model has a functionality to vary the machinery usage by the age of the machine. For certain machinery types (e.g. excavators, loaders, dumpers, terminal tractors, shuttle carriers) used in the “Construction” and “Port” sectors, a decreasing usage profile with increasing age has been applied as stakeholders from these sectors have indicated older equipment tends to be used less than newer, cleaner more energy efficient machinery. For machinery in the other sectors, the limited survey data do not show a strong correlation in decreasing usage by age, so a constant usage profile is assumed throughout its lifetime. However, this can be adjusted if new information can be made available. For mobile generators, usage will generally remain consistent throughout its lifetime.

3.2.2 Hours of Use Index

The current NAEI NRMM model has the option to add an hours of use index to scale hours of use across the yearly time series by machinery type. This could be used to account for variation in the hours of use due to external circumstances such as economic downturn or, for example, the recent pandemic crisis for any given year.

3.2.3 Sector Disaggregation

The current NAEI NRMM model calculates bottom-up emissions and fuel consumption for the following sectors: construction, mining & quarrying, waste operations, airports, seaports and other. Depending on the machinery type, the ‘other’ category may cover industrial sectors, warehousing, logistics, supermarkets, road surface treatment etc. The methodology used to assign machinery to a sector was:

- Assign fractions of population by sector for each machinery type, fuel type, and power rating band combination. This is based on various sources: the IFF Research (2019) survey results gathered on behalf of the HMRC and HM Treasury[8] (from 500 UK businesses using NRMM in industries other than agriculture) into the relative number of machines used between different sectors, survey data, the London NRMM registry (which inform the types of machineries used in different sectors) or by expert judgement.

[8] IFF Research (2019) Non-agricultural use of red diesel for non-road mobile machinery, HM Revenue & Customs and HM Treasury Research Report 534.

- Assign annual hours of use values specific to each machinery type, fuel type, power rating band, and sector.
- Combine these along with other parameters from the equation as shown at the beginning of section 3.1 to derive sector-specific emissions or fuel consumption.

3.2.4 Geographic Disaggregation

The current NAEI NRMM model has built in functionality for **future use** to disaggregate emissions by geographic region (e.g. outside London) and area type (e.g. urban) using various proxies depending on the geographical location as shown in Table 3-1.

Table 3-1 Geographic disaggregation

Geographic region	Area type
England (London)	Urban / Rural
England (outside London)	Urban / Rural
Scotland	Urban / Rural
Wales	Urban / Rural
Northern Ireland	Urban / Rural

As a first attempt, the following approach has been set up in the current NAEI NRMM model: The location of waste collection, treatment & disposal facilities, mining/quarrying sites, other industrial sites, and the location of airports and ports in the UK is taken from the NAEI mapping database. Due to project resource constraints, the geographic splits were calculated using 2017 data (which was more readily available at the time when the Defra research project was undertaken) and then it is assumed that the % splits remain constant across the time-series. Data for the UK construction sites is taken from a third body dataset, https://www.constructionmap.info/map, which is assumed to provide a better source to define the area type split (including for London).

For sense check purpose, the project team has made an attempt to calculate total annual hours of use for all the construction machineries registered under the London NRMM registry in 2018 based on their length of deployment time and assumptions on the hours of use per day per machinery[9]. Such approach has resulted in a very low hours of use (~1%) for London as a % of total UK which may not seem realistic. It may be that the coverage of the NRMM registry[10], deployment time[11] and hours of use assumptions need further adjustment, and thus further exploration with GLA and KCL research work will be needed before using the NRMM registry dataset for geographical split purpose in the future. A simple approach has been followed to define the urban domain and thus estimate the area type split of the national total NRMM emissions. The methodology to do this is:

- For England and Wales, the Built-Up Areas[12] (December 2011) Boundaries V2 guidance note is used to define the urban domain in England and Wales.

