Category		Title
NFR	1.A.2.g vii 1.A.4.a.ii 1.A.4.b ii 1.A.4.c ii 1.A.4.c iii 1.A.5.b	Mobile Combustion in manufacturing industries and construction Commercial/institutional: Mobile Residential: Household and gardening (mobile) Agriculture/Forestry/Fishing: Off-road vehicles & other machinery Agriculture/Forestry/Fishing: National fishing Other, Mobile (inc. military, land based and recreational boats)
SNAP	0808 0809 0806 0807 0801	Other mobile sources and machinery — Industry Other mobile sources and machinery — Household and gardening Other mobile sources and machinery — Agriculture Other mobile sources and machinery — Forestry Other mobile sources and machinery — Military
ISIC		
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Contents

1 Overview

This chapter provides methodologies for the estimation of combustion and evaporative emissions from selected non-road mobile machinery sources. Categories excluded from this guidance are:

- aviation
- road transport
- railways
- and navigation ([1]).

This chapter covers a mixture of 'other' equipment which is distributed across a wide range of industry sectors, typically land based, and is commonly referred to collectively as "*Non-Road Mobile Machinery*" (NRMM). However, despite this diversity there is the common theme that all the equipment covered uses reciprocating engines, fuelled with liquid hydrocarbon-based fuels. They comprise both diesel- (compression ignition), petrol- and LPG- (spark ignition) engined machinery.

More specifically, the types of equipment covered in this chapter are included in the following NFR categories:

- 1.A.2.g vii Mobile combustion in manufacturing industries and construction;
- 1.A.4.a.ii Commercial and institutional mobile machinery;
- 1.A.4.b ii Mobile combustion used in residential areas: household and gardening mobile machinery;
- 1.A.4.c ii Off-road vehicles and other machinery used in agriculture/forestry mobile machinery (excluding fishing);
- 1.A.5.b Other mobile including military mobile machinery.

For all these types of equipment, the emissions originate from the combustion of fuel to power the equipment ([2]).

In terms of relative size, the importance of these sectors varies from sector to sector and from nation to nation. For many countries, the contribution to the national total emission will be small i.e. the individual sources are not key sources. However, the contributions from some sectors to some nations' inventories may be moderately important.

The more important species include: SO_2, NO_x, CO_2 PM, CO and NMVOCs, with the relative importance of the species depending on the type of engine (diesel compression ignition or petrol spark ignition), and the type of equipment. The methodology used for estimating emissions of CO_2 and SO_2 are predominantly fuel-based, and therefore independent of engine technology/type of equipment.

([1]) Navigation is excluded, but "recreational craft" are included in this chapter.
([2]) Evaporative emissions of NMVOC are considered in the Tier 3 methodology – see section 3.4.2

Emission factors

This chapter includes emission factors for machinery currently in use. In addition, this chapter also includes information on machinery complying with the European Commission's proposed "Stage V" emission limits. Whilst this legislation is not yet in place, it is expected that machinery complying with Stage V emission limits will be in use from 2019 onwards.

Activity data

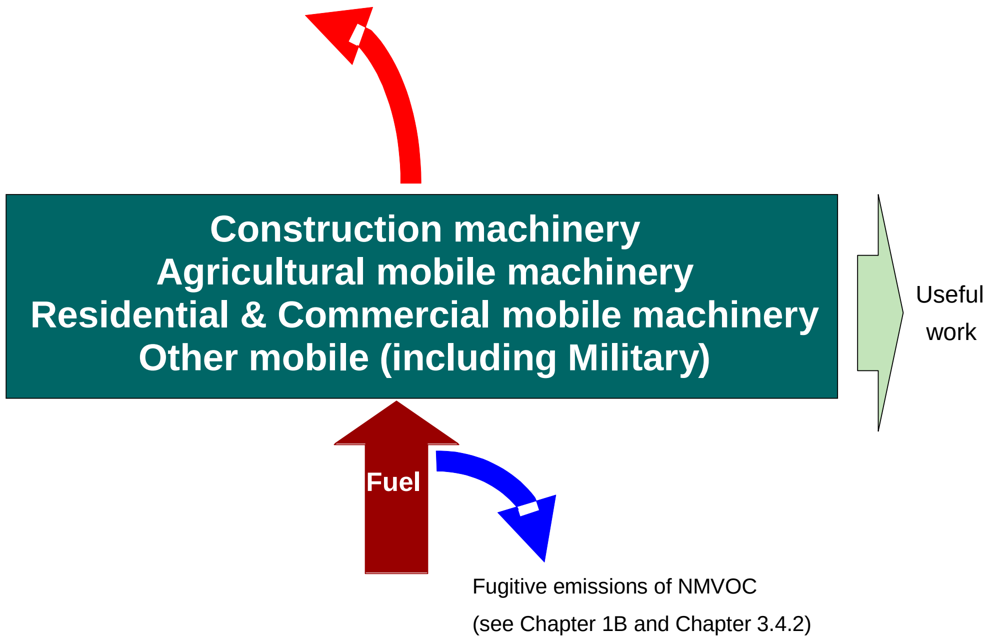
One of the more significant challenges for estimating emissions from these sources relates to obtaining activity data. Calculations can be made on the basis of fuel consumption or hours of operation of machinery. It is rare for fuel consumption data (whether obtained from national energy balance tables or sales data) to resolve the fuel specifically used in NRMM from that consumed by road transport. It is good practise to ensure that the fuel assigned to road transport does not include that used by NRMM, and care must be taken to avoid double counting of emissions. This is relevant whether estimating emissions of NRMM is based on a fuel used or hours of operation approach.

2 Description of sources

2.1 Process description

Exhaust emissions from NRMM arise from the combustion of diesel, gasoline and LPG. The NRMM sources which account for the majority of emissions are shown in the flow diagram in Figure 2.1.

Figure 2-1 Flow diagram for the contribution of NRMM categories to combustion emissions



2.2 Types of equipment used

The types of equipment used under the collective NRMM label represents a very broad list. Several inventorying systems have developed detailed lists of these. Chapter 2.3 – 2.6 provide an example of these, based on the SNAP nomenclature.

In some cases, there is a risk of misallocation, overlap or double counting, because it is not always clear whether e.g. specialised utility vehicles such as fire trucks, refuse collectors, sewage trucks, road tankers, etc. are included in the on-road vehicle reporting categories. In addition, some of the vehicles may have a second combustion engine in order to operate specialist equipment or machinery. Where possible, the machinery should be reported under the appropriate NRMM reporting category and not road transport. If it is not possible to resolve the fuel used by the main vehicle and the on-board mobile machinery, then then emissions from the mobile machinery can be reported under the same source category as the main vehicle.