[9] Based on Desouza et al (2020), Real-world emissions from non-road mobile machinery in London, available at: http://www.clec.uk/sites/default/files/1-s2.0-S1352231020300431-main.pdf, generators were assumed to run for 24 hours a day, while all other machines were assumed to operate for 8 hours

[10] GLA has indicated the NRMM registry is, in principle, provided for all development sites subject to the relevant planning conditions creating the NRMM LEZ. However, in practice it has been difficult to establish what proportion of live development sites in London are actually represented in the London NRMM registry as they have not been able to effectively match the site with the London Development Database.

[11] GLA has indicated that end dates for sites and machines are manually entered at the start of deployment and are rarely corrected if the machine leaves early or the site finishes early, or if there are overruns. This means that the length of time of deployment is on average likely to be wrong, and the trend is more likely that deployments are too long rather than too short (but this will not always be the case).

12 Office for National Statistics (2019), Built-Up Areas (December 2011) Boundaries V2, available at: http://geoportal.statistics.gov.uk/datasets/built-up-areas-december-2011-boundaries-v2

- For Scotland, the Scottish Government Urban Rural Classification[13] guidance note is used to provide a consistent way of defining urban and rural areas across Scotland.
- For Northern Ireland, the Settlement Development Limits[14] guidance note is used to define the classification and delineation of urban/rural areas and settlements in Northern Ireland.

The project team recommends further work is needed to provide more detailed geographic splits for the NRMM emissions. The current method used is a very simple and crude approach by distributing emissions according to the locations of various source sectors (e.g. location of waste facilities). However, in reality, the use of NRMM will vary according to the size and type of the operators, while hired machineries or construction sites will be moved around over time. Time-series data should be gathered and analysed to estimate their spatial distribution in the UK. In addition, the construction sites data could be further analysed per major and minor sites, and type of construction sites.

3.3 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

The current NAEI NRMM model was developed using the R script as it has the advantage of dealing with large volumes of data and the model has been quality checked in the following ways:

- **Verification** – 1) formulae correctness in the R script are checked by comparing and checking the output results are identical to the results calculated by a simple Excel spreadsheet using the same input assumptions; 2) the exact same NAEI assumptions were inputted for a few machinery types to test that the updated model will give identical (or known different) results to the existing NAEI NRMM model; 3) further spot checks are done by combining the individual parameters manually and compared against the updated NRMM model results.
- **Internal consistency checks** – this includes checking of 1) the modelled populations are the same in the intermediate calculation step and in the final output file; 2) sum of emissions when split by sector equals the sum of emissions at more aggregated level; 3) sum of emissions when split by area type and region equals the sum of emissions at a more aggregated level; 4) where fractions are used, the sum is equal to 100%
- **Validations** – this includes 1) comparisons against the existing NAEI results; 2) comparisons again gas oil fuel consumption data from DUKES; 3) comparisons against fuel consumption data provided through survey data.

13 Geographic Information Science & Analysis Team, Rural and Environment Science and Analytical Services Division (2016), Scottish Government Urban Rural Classification, available at: https://www2.gov.scot/Resource/0054/00542959.pdf

14 Northern Ireland Statistics and Research Agency (2015), Settlement Development Limits, available at: https://www.nisra.gov.uk/support/geography/urban-rural-classification

APPENDICES

Appendix 1 – Desk Review Summary

Appendix 2 – Transfer Refrigeration Unit (TRU) Assumptions

Appendix 3 – Input Assumptions used in the NAEI NRMM Model for the Base Year 2018

APPENDIX 1 - DESK REVIEW SUMMARY

Literature Source	Author/Organisation Name	Source	Publication date	High-level summary
Efficacy of abatement and mitigation techniques used in the control of dust and emissions in the demolition and construction	King's College London	http://www.clec.uk/sites/default/files/Efficacy of abatement and mitigation techniques used in the control of dust and emissions in the demolition and construction industries DM 2018.pdf	2014	Describes the approach used to estimate NRMM emissions for the LAEI. Approach appears to involve the scaling of emissions from the NAEI via proxies related to the employment and spatially distributed through data relating to construction projects in the London Development Database (or LDD). It should be noted that this report is focused towards construction in totality, not just NRMM and therefore has sections commenting towards dust emissions from non NRMM sources (i.e. dust suppression systems). Report provides an overview of the introduction of NRMM emission standards for the ULEZ and measures employed in response, with relation to engine idling management systems or retrofitting through diesel catalysts, flow-through/particulate filters or re-powering (replacement of the engine). Note the NRMM work conducted by King's College London is also associated with the Centre for Low Emission Construction (CLEC).
Non-road Mobile Machinery Register	King's College London	http://www.clec.uk/sites/default/files/Non Road Mobile Machinery Register updates and feedback.pdf	2017	A presentation given at 'Cleaner Machinery for London' event at City Hall on February 3rd, 2017 to raise awareness of the air quality and health impacts of emissions from NRMM as well as allow direct feedback to the GLA about the policy and NRMM London register. The presentation details the potential data the London NRMM register may hold, including the regulatory background and connections to the Mayor of London Supplementary Planning Guidance (SPG).
Low Emission Construction for London "Best in Class" Emission Reduction	King's College London (CLEP)	http://www.clec.uk/sites/default/files/3. Best in class emission reduction.pdf	2019	Presentation summarising Centre for Low Emission Construction's 'Best in Class' guidance towards emission reductions for construction industries. Summarises current proposals towards London's NRMM low emission zone in addition to potential responses to tighter regulations.
Characterising Non-Road Mobile Machinery Emissions through Portable Emissions Testing and Emissions Inventory Development studentship	King's College London (CLEP)	https://www.kcl.ac.uk/health/study/studentships/div-studentships/aes/green	2016	Lists a studentship which collaborates with Emission Analytics to generate emission estimates for NRMM across London. Potential source of emission factors.

Literature Source	Author/Organisation Name	Source	Publication date	High-level summary
EST Register of NRMM Emission Reduction Systems	Energy Saving Trust	https://www.energysavingtrust.org.uk/business/products?field_product_category[0]=5742	2019	The EST Register identifies and lists all certified emissions reduction systems, so authorities or owners of machinery can choose a system or check that a system is compliant. Independent certification for NRMM is the only one of its kind in the UK and certifies the emissions reduction systems that can be retrofitted to NRMM (or construction machinery) to allow them to be used in areas which have emissions restrictions. Only 11 retrofit systems currently certified.
NRMM retrofit and emission reduction system certification - EST	Energy Saving Trust	http://www.clec.uk/sites/default/files/upload-docs/Collin Smith - EST.pdf	2016	Presentation given at the NRMM Seminary at Kings College London in 2016. Provides the Energy Saving Trusts perspective on available abatement technologies but otherwise little substance. Suggests, in 2016, Selective Catalytic Reduction systems (SCRs) are poorly developed for NRMM in comparison to Particulate filters, suggesting retrofit may be concerned primarily with PM standards.
Prodcom	Eurostat	https://ec.europa.eu/eurostat/web/prodcom/data/excel-files-nace-rev.2	2019	Provides machinery across time period according to Prodcom code. Difficult to identify what Prodcom codes map onto several types of NRMM, particularly as there are few indications towards fuel type, only terminology regarding propulsion (e.g. self-propelled or 'excluding self-propelled'). However, data is limited or confidential when using these codes (no quantities are available)
Implementation of Non-Road Mobile Machinery (NRMM) Diesel Engine Emissions Control on Crossrail	Crossrail	https://learninglegacy.crossrail.co.uk/wp-content/uploads/2016/02/ENV12-01_NRMM-DieselEngEmissions_Implementation.pdf	2013	Internal advisory report by Crossrail regarding consultations across Crossrail's NRMM fleet and how this informs compliance with NRMM requirements across London.
Construction Notifications. Form 10 (F10) Database	Heath and Safety Executive (HSE)	https://data.gov.uk/dataset/77654361-9496-46df-b762-a5d6c06faf58/construction-notifications-form-10-f10-database	2013	Provides details of planned construction projects over a certain duration. Informed via the HSE's F10 form notification process. The database itself however is not publicly available and appears to have not been maintained past 2013.
Outline of Non-Road Mobile Machinery (NRMM) Emissions Regulations	Vehicle Certification Agency	https://www.vehicle-certification-agency.gov.uk/other/non-road-mobile-mach.asp	2019	Summary of NRMM regulations currently in place. The VCA are the sole approval authority for type approving engines manufactured for NRMM, and therefore could provide data on certifications which may act as a proxy for total population of NRMM. Engines imported, however, may undergo type approval by another authority within the EU and it is unclear whether the VCA then would have data on these certifications outside of national remit.