In some other cases, machinery is mobile in principle, but actually stays at the same site for long periods, or is only mobile within a small radius, e.g., some excavators and cranes. In many cases it will be appropriate to report these as 'Other mobile sources and machinery', but allocation to other NRMM categories is also possible. Similarly there are large mobile generator sets, e.g. above 1 MW, which are mobile but in reality are not often moved. Care is needed to ensure that equipment such as mobile generators are not included in stationary combustion reporting categories (such as SNAP sectors 1, 2 or 3). A similar example arises at airports, where resolving fuel used by NRMM from other stationary combustion sources can be challenging, and care must be taken to avoid double counting the mobile machinery component.

At a detailed level, the information available may be very country specific, and approaches will need to be adjusted accordingly. It is good practice to resolve the emissions from NRMM from other sources such as road vehicles and stationary combustion wherever possible. Detailed documentation is needed to explain provide the allocation of different vehicle and machinery types to emissions reporting categories.

Machinery by engine type

The reciprocating engines used in this mixture of other mobile sources comprise diesel engines, four-stroke and two-stroke petrol or LPG engines:

- The diesel engines range from large diesel engines > 200 kW (installed in cranes, graders/scrapers, bulldozers, etc.) to small diesel engines, around 5 kW, fitted to household and gardening equipment (e.g. lawn and garden tractors, leaf blowers, etc).
- Petrol-fuelled engines are virtually all of smaller power, typically less than 10 kW, and are principally used in household and gardening equipment, with a small number being used in industry (e.g. to power fork-lift trucks or small electrical generator sets). Two-stroke petrol engines are generally smaller than four-stroke engines. The equipment used in each application is described in more detail.
- LPG is used in two and four stroke petrol engines as an alternative fuel i.e. there are no significant differences in engine technology or design. The most common reason for using

LPG rather than petrol is one of cost, but air quality issues can also be an important consideration.

In addition to the division by fuel, an important classification is the division of the engines into variable and constant speed engines. However, it can be challenging to obtain information that allows the machinery fleet to be classified in this way:

- Constant speed engines are principally those used in generator sets, where they produce electric power at a constant frequency by running the generator at a constant shaft speed. They are potentially important – for example accounting for 25% of the NRMM diesel (gas oil) consumption in the UK.
- Variable speed engines are used in most types of equipment, including agricultural tractors, excavators etc, where the equipment's engine's speed varies according to the task it is undertaking.

The distinction between these two engine types is important because the emission standards that machinery is required to comply with differs between constant speed and variable speed machinery. However this information can only be utilised in estimating emissions when a Tier 3 methodology is used (see Chapter 3.4).

Trends in machinery types and usage patterns

The information included in Chapter 2.3 below represent comprehensive descriptions of machinery types that are in use. There is evidence that there are trends in the usage patterns of NRMM, in terms of the rated power of machinery and the patterns of usage. There are also new machinery types becoming available which are increasingly difficult to allocate to a simple categorisation structure.

To date, it has not been possible to source definitive information to update the sections below, so comments are included here for consideration and information:

Power ratings - There is a general trend for some types of modern machinery to be larger, and hence equipped with engines that have higher power ratings. Examples can be found in the agriculture sector, where modern tractors and combine harvesters are larger than older units. However, in some selected cases, modern machinery is more efficient than older units, meaning that they can be equipped with engines that are of a lower power rating. Information can be sourced from manufacturers' web-sites (which include detailed technical specifications).

Equipment age profiles - As plant has become more specialised, complex and expensive, construction companies increasingly hire rather than own equipment. NRMM owned by a hire company is generally used for more hours in a year. This means that the usable lifetime of construction equipment is reduced, and it is replaced more frequently. This will mean that new emissions standards penetrate the fleet more swiftly, thereby reducing emissions more quickly than occurs where machinery is owned by the user. Information can be obtained from trade organisations and associations representing industry.

2.3 Industry

In order to identify the vehicles and machinery dealt with, it is helpful to provide a brief description of the types of vehicles and machinery used in industry. A summary of the engine types used by the machinery is also included below.

Pilers (SNAP 080700)

Originally included in the agriculture sector only, mobile piler units are now used on many building sites. They are diesel engined and can be variable or constant speed, with a rated power greater than 56kW.

Asphalt pavers/concrete pavers (SNAP 080801)

These wheeler crawler-type machines (road pavers, slurry seal pavers, chip spreaders, large pavement profilers, and pavement recyclers) are street finishers which use asphalt or concrete as paving material. They are equipped with three- to six-cylinder diesel engines with a power output between 15 and 160 kW. Larger engines are turbo charged.

Plate compactor/tampers/rammers (SNAP 080802)

Small compaction equipment is powered by two-stroke gasoline engines having about 1 to 3 kW output; medium-size and large-size compaction equipment is equipped either with four-stroke gasoline engines or with diesel engines of 2 to 21 kW. Tampers and rammers are tools for surface treatment operated by two-stroke petrol engines of about 1–3 kW power output. Large rammers fall under ‘Other construction equipment’.

Rollers (SNAP 080803)

These machines (e.g. smooth drum rollers, single drum rollers, tandem rollers, padfoot rollers), used for earth compaction, are all diesel engine equipped having a power output in the range of 2 to 390 kW. Modern rollers typically vibrate and can therefore be lighter, and hence equipped with engines of lower power rating. New models are typically of rated power up to 55kW.

Trenchers/mini excavators (SNAP 080804)

These crawler or wheel-type machines can be considered as a special type of a mini-excavator used for digging trenches. Some are equipped with special tools, e.g. cable plows. They are diesel engines equipped with a power output of 10 to 40 kW.

Excavators (wheel / crawler type) (SNAP 080805)

Excavators are mainly used for earth movement and loading work. Hydraulic and cable models are covered by this category. Some have special tools like fork arms, telescopic booms, rammers, etc. Excavators can be divided into three classes. Small ones used for digging work to put pipes or cables into the earth have a power output of about 10 to 40 kW. They are equipped with two- to four-cylinder diesel engines and fall under the sub-category ‘Trenchers’. Medium-size hydraulic and dragline excavators used for general earthmoving work have a power output of about 50 to 500 kW. The engines have 4 to 12 cylinders. Many of the engines are turbo charged. Large excavators and crawler tractors used for heavy earthwork and raw material extraction start at above 500 kW. The power output can be as high as several thousand kW, having 8 to 16 cylinders. All engines are turbo charged.

Cement and mortar mixers (SNAP 080806)

Small concrete mixers run on electric power or four-stroke petrol engines of about 1 to 7.5 kW power output. Larger mixers run on diesel engines having a power output of 5 to 40 kW.