Literature Source	Author/Organisation Name	Source	Publication date	High-level summary
Non-Road Mobile Machinery (NRMM)	Vehicle Certification Agency	https://data.gov.uk/dataset/13e991ff-6322-447f-bad4-54d3151ca7cc/non-road-mobile-machinery-nrmm	2013	Potential dataset includes engine type, engine family, emissions levels, approval type number. Limited available information about dataset.
Liquid Air on the Highway The environmental and business case for liquid air commercial vehicles in the UK	Centre for Low Carbon Futures	https://www.birmingham.ac.uk/Documents/college-eps/energy/liquid-air-highway.pdf	2014	Think Tank paper exploring the potential commercial viability in the use of Liquid Air (or Liquid Nitrogen) in vehicles. The aspect relevant to this project is the exploration of Liquid Air as a replacement technology for conventional TRUs and therefore the data used to demonstrate the investment case and potential to mitigate environmental impacts (e.g. NOx, PM). Only data provided, however, is projected sales of own engine technologies (Dearman liquid air engines) as a displacement of diesel powered TRUs.
FOOD TRASPORT REFRIGERATION	Brunel University	https://grimsby.ac.uk/documents/defra/trns-refrigeenergy.pdf	2006 (estimated	Short academic document considering efficiency in cold-chain transport. Specifically, the document contains some quantitative numbers sufficient to derive a broad estimate.
The UK's Construction Equipment Sector Report 2019	CEA (The Construction Equipment Association)	https://www.thecea.org.uk/download/cea-sector-report-2019/ (log in required)	2019	The report is published by the UK construction equipment association, whose members are: Original Equipment Manufacturers (OEMs) with UK production facilities- only JCB is UK owned, Overseas OEMs with UK offices, Component and accessory suppliers, Trade publishers, Specialist service providers, Equipment distributors, international companies. It focuses on the UK manufacturers of construction machinery rather than on how and who are using them. It provides data on UK sales for 2018 but when compared with the UK production data (not year specific), it becomes obvious that imports and exports play a key role in this sector.
Auxiliary Temperature Reduction Units in the Greater London Area	Cenex/TfL	http://content.tfl.gov.uk/auxiliary-temperature-reduction-units-in-the-greater-london-area.pdf	2017	Report details fleet composition for TRUs entering London, alongside a range of alternative technologies designed to mitigate their air quality impact. The report does include an estimation of emissions from TRUs, but it is not clear what emission factors are used and the data is highly uncertain.