Cranes (SNAP 080807)

Cranes (e.g. crawler mobile cranes, carry cranes, tower cranes) have an output of about 100 to 250 kW. Models with a special design can have a significantly higher power output. The vast majority of tower cranes are now powered by dedicated generator units (see below). These generators are constant speed engines, rather than a variable speed engine built into the crane.

Graders/scrapers (SNAP 080808)

Graders (e.g. articulated steered or wheel-steered) are used to level surfaces. They have a power output of about 50 to 190 kW. Scrapers (e.g. wheel-steered tractor scrapers, articulated steered tractor scrapers) are used for earthwork. They have a power output of about 130–700 kW and are all diesel-engine powered.

Off-highway trucks (SNAP 080809)

These are large trucks (e.g. rigid frame dumpers, wheel-steered mine dumpers, articulated-steered mine dumpers, etc.) used for heavy goods transport on construction sites and quarries (but not on public roads), e.g., to transport sand, rocks, etc. They run on diesel engines of 300 to 500 kW power output, nearly all turbo charged.

Bulldozers (SNAP 080810)

This category includes wheel dozers, articulated-steered dozers, crawler dozers, crawler loaders, etc. They are mainly used for demolishing and earthmoving work and are all diesel engine equipped with a power output of about 30 to 250 kW. Large engines are turbo charged (some might have a significantly larger power output).

Tractors / loaders/backhoes (SNAP 080811)

Tractors are used for general transport work. They are all diesel engine equipped with a power output of 25 to 150 kW. Loaders (e.g. wheel loaders, articulated steered wheel loaders, landfill compactors) are used for earth work or can be equipped with special tools (e.g. with brush cutters, forearms, handling operation devices, snow-thawers, etc.). Crawler loaders should be treated under 'Bulldozers'. They are all diesel engine equipped.

As is the case for excavators, loaders fall into three classes:

- 'Minis' have about 15 to 40 kW and are equipped with three- or four-cylinder diesel engines, with normal aspiration.
- Medium-size loaders have a power output between 40 to 120 kW. These are typically turbo-charged.
- Large loaders go up to about 250 kW. These are typically turbo-charged.

Backhoes are combinations of a wheel loader and a hydraulic excavator. They run on diesel engines with a power output of about 10 to 130 kW.

Skid steer loaders (SNAP 080812)

These are small wheel loaders, some with independent steering. They run on diesel engines having a power output between 15 to 60 kW.

Dumpers/tenders (SNAP 080813)

Small dumpers and tenders (e.g. wheel steered site dumpers, articulated steered site dumpers, crawler dumpers, etc.) are used for transport of goods at construction sites. Most of them run with diesel engines with a power output of about 5 to 50 kW, some smaller units have four-stroke petrol engines with a power output between 5 to 10 kW.

Aerial lifts (SNAP 080814)

Small aerial lifts (< 2 kW) run mainly on electrical engines, while only some on small (mainly two-stroke) petrol engines with a power output of 3 to 10 kW. Large aerial lifts and work platforms are mounted on a truck chassis and are operated by separate engines with a power output of 5 to 25 kW or by a vehicle engine utilizing a pneumatic system. As these units are often mounted on a specialist road vehicle, attention must be paid to avoid double counting with the category 1.A.3.b Road Transport.

Fork lifts (SNAP 080815)

Forklift trucks, from small ones (e.g. pallet stacking trucks) to large ones (e.g. stacking straddle carriers), are equipped with electrical or internal combustion engines. Electrical engines are mostly used for indoor material handling. The internal combustion engines run with petrol or LPG and/or diesel fuel. In general, they have a power output between 20 and 100 kW. The engine capacity is between 1.5 to 4 litres for four-stroke petrol/LPG engines and 2.5 to 6 litres for diesel engines.

Generator sets (SNAP 080816)

There are three main groups of generator sets used:

- Small units which can be carried by one or two persons. They have an output of 0.5 to 5 kW and are powered by four-stroke engines. Some of the very small sets still run with two-stroke engines.
- Medium-sized units which can be put on small one axle/two or four-wheeled trailers. They are three- or four-cylinder diesel-engine powered and have an output of about 5 to 100 kW. Larger engines are turbo charged.
- Larger generator sets are actually small mobile power plants, put into a container and having a power output of 100 to about 1000 kW. Nearly all engines are turbo charged.

Generator sets above 1000 kW are not classed as mobile machinery.

Pumps (SNAP 080817)

Mobile pumps typically have a power range between 0.5 to 70 kW. Many of the pumps in use are operated with electric engines, but those using internal combustion engines use all types of fuels except LPG. However, above about 10 kW and 20 kW power output for two and four-stroke respectively, diesel engines predominate.

Air/gas compressors (SNAP 080818)

Nearly all of the small compressors used for handicraft purposes run with electric engines. Large compressors used for construction works are equipped with diesel engines with a power output between 10 and 120 kW.

Welders (SNAP 080191)

Small mobile welders (< 10 kW) are typically equipped with four-stroke petrol engines, and larger units are diesel-engined going up to about 40 kW.

Refrigerating units (SNAP 080820)

Diesel engines are used to operate refrigerators which are mounted on trucks and train wagons for cooling purposes. The power output of such units is in the range of 10 to 20 kW.

Other general industrial equipment (SNAP 080821)

These are sweepers, scrubbers, broomers, pressure washers, slope and brush cutters, swappers, piste machines, ice rink machines, blowers, vacuums, etc. not belonging to on-road vehicles. Petrol and diesel engines are used, and engine sizes vary considerably.

Other material handling equipment (SNAP 080822)

These are, for example, conveyors, tunnel locomotives, snow clearing machines, industrial tractors, pushing tractors. Diesel engines are primarily used.

Other construction equipment (SNAP 080823)

Examples of mobile machinery in this category include paving and surfacing equipment, bore/drill rigs, crushing equipment, peat cutting and processing machines, concrete breakers/saws, pipe layers, etc. Mainly diesel and two-stroke gasoline engines are used.

2.4 Agriculture and forestry

Two-Wheel Tractors (SNAP 080601)

Tractors are used in agriculture (and forestry) as universal working machines. Very small single axle/two wheel tractors only have a few kW power output (about 5 to 15 kW) and are equipped with two-stroke or four-stroke petrol or with diesel engines.

Agricultural tractors (SNAP 080602)

Two axle/four wheel tractors (there are also some articulated-wheel and crawler-type tractors which fall under this category) are nearly all exclusively diesel-engine powered and have a wide range of power output, between 20 and about 250 kW. The main power range used for agricultural purposes is 100 to 130 kW, and where a second tractor is used to accompany this, it is typically smaller, having a power output of 20 to 60 kW. In forestry, the same tractors are used as in agriculture, having a power range of about 60 to 120 kW. In general, over the last 30 years there has been a clear trend towards the use of higher power outputs and towards four-wheel drive tractors. Larger four- and six-cylinder diesel engines are equipped with turbo charger. However, for selected agricultural activities, small tractors are still used e.g. for vineyards, typical power outputs are 30 to 50 kW.

Harvesters/combiners (SNAP 080603)

These machines are used mainly for harvesting grain (chaff, beet, etc.), and are all diesel engine equipped. Older machinery has a power output between 50 and 150 kW, but more modern units are typically larger, with power output up to 500 kW.

Others (SNAP 080604)

Agricultural equipment included in this category include: sprayers, manure distributors, mowers, balers and tillers. They are mainly diesel engines, but two- and four-stroke gasoline engines are also used in these machines. The power output is in the range of 5 to 50 kW.

Professional chain saws/clearing saws (SNAP 080701)

These are chain saws for professional use; all are two-stroke petrol-engine driven with a power output of about 2 to 6 kW.

Forest tractors/harvesters/skidders (SNAP 080702)

These are vehicles (e.g. wheel forwarder, crawler forwarder, grapple skidder, cable skidder, etc.) used for general transport and harvesting work in forests. They are all diesel engine equipment with a power output of about 25 to 75 kW.

Others (SNAP 080703)

This heading covers machines such as tree processors, haulers, fellers, forestry cultivators, shredders and log cultivators. They are mainly diesel engine equipment; some use two-stroke engines.

2.5 Military, land based

In Military (SNAP 080100), no detailed information is provided on the specific machinery types used. It is assumed that all equipment is diesel-engine powered, however it is possible that petrol-engined machinery, similar to that classified in other sectors, may be used.

2.6 Household and gardening

Trimmers/strimmers/edgers/brush cutters (SNAP 080901)

This equipment is mainly two-stroke petrol engine equipped and has about 0.25 to 1.4 kW power output.

Lawn mowers (SNAP 080902)

Domestic mowers are either two-stroke or four-stroke petrol-engine powered, having a power output between 0.5 and 5 kW. Ride-on mowers in the domestic sector are mainly one- or two-cylinder diesel engines and four-stroke petrol engines. Mowers for professional use, are typically diesel or four-stroke petrol-engine powered. Ride-on mowers have a power output of about 5 to 15 kW, with, displacements between 100 and 250 ccm.

Hobby chain saws (SNAP 080903)

Do-it-yourself motor saws are mainly equipped with two-stroke petrol engines (care must be taken not to include those with electric motors). Small (hobby) motor saws have a power output of about 1 to 2 kW (professionally-used motor saws of about 2 to 6 kW, cf. sector 'Forestry').

Snow mobiles/skidoos (SNAP 080904)

Snow vehicles are generally equipped with two- and four-stroke gasoline engines with a power output of 10 to 50 kW. There has been a trend towards more powerful machines across the last two decades.

Other household and gardening equipment (SNAP 080905)

Lawn and garden tractors, wood splitters, snow blowers, tillers, and similar gardening machinery is included under this category.

Other household and gardening vehicles (SNAP 080906)

This category includes non-road vehicles like all-terrain vehicles such as quads, off-road motor cycles, golf carts, etc.

2.7 Emissions

The emissions originate from the combustion of fuel in diesel compression ignition or petrol spark ignition engines to power the machinery considered. NO_x, PM, CO, NMVOCs, SO_2 and CO_2 are all important species emitted from the fuel combustion, the latter two typically being estimated directly from the fuel use. The emission characteristics of diesel and petrol engines are different. When compared to petrol engines (fuel rich), diesel engines (fuel lean) produce more PM and NO_x, and less CO and NMVOCs. The emissions also differ between two-stroke and four-stroke gasoline engines, and the age of the equipment (see Chapter 2.9 Controls).

2.7.1 PM Emission Estimates

PM emission factors presented in the Guidebook represent primary emissions i.e. the formation of secondary aerosol from chemical reaction in the atmosphere after release are not included. A number of factors influence the determination of primary PM emissions from activities. The quantity of PM determined in an emission measurement depends to a large extent on the measurement conditions and techniques used. This is particularly true of activities involving high temperature and semi-volatile emission components – in such instances the PM emission may be partitioned between a solid/aerosol phase and material which is gaseous at the sampling point but which can condense in the atmosphere (the “condensable component”). The proportion of filterable and condensable material will vary depending on the temperature of the flue gases and in sampling equipment.

The measurement approach for determining PM emissions from NRMM most commonly includes dilution where sampled flue or exhaust gases are mixed with ambient air (either using a dilution tunnel or dilution sampling systems) which collect the filterable and condensable components on a filter at lower temperature (52°C).

As part of the 2015 Guidebook review, selected Tier 1 and/or Tier 2 PM emission factors have been reviewed to identify whether the data represent “filterable PM” or “total PM” (filterable and condensable components).

The review identifies whether the PM emission factors (for TSP, PM10 and PM2.5) represent filterable PM, total PM, or whether the basis of the emission factor cannot be determined. This information is presented in each of the emission factor tables.

2.7.2 Portable Emissions Measurement Systems (PEMS)

Portable Emissions Measurement Systems (PEMS) utilise relatively new technology to measure emissions from combustion engines as the vehicle or the equipment is being used. The use of PEMS is particularly attractive because it can, potentially, confirm both emissions during real-world usage patterns, and also in-service compliance of emissions with required standards.

PEMS technologies have developed to provide a complete and very accurate real-time monitoring of a range of pollutants emitted by combustion engines (e.g. HC, CO, CO2, NOx and a range of particle metrics), and systems can also record a range of associated engine, vehicle and ambient parameters. To achieve this, PEMS used for emissions regulatory purposes integrate advanced gas analysers, exhaust mass flow meters, weather station, Global Positioning System (GPS) and connection to the vehicle networks ([3]).

Since this technique is able to measure emissions directly whilst machinery is operating under real-world conditions, it is considered that it leads to the more accurate determination of EFs.

PEMS therefore offer an important alternative approach to the laboratory-based emissions measurement techniques in assessing emissions from different types of combustion engines. This is an important consideration, because it has become evident that some engine types and emission control technologies used for road vehicles perform very differently in the real-world compared to laboratory conditions. There is concern that similar issues may arise with the engines used for NRMM, and in particular that future emission limits might be found to be overly optimistic.