APPENDIX 2 - TRANSPORT REFRIGERATION UNIT (TRU) ASSUMPTIONS

Parameters	7.5t to 26t refrigerated trucks	Refrigerated trailers	Notes on assumptions
Population (units)	15,000	30,000	**TRU expert advice (based on purchased data from SMMT):** The number of truck TRUs units sold in the UK for use on 7.5t to 26t refrigerated trucks historically averaged around 2,000 units per annum. Operational lifetime on UK roads varies, but for diesel units it is estimated to be 10 years. With non-diesel TRU sales equating to around 500 per annum we are left with 1,500 diesel units sold per year x 10 years gives a UK population of some 15,000 machines. For trailers the number will be higher, and with around 99% of all trailer TRUs' being diesel powered, it is conservatively estimated an average of 2,500 units per annum and a 12-year UK operational life. This gives an estimated population of some 30,000 units.
Average Power rating (kW)	8 – 17	17 – 25	**TRU expert advice:** The size of diesel engine fitted to TRUs generally range between 11kW and 25kW. **Ricardo:** This is consistent with the information provided by the survey responses.
Typical hours of use (hours per year per unit)	1400 - 2900	1400 - 2900	**TRU expert advice:** Most distribution trucks travel on average somewhere between 50,000 and 100,000 miles per annum. At an average speed of 35 MPH that would equate to a run time of between 1,429 and 2,857 hours per year. **Ricardo:** These figures are comparable to the usage values provided by survey responses.
Average lifetime (years)	10	12	As per TRU expert advice above. **Ricardo:** These values are comparable to figures quoted by responses to the 2018 Defra's Call for Evidence on Red Diesel (First life 8 years for trucks / 12 years for trailers)
% Population by Emission Stage	2018: Pre-Stage 1 (100%) 2019:	2018: Pre-Stage 1 (100%) 2019:	These values are modelled by Ricardo and have been cross-checked with the TRU expert, based on the assumed lifetime mentioned above.

Parameters	7.5t to 26t refrigerated trucks	Refrigerated trailers	Notes on assumptions
	Pre-Stage I (90%) Stage V (10%)	Pre-Stage I (90%) Stage V (8%)	
Load Factor (A dimensionless value reflecting whether an engine is working on its full rated power)	Urban areas: Under high load (90%) for 75% of the time. Under low load (25%) for 25% of the time Rural/motorways: Under high load (90%) for 20% of the time. Under low load (25%) for 80% of the time	Urban areas: Under high load (90%) for 75% of the time. Under low load (25%) for 25% of the time Rural/motorways: Under high load (90%) for 20% of the time. Under low load (25%) for 80% of the time	**TRU expert advice:** There are various factors that will influence the cooling/heating load and therefore the capacity load/engine speed of the TRU. In general, high-speed operation will be the norm for a high percentage of the time for TRUs' operating on multiple delivery distribution vehicles in cities and towns while much less for units on long distance or international operations. In urban areas, we propose to assume 75% of time are under high-speed operation (**Ricardo:** this is interpreted as equivalent to high load and we will assume engine is working at 90% of its rated power). In long distance journeys (rural/motorway areas), we propose to assume 80% of time are under low-speed operation (**Ricardo:** assume it is equivalent to a low load on a type approval/old steady-state certification, i.e. engine is working at 25% of its rated power).
% time spent in London, outside London (urban) and outside London (rural)	London % = 8% Outside of London - Urban % = 72% Outside of London - Rural % = 20%	London % = 1% Outside of London - Urban % = 47% Outside of London - Rural % = 52%	**Ricardo:** The assumptions quoted here are derived from the vkm travelled on different road types by rigid and artic HGVs in 2018 (as provided by DfT), then converted into time along with speed assumptions for different road types. The values for 7.5t to 26t refrigerated trucks show good agreement with the survey responses. The low assumed % of refrigerated trailers in London also appears to tally with the observations made by the TfL (2018) study[15] on TRU which found that the rated power output of diesel TRUs in London are ranged from 3.3kW to 15kW (meaning most activity are done by 7.5t to 26t refrigerated trucks). In general, these assumptions also reflect the suggestion from the Cold Chain Federation (CCF) that the larger vehicles were not in urban areas as much as the smaller ones.

[15] TfL (2018) Auxiliary temperature reduction units in the Greater London area, Overview of the study progress to date, March 2018.

APPENDIX 3 - INPUT ASSUMPTIONS USED IN THE NAEI NRMM MODEL FOR THE BASE YEAR 2018

Notes: Hours of use (approximates) are shown for the base year 2018 and proxy statistics are used to vary the hours of use across the time series by sector and machinery types, this is to recognise that for any given year, the hours of use (i.e. level of activity) may be affected by circumstances such as economic downturn (while the total number of machines might not be changed). Further details on the proxy statistics used are described in the latest UK Informative Inventory Report[16]. Hours of use are shown as blank if it is assumed to be not relevant for that sector. Depending on the machinery type, the 'other' sector may cover industrial sectors, warehousing, logistics, supermarkets, road surface treatment etc.