To address this concern, in-use emissions testing with PEMS has become one of the key elements of the European emissions legislation. The first 'official' step was the publication of the procedures to verify the conformity of gaseous emissions from heavy-duty engines, under the Commission Regulations (EU) 582/2011 ([4]) and (EU) 64/2012 ([5]). To adapt these procedures to NRMM, a pilot program was launched and will address the specificities for testing and data evaluation. It will also stimulate the dissemination of know-how and the development of good practices ([6]). PEMs are included in the 2016 EU Regulation (2016/1628) relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery (EU, 2016) ([7]).

However, there is not yet an extensive emissions measurement-base from a wide range of mobile machinery using PEMS - studies to date having only included a small number of NRMM which may not be representative of the whole. Furthermore, it is recognised that the emissions for a piece of NRMM is cycle dependent.

As a result, more measurements are needed to gain a better understanding of both current mobile machinery, and the emissions performance of machinery that will be put into the market in future years.

([3]) http://iet.jrc.ec.europa.eu/pems/portable-emissions-measurement-systems-pems
([4]) Commission Regulation (EU) No. 64/2012 amending Regulation (EU) No 582/2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:028:0001:0023:EN:PDF
([5]) Commission Regulation (EU) No. 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council. EC – European Commission. Official Journal of the European Union L 167, pp. 1-168. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:167:0001:0168:en:PDF
([6]) http://iet.jrc.ec.europa.eu/pems/pems-non-road-mobile-machinery-nrmm-engines
([7])http://eur-lex.europa.eu/eli/reg/2016/1628/oj

2.8 Contribution to total emissions

All source sectors considered in this chapter can make significant contributions to emission total of either NOx, PM_{10} or NMVOC. Contributions from a single source sector range from 0.1 to 11% of the total emission, but are typically less than 5% of the total emission.

Table 2-1 Contribution to total NOx, PM10 and NMVOC emissions from the 2015 EMEP database (WebDab)

NFR14 Sector	Data	NOx	PM_{10}	NMVOC
1A2gvii Mobile Combustion in manufacturing industries and construction	No. of countries reporting	17	16	17
	Lowest value	0%	0.0%	0.0%
	Typical Contribution	3%	0.4%	0.5%
	Highest value	7%	2.7%	0.9%
1A4aii Commercial/institutional: Mobile	No. of countries reporting	6	6	6
	Lowest value	0%	0.0%	0.1%
	Typical Contribution	1%	0.0%	0.8%
	Highest value	2%	0.1%	2.9%
1A4bii Residential: Household and gardening (mobile)	No. of countries reporting	10	10	10
	Lowest value	0%	0.0%	0.1%
	Typical Contribution	0%	0.0%	2.0%
	Highest value	1%	0.2%	7.4%
1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	No. of countries reporting	19	19	19
	Lowest value	0%	0.0%	0.2%
	Typical Contribution	5%	0.5%	1.3%
	Highest value	11%	3.4%	3.6%
1A5b Other, Mobile (including military, land based and recreational boats)	No. of countries reporting	12	11	12
	Lowest value	0%	0.0%	0.0%
	Typical Contribution	1%	0.1%	0.5%
	Highest value	1%	0.3%	5.0%

The “No. of countries reporting” is defined here as those reporting both the sector emission and a total emission.

In total, and looking at the pollutants covered by the United Nations Economic Commission for Europe (UNECE) protocols only, it can be assumed that the sectors covered by this chapter contribute significantly to total NO_x, PM_{10} and VOC emissions in most countries.

Similar data may be obtained, with slightly more detailed source sectors, can also be obtained by analysing data from the US Environmental Protection Agency (US-EPA). Table 2-2 shows a first broad evaluation.

Table 2-2 Contribution of 'off-road' machinery to total emission [in percent], as estimated by US-EPA for different non-attainment areas

Pollutant	NO_x	PM	VOC	CO
Total over all areas[1)]	15.9	1.4	10.9	7.3
Total by areas	8–29	0.3–5.2	4–19	3–14
by category				
Agriculture	0.5–11	0.02–0.8	0.1–1.2	0.02–0.6
Airport service	0–3.5	0–0.2	0–0.25	0–0.8
Recreational marine	0–1.5	0–0.3	0–6.5	0–0.8
Construction	3–23	0.1–2.1	0.5–1.8	0.2–1.8
Industry	0.3–3.0	0.02–0.4	0.1–0.8	0.3–2.9
Lawn and garden	0.1–0.5	0.02–0.2	1.9–10.5	0.02–4.5
Light commercial	0.1–0.5	0.01–0.15	0.3–2.3	1.0–7.5
Forestry	0–0.1	0–0.3	0.02–0.16	0.02–0.35
Recreation	0–0.1	0–0.1	0.2–2.1	0.2–3.9

Note
[1)] Average of two different industries.

In the light of these results, the following sectors/sub-sectors seem of greatest importance for the different pollutants:

- for NO_x: agriculture
  construction (part of 'industry')
- for PM: agriculture
  construction (part of 'industry')
- for VOC: lawn and garden (part of 'household and gardening')
- for CO: light commercial (part of 'industry')
  lawn and garden (part of 'household and gardening')

Efforts to gather data on the different sectors can be tailored to the level of contribution to the emissions total. For heavy metals, in particular lead, it is the consumption of gasoline that is important. Higher levels of gasoline consumption can typically be found in the Residential sector (or 'Lawn and garden' in Table 2-2).

When comparing emissions of PM_{10} to those of the more physiologically toxic $PM_{2.5}$, whilst the general patterns of importance remain, the significance of $PM_{2.5}$ from off-road machinery to the total emissions is higher than for total PM_{10}. This is because internal combustion engines produce PM with a much smaller mean size than, for example, many industrial processes.

2.9 Controls

Gaseous emissions can be controlled by two mechanisms: control of the combustion technology which can be combined with exhaust gas treatment and control of the fuel quality. Both these measures are used for non-road mobile machinery (NRMM).

A number of technical control technologies are available, including exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) to control NO_x emissions, and diesel particulate filters (DPF) to control PM emissions. These technologies are better developed for the diesel engines used in road transport (particularly powering heavy-duty vehicles) and are currently only rarely used in conjunction with NRMM.

Within Europe emissions from NRMM are regulated by the non-road mobile machinery directives. The emission directives list specific emission limit values (g/kWh) for CO, VOC, NO_x (or VOC + NO_x) and TSP, depending on engine size (kW for diesel, ccm and kW for gasoline) and date of implementation (referring to engine market date). Stage V legislation, currently being finalised, includes further reductions of emission limits, and also introduces emission limits for particle numbers, to control emissions of ultrafine particulates.