Machinery Type	Fuel Type[17]	Power Rating Band (kW)	Load Factor	Lifetime	Annual hours of use - Port	Annual hours of use - Waste	Annual hours of use - Airport	Annual hours of use - Other	Annual hours of use - Construction	Annual hours of use – Mining & quarrying
Aerial lifts	Gas oil	8 <= P < 19	0.15	8	-	-	-	1400	1400	100
Aerial lifts	Gas oil	19 <= P < 37	0.15	8	-	-	-	1400	1400	100
Aggregate applicator	Gas oil	75 <= P < 130	0.7	15	-	-	-	1500	-	-
Air compressors	Gas oil	19 <= P < 37	0.3	6	-	-	-	-	875	-
Air compressors	Gas oil	37 <= P < 56	0.3	6	-	-	-	-	875	-
Air compressors	Gas oil	56 <= P < 75	0.3	6	-	-	-	-	875	-
Aircraft support equipment	Gas oil	37 <= P < 56	0.4	11	-	-	3085	-	-	-
Asphalt / concrete pavers	Gas oil	37 <= P < 56	0.35	6	-	-	-	-	480	-
Asphalt / concrete pavers	Gas oil	75 <= P < 130	0.35	6	-	-	-	-	390	-
Bitumen applicator	Gas oil	130 <= P < 560	0.7	15	-	-	-	2500	-	-
Bore/drill rigs	Gas oil	130 <= P < 560	0.6	7	-	-	-	-	1255	1500
Bulldozers	Gas oil	75 <= P < 130	0.35	7	-	1690	-	-	1285	750
Bulldozers	Gas oil	130 <= P < 560	0.35	7	-	1680	-	-	1280	750

[16] Reports - NAEI, UK (beis.gov.uk)

[17] 2sp and 4sp refer to 2-stroke petrol and 4-stroke petrol engines

Machinery Type	Fuel Type[17]	Power Rating Band (kW)	Load Factor	Lifetime	Annual hours of use - Port	Annual hours of use - Waste	Annual hours of use - Airport	Annual hours of use - Other	Annual hours of use - Construction	Annual hours of use – Mining & quarrying
Cement & mortar mixers	Gas oil	P < 8	0.5	10	-	-	-	-	1250	-
Cement & mortar mixers	Gas oil	37 <= P < 56	0.5	10	-	-	-	-	1115	-
Cement & mortar mixers	Gas oil	56 <= P < 75	0.5	10	-	-	-	-	1125	-
Cement & mortar mixers	Gas oil	75 <= P < 130	0.5	10	-	-	-	-	1125	-
Cement & mortar mixers	Gas oil	130 <= P < 560	0.5	10	-	-	-	-	1115	-
Cement & mortar mixers	4sp	P < 8	0.5	10	-	-	-	540	540	-
Concrete / industrial saws	Gas oil	19 <= P < 37	0.75	5	-	-	-	-	1145	-
Concrete / industrial saws	Gas oil	37 <= P < 56	0.75	5	-	-	-	-	1145	-
Concrete pumps	Gas oil	37 <= P < 56	0.15	15	-	-	-	-	410	-
Concrete pumps	Gas oil	75 <= P < 130	0.15	15	-	-	-	-	535	-
Concrete pumps	Gas oil	130 <= P < 560	0.15	15	-	-	-	-	885	-
Cranes	Gas oil	75 <= P < 130	0.2	10	-	-	-	-	1890	-
Cranes	Gas oil	130 <= P < 560	0.2	10	2800	-	-	-	1890	-
Crushing / processing equipment	Gas oil	75 <= P < 130	0.5	11	-	-	-	-	1350	1350
Crushing / processing equipment	Gas oil	130 <= P < 560	0.5	11	-	-	-	-	1350	1350
Dumpers / tenders	Gas oil	8 <= P < 19	0.15	6	-	-	-	-	200	-
Dumpers / tenders	Gas oil	19 <= P < 37	0.15	6	-	-	-	-	275	-
Dumpers / tenders	Gas oil	37 <= P < 56	0.15	6	-	-	-	-	310	-
Dumpers / tenders	Gas oil	56 <= P < 75	0.15	6	-	-	-	-	620	-
Dumpers / tenders	Gas oil	75 <= P < 130	0.15	6	-	-	-	-	680	-
Dumpers / tenders	Gas oil	130 <= P < 560	0.15	6	-	1710	-	-	1230	1100
Dumpers / tenders	Gas oil	P > 560	0.15	6	-	-	-	-	-	2350

Machinery Type	Fuel Type[17]	Power Rating Band (kW)	Load Factor	Lifetime	Annual hours of use - Port	Annual hours of use - Waste	Annual hours of use - Airport	Annual hours of use - Other	Annual hours of use - Construction	Annual hours of use – Mining & quarrying
Excavators	Gas oil	8 <= P < 19	0.28	5	-	-	-	-	440	-
Excavators	Gas oil	19 <= P < 37	0.28	5	-	-	-	-	470	-
Excavators	Gas oil	37 <= P < 56	0.28	5	-	-	-	-	540	-
Excavators	Gas oil	56 <= P < 75	0.28	5	-	-	-	-	1000	-
Excavators	Gas oil	75 <= P < 130	0.28	5	-	1100	-	-	1130	1000
Excavators	Gas oil	130 <= P < 560	0.28	5	-	1315	-	-	1300	890
Forklifts	Gas oil	19 <= P < 37	0.3	9	775	-	-	970	2275	750
Forklifts	Gas oil	37 <= P < 56	0.3	9	775	-	-	970	2275	750
Forklifts	Gas oil	56 <= P < 75	0.3	9	780	-	-	990	2300	750
Forklifts	Gas oil	75 <= P < 130	0.3	9	780	-	-	990	2300	750
Forklifts	LPG	37 <= P < 56	0.3	7	-	-	-	670	-	-
Gas compressors	Gas oil	19 <= P < 37	0.3	6	-	-	-	875	-	-
Generators	4sp	P < 8	0.6	12	-	-	-	200	-	-
Generators	Gas oil	8 <= P < 19	0.32	8	-	-	-	-	2000	-
Generators	Gas oil	19 <= P < 37	0.32	8	-	-	-	-	2000	-
Generators	Gas oil	37 <= P < 56	0.32	8	-	-	-	-	2000	-
Generators	Gas oil	56 <= P < 75	0.32	8	-	-	-	-	2000	-
Generators	Gas oil	75 <= P < 130	0.32	8	-	-	-	100	1395	-
Generators	Gas oil	130 <= P < 560	0.32	8	-	-	-	100	1395	-
Generators	Gas oil	P > 560	0.32	8	-	-	-	-	1000	-
Generators	2sp	P < 8	0.6	8	-	-	-	100	-	-
Graders	Gas oil	130 <= P < 560	0.38	12	-	-	-	-	375	-