For diesel, Directives 97/68/EC and 2004/26/EC relate to non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. The latter directive also comprises emission limits for railway machinery. For tractors the relevant directives are 2000/25 and 2005/13. For gasoline, Directive 2002/88/EC distinguishes between hand-held (SH) and non hand-held (NS) types of machinery. New Stage V emission limits (EU, 2016)) include a wider range of machinery types, and in particular machinery at the low and high ends of the power rating range.

In recent years there has been a recognition that testing emission performance by using portable emission measurement systems provides an improved assessment of real-world emissions. The Stage V documentation, refers to the future adoption of such a testing methodology (see Chapter 2.7.2).

The following tables provide an overview of the EU emssion limits implemented through different Directives. The tables present emission limits for diesel and petrol engined non-road mobile machinery respectively.

Table 2-3 Overview of EU directive requirements relevant for emissions control from diesel-fuelled non-road machinery

Stage	Engine size	CO	VOC	NO_x	VOC+NO_x	PM	Diesel machinery			Tractors	
							EU Directive	Implement. date		EU Directive	Implement. Date
	[kW]			[g/kWh]				Transient	Constant		
Stage I											
A	130<=P<560	5	1.3	9.2	-	0.54	97/68	1/1 1999	-	2000/25	1/7 2001
B	75<=P<130	5	1.3	9.2	-	0.7		1/1 1999	-		1/7 2001
C	37<=P<75	6.5	1.3	9.2	-	0.85		1/4 1999	-		1/7 2001
Stage II											
E	130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002

F	75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
G	37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
D	18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA											
H	130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
I	75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
J	37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
K	19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB											
L	130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
M	75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
N	56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
P	37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV											
Q	130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014	1/1 2014	2005/13	1/1 2014
R	56<=P<130	5	0.19	0.4	-	0.025		1/10 2014	1/10 2014		1/10 2014
Stage V[A]											
NRE-v/c-7	P>560	3.5	0.19	3.5		0.045	2016/1628		2019		2019
NRE-v/c-6	130≤P≤560	3.5	0.19	0.4		0.015			2019		2019
NRE-v/c-5	56≤P<130	5.0	0.19	0.4		0.015			2020		2020
NRE-v/c-4	37≤P<56	5.0			4.7	0.015			2019		2019
NRE-v/c-3	19≤P<37	5.0			4.7	0.015			2019		2019
NRE-v/c-2	8≤P<19	6.6			7.5	0.4			2019		2019
NRE-v/c-1	P<8	8.0			7.5	0.4			2019		2019
Generators	P>560	0.67	0.19	3.5		0.035			2019		2019

A = For selected machinery types, Stage V includes emission limit values for particle number.

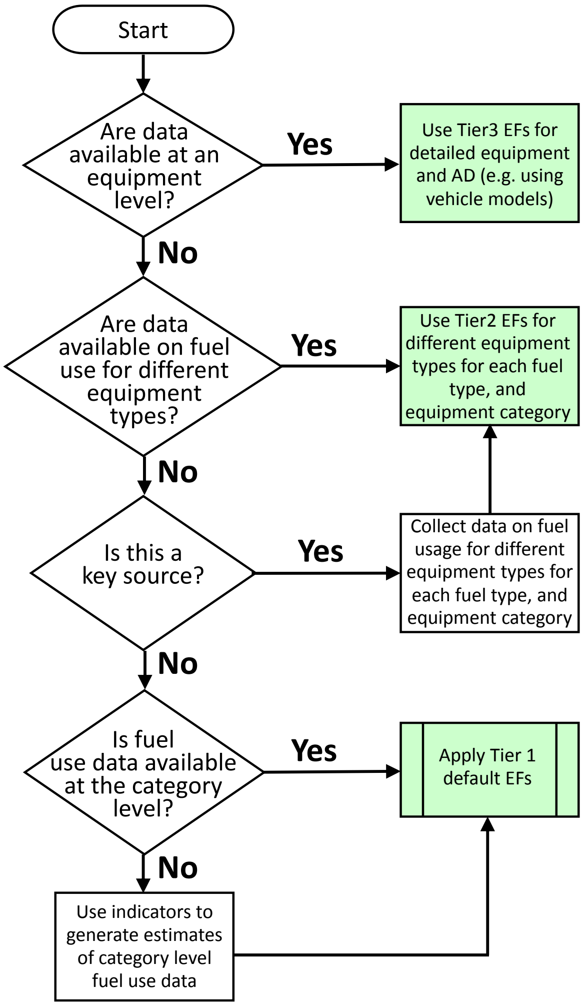
Table 2-4 Overview of the EU directive requirements relevant for emissions control from gasoline-fuelled non-road machinery

	Category	Engine size [ccm]	CO [g pr kWh]	HC [g pr kWh]	NO_X [g pr kWh]	HC+NO_X [g pr kWh]	Implement. date
	Stage I						
Hand held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Not hand held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Not hand held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
	Stage V						
Hand held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	805	-	-	72	2019
Not hand held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Not hand held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Not hand held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019

* Or any combination of values satisfying the equation (HC+NOx) × $CO^{0.784}$ ≤ 8.57 and the conditions CO ≤ 20.6 g/kWh and (HC+NOx) ≤ 2.7 g/kWh

3 Methods

3.1 Choice of method



presents the procedure for selecting the appropriate methods for estimating the emissions from NRMM. This decision tree is applicable to all nations. The basic concepts are:

- if detailed information is available then use as much as is possible;
- if this source category is a key source, then a Tier 2 or Tier 3 method should be used for estimating the emissions.

The method of choice will vary from source type to source type. The EMEP/EEA Emissions Inventory Guidebook typically includes details and emission factors for Tier 1 and Tier 2 methodologies. Tier 3 methodologies are considered detailed and highly country specific. However, mobile machinery is an atypical source in that whilst there are many different individual components within a source sector, the emissions characteristics from a specific type of NRMM will be similar in different countries. Therefore, it is possible to provide highly disaggregated and detailed information on EFs that can be used across different countries, should they be able to source suitably detailed activity data. Therefore information is included in this chapter beyond Tier 1 and Tier 2 methodologies:

Tier 1 Methodology: Emissions are estimated using a single average EF per pollutant for the broad NFR categories fuel type and broad engine type (two-stroke or four-stroke).

It can be challenging to obtain even the most basic activity data such as fuel use, for the different mobile machinery sectors. This is because the fuel used by mobile machinery in a particular source sector is not commonly reported as an amount that is resolved from the sector total fuel use. In recognition of this particular challenge, a simple methodology is included in this chapter that allows fuel used by NRMM to be estimated from a total sector fuel use, for some NRMM sectors. This is made possible by the use of generic “indicators”. The estimated sector level NRMM fuel use can then be combined with Tier 1 EFs to generate emission estimates. However, the levels of uncertainty in the resulting emission estimates would, of course, be higher than using fuel use data from more reliable sources, such as national energy balance tables.

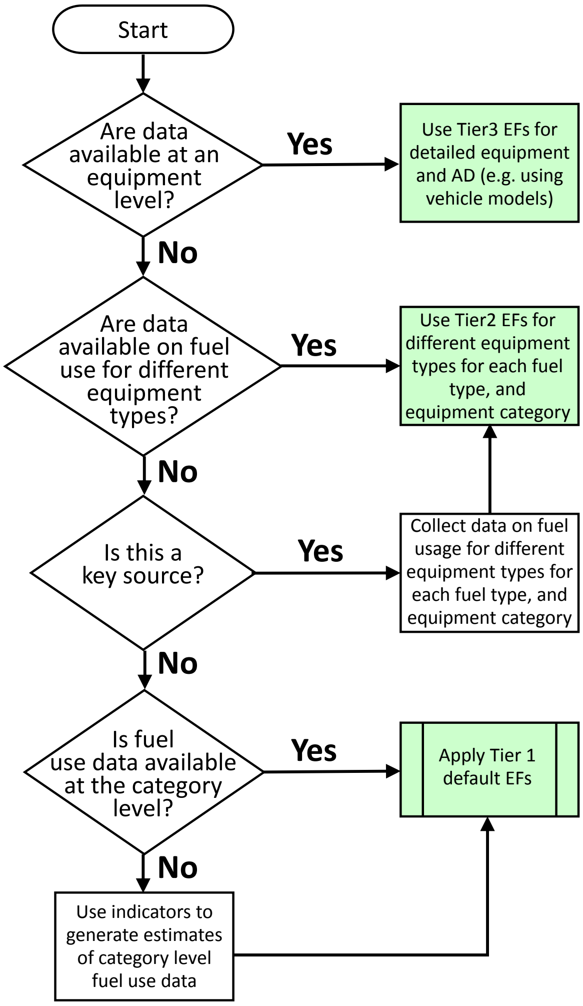
Tier 2 Methodology: Where activity data is resolved into more detailed machinery classifications, a Tier 2 methodology may be used. Emissions, and corresponding EFs, are separated into more detailed classifications for the purposes of estimating emissions. This detailed level classifies the equipment into the fuel types and layers of engine technology. The engine technology layers are stratified according to the EU emission legislation stages, and three additional layers are added to cover the emissions from engines prior to the first EU legislation stages.

Tier 3 Methodology: The NRMM is disaggregated to the equipment level, including specific operational data and size of engine. Rather than providing EFs in terms of emissions per unit of fuel consumed, the hours of operation are required and the EFs are presented as emission emissions per kW hour. Legislation relating to Stage V emission limits have not yet been finalised, but expect EFs and the years of introduction have been included.

Several methods to calculate emissions can be foreseen. In all cases, emission estimates will need to be based on a mixture of some factual data and a large number of assumptions. It is therefore important to define a method to be used for the estimation which builds upon as much data as can be obtained, hence reducing the number and impact of assumptions. It is likely that the methodology will vary from NRMM category to category.

It is acknowledged that for these NFR codes there may be difficulties with activity data because of the number and diversity of the equipment types, locations and usage patterns associated with the different types of machinery. Furthermore, statistical data on fuel consumption by off-road vehicles are often not collected and published. For this reason methodologies have been included that allow a basic estimate of fuel used to be estimated. However, where information is available, it is particularly important to use higher Tier methods, because emissions from NRMM are more dependent on technology and operating conditions than the emissions from e.g. road transport (the other principal consumer of the diesel and gasoline fuels).

Figure 3-1 Decision tree for other off-road mobile machinery



3.2 Tier 1 default approach

3.2.1 Algorithm

For the Tier 1 approach emissions are estimated using the total fuel consumed in each of the source categories covered in this chapter. For each source category the algorithm is:

$$E_{pollutant} = \sum_{fuel\,type} FC_{fuel\,type} \times EF_{pollutant\,fuel\,type} \quad (1)$$

Where:

$E_{pollutant}$ = the emission of the specified pollutant,

$FC_{fuel\ type}$ = the fuel consumption for each fuel (diesel, LPG, four-stroke gasoline and two-stroke gasoline) for the source category,

$EF_{pollutant}$ = the emission factor for this pollutant for each fuel type.

This equation is applied at the national level, using annual national fuel consumption for the off-road source categories included in this chapter.

Emission factors are provided for each type of fuel for each off-road source category.

3.2.2 Default emission factors

Table 3-1 presents the emission factors for Tier 1. The Tier 1 emission factors are based on data from the Danish Inventory; Winther (2015a) with heavy metals and POPs taken from EMEP/EEA Emissions Inventory Guidebook (2006). The approach for deriving the Tier 1 and 2 emission factors for this Guidebook is outlined in Appendix C, and draws on detailed information on EFs for NRMM from the TREMOD model, combined with fleet data from the Danish emissions inventory (Winther 2016). Updates from the previous version of the Guidebook relate to the inclusion of new Stage IIIB, IV and V diesel engine emission technology stages which enter into the fleet between 2011-2013, 2014-2015 and 2019-2020, respectively. Updated data (EFs and load factors) are also included for the technologies up to Stage IIIA.

For some pollutants (heavy metals, SO_2 and CO_2,) the emission factors are independent of the equipment technology, i.e. are simply fuel derived. For the various size fractions of particulate matter and emissions of POPs, whilst these emission factors do vary with equipment technology, they can be taken as a constant proportion of the PM_{10} or NMVOC emissions. Hence the key species, which do vary with differing equipment technologies, are PM_{10}, NO_x, NMVOC and CO.

Table 3-1 Tier 1 emission factors for off-road machinery

Tier 1 emission factors				
Fuel	NFR sector	Pollutant	Units	Emission factor
Diesel	1.A.4.c.ii-Agriculture	BC	g/tonnes fuel	1111
		CH4	g/tonnes fuel	87
		CO	g/tonnes fuel	11469
		CO2	kg/tonnes fuel	3160
		N2O	g/tonnes fuel	136
		NH3	g/tonnes fuel	8
		NMVOC	g/tonnes fuel	3542
		NOx	g/tonnes fuel	34457
		PM10	g/tonnes fuel	1913
		PM2.5	g/tonnes fuel	1913
		TSP	g/tonnes fuel	1913
	1.A.4.c.ii-Forestry	BC	g/tonnes fuel	626
		CH4	g/tonnes fuel	49
		CO	g/tonnes fuel	7673
		CO2	kg/tonnes fuel	3160
		N2O	g/tonnes fuel	138
		NH3	g/tonnes fuel	8