Machinery Type	Fuel Type[17]	Power Rating Band (kW)	Load Factor	Lifetime	Annual hours of use - Port	Annual hours of use - Waste	Annual hours of use - Airport	Annual hours of use - Other	Annual hours of use - Construction	Annual hours of use – Mining & quarrying
Industrial tractors, burden and personnel carriers	Gas oil	75 <= P < 130	0.35	10	-	-	-	500	-	-
Industrial tractors, burden and personnel carriers	Gas oil	130 <= P < 560	0.35	10	-	-	-	500	-	-
Landfill compactors	Gas oil	130 <= P < 560	0.3	18	-	955	-	-	-	-
Loaders	Gas oil	19 <= P < 37	0.3	7	-	-	-	-	440	-
Loaders	Gas oil	37 <= P < 56	0.3	7	-	-	-	-	540	-
Loaders	Gas oil	56 <= P < 75	0.3	7	-	-	-	-	590	-
Loaders	Gas oil	75 <= P < 130	0.3	7	-	1500	-	-	685	1340
Loaders	Gas oil	130 <= P < 560	0.3	7	-	1490	-	-	1075	1340
Loaders	Gas oil	P > 560	0.3	7	-	-	-	-	-	1340
Other general industrial equipment	Gas oil	8 <= P < 19	0.6	6.5	-	-	-	1460	-	-
Other material handling equipment	Gas oil	19 <= P < 37	0.3	8	-	-	-	1355	-	-
Plate compactors	Gas oil	8 <= P < 19	0.6	8	-	-	-	-	1250	-
Pressure washers	Gas oil	P < 8	0.6	5	-	-	-	940	940	-
Pressure washers	Gas oil	8 <= P < 19	0.6	5	-	-	-	940	940	-
Pumps	Gas oil	P < 8	0.6	9	-	-	-	-	1980	-
Reachstackers	Gas oil	130 <= P < 560	0.3	15	1490	-	-	-	-	-
Rollers	Gas oil	8 <= P < 19	0.5	11	-	-	-	-	85	-
Rollers	Gas oil	19 <= P < 37	0.5	11	-	-	-	-	85	-
Rollers	Gas oil	75 <= P < 130	0.5	11	-	-	-	1500	650	-

Machinery Type	Fuel Type[17]	Power Rating Band (kW)	Load Factor	Lifetime	Annual hours of use - Port	Annual hours of use - Waste	Annual hours of use - Airport	Annual hours of use - Other	Annual hours of use - Construction	Annual hours of use – Mining & quarrying
Rough terrain forklifts	Gas oil	37 <= P < 56	0.3	7	-	-	-	-	385	100
Rubber tyred gantry cranes	Gas oil	130 <= P < 560	0.2	18	1955	-	-	-	-	-
Scrapers	Gas oil	130 <= P < 560	0.3	14	-	-	-	-	500	-
Shuttle carrier / straddle carrier	Gas oil	130 <= P < 560	0.2	15	2085	-	-	-	-	-
Surfacing equipment	Gas oil	19 <= P < 37	0.6	8.5	-	-	-	-	1095	-
Sweepers / scrubbers	Gas oil	56 <= P < 75	0.6	9	-	2700	-	-	1560	-
Sweepers / scrubbers	Gas oil	75 <= P < 130	0.6	9	-	2700	-	-	1560	-
Tampers / rammers	2sp	P < 8	0.75	6.5	-	-	-	-	1045	-
Telehandlers	Gas oil	37 <= P < 56	0.3	7	815	720	-	-	385	500
Telehandlers	Gas oil	56 <= P < 75	0.3	7	820	580	-	-	485	500
Telehandlers	Gas oil	75 <= P < 130	0.3	7	820	510	-	-	675	500
Terminal tractors	Gas oil	75 <= P < 130	0.38	15	-	-	2700	-	-	-
Terminal tractors port	Gas oil	130 <= P < 560	0.38	10	2230	-	-	-	-	-
Trenchers / mini excavators	Gas oil	8 <= P < 19	0.4	6	-	-	-	-	440	-
Trenchers / mini excavators	Gas oil	19 <= P < 37	0.4	6	-	-	-	-	460	-
Trenchers / mini excavators	Gas oil	37 <= P < 56	0.4	6	-	-	-	-	550	-
Trenchers / mini excavators	Gas oil	56 <= P < 75	0.4	6	-	-	-	-	610	-
TRUs	Gas oil	19 <= P < 37	0.18	12	-	-	-	2000	-	-
TRUs	Gas oil	8 <= P < 19	0.18	10	-	-	-	2000	-	-
Welding equipment	Gas oil	19 <= P < 37	0.4	9.25	-	-	-	1120	1120	1120

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