Tier 1 emission factors				
Fuel	NFR sector	Pollutant	Units	Emission factor
		NMVOC	g/tonnes fuel	1997
		NOx	g/tonnes fuel	28471
		PM10	g/tonnes fuel	943
		PM2.5	g/tonnes fuel	943
		TSP	g/tonnes fuel	943
	1.A.2.g.vii and 1.A.4.a.ii	BC	g/tonnes fuel	1306
		CH4	g/tonnes fuel	83
		CO	g/tonnes fuel	10774
		CO2	kg/tonnes fuel	3160
		N2O	g/tonnes fuel	135
		NH3	g/tonnes fuel	8
		NMVOC	g/tonnes fuel	3377
		NOx	g/tonnes fuel	32629
		PM10	g/tonnes fuel	2104
		PM2.5	g/tonnes fuel	2104
		TSP	g/tonnes fuel	2104
	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	Cadmium	mg/kg fuel	0.010
		Copper	mg/ kg fuel	1.70
		Chromium	mg/ kg fuel	0.050
		Nickel	mg/ kg fuel	0.07
		Selenium	mg/ kg fuel	0.01
		Zinc	mg/ kg fuel	1.00
		Benz(a)anthracene	µg/kg fuel	80
		Benzo(b)fluoranthene	µg/kg fuel	50
		Dibenzo(a,h)anthracene	µg/kg fuel	10
		Benzo(a)pyrene	µg/kg fuel	30
		Chrysene	µg/kg fuel	200
		Fluoranthene	µg/kg fuel	450
		Phenanthene	µg/kg fuel	2500
LPG	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	BC	g/tonnes fuel	11
		CH_4	g/tonnes fuel	354
		CO	g/tonnes fuel	4823
		CO_2	kg/tonnes fuel	2990
		N_2O	g/tonnes fuel	161

Tier 1 emission factors				
Fuel	NFR sector	Pollutant	Units	Emission factor
		NH_3	g/tonnes fuel	10
		NMVOC	g/tonnes fuel	6720
		NO_x	g/tonnes fuel	28571[8]
		PM_{10}	g/tonnes fuel	225
		$PM_{2.5}$	g/tonnes fuel	225
		TSP	g/tonnes fuel	225
Gasoline: four-stroke	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	BC	g/tonnes fuel	8
		CH4	g/tonnes fuel	665
		CO	g/tonnes fuel	770368
		CO2	kg/tonnes fuel	3197
		N2O	g/tonnes fuel	59
		NH3	g/tonnes fuel	4
		NMVOC	g/tonnes fuel	18893
		NOx	g/tonnes fuel	7117
		PM10	g/tonnes fuel	157
		PM2.5	g/tonnes fuel	157
		TSP	g/tonnes fuel	157
Gasoline: two-stroke	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	BC	g/tonnes fuel	188
		CH4	g/tonnes fuel	17108
		CO	g/tonnes fuel	620793
		CO2	kg/tonnes fuel	3197
		N2O	g/tonnes fuel	17
		NH3	g/tonnes fuel	3
		NMVOC	g/tonnes fuel	227289
		NO_x	g/tonnes fuel	2765
		PM_{10}	g/tonnes fuel	3762
		$PM_{2.5}$	g/tonnes fuel	3762
		TSP	g/tonnes fuel	3762
Gasoline	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii	Cadmium	mg/kg fuel	0.01
		Copper	mg/kg fuel	1.70
		Chromium	mg/kg fuel	0.05

[8] EMEP/EEA Emission Inventory Guidebook 2007

Tier 1 emission factors				
Fuel	NFR sector	Pollutant	Units	Emission factor
		Nickel	mg/kg fuel	0.07
		Selenium	mg/kg fuel	0.01
		Zinc	mg/kg fuel	1.00
		Benz(a)anthracene	µg/kg fuel	75
		Benzo(b)fluoranthene	µg/kg fuel	40
		Dibenzo(a,h)anthracene	µg/kg fuel	10
		Benzo(a)pyrene	µg/kg fuel	40
		Chrysene	µg/kg fuel	150
		Fluoranthene	µg/kg fuel	450
		Phenanthene	µg/kg fuel	1200

Notes:

For land based military emissions, use emission factors for 1.A.2.g.vii as no other data are available.

Black carbon: For agriculture, forestry, industry and gasoline/LPG machinery, the following BC fractions of PM (f-BC) are used: 0.57, 0.65, 0.62 and 0.05, c.f. Appendix E.

SO_2: The emissions of SO_2 are estimated by assuming that all sulphur in the fuel is transformed completely into SO_2 using the formula:

$$E_{SO2} = 2 \sum_j \sum_l k_{S,l}\, b_{j,l}$$

where

$k_{S,l}$ = weight related sulphur content of fuel of type l [kg/kg],

$b_{j,l}$ = total annual consumption of fuel of type l in [kg] by source category j.

For the actual figure of $b_{j,l}$ the statistical fuel consumption should be taken, if available.

PM: These PM factors represent total PM emissions (filterable and condensable fractions)

Lead: Emissions of lead are estimated by assuming that 75 % of lead contained in the fuel is emitted into air. The formula used is:

$$E_{Pb} = 0.75 \sum_j \sum_l k_{Pb,l}\, b_{j,l}$$

where

$k_{Pb,l}$ = weight-related lead content of fuel of type l in [kg/kg].

Since the simple methodology outlined above averages over different types of engines, using different types of fuels, it can provide only broad estimates at best.

3.2.3 Activity data

Activity data should be collected from national statistics. Where there is no explicit off-road machinery consumption statistics, it is good practice to use sample, survey or industry data to define an appropriate split for mobile and stationary combustion. Where no other data are available, it should be assumed that all gasoline and diesel-fuel consumption for the NFR categories in this chapter is for off-road machinery.

Generating estimates of fuel used by NRMM

There may be occasions where fuel use data for NRMM categories, or even NRMM as a whole, cannot be determined. This can arise where fuel used for NRMM is not resolved from road transport or stationary sources of the same source sector. Under these circumstances, emissions from NRMM can be as "included elsewhere" (i.e. included in 1A3b Road Transport or the corresponding stationary source categories e.g. 1A2a-f Stationary combustion in manufacturing industries and construction). However, it is better to resolve the fuel consumption into the different components and hence be able to report the emissions from NRMM sources sectors. It is possible to generate estimates of the fuel consumption in different NRMM categories by using surrogate data, as outlined below. However, this approach is high in uncertainty compared to using fuel consumption data from e.g. national energy balance tables.

Dore et al (2015) undertook an assessment of the NRMM fuel use data reported by Parties under the CLRTAP (1990 – 2013 emission inventory submissions). The purpose of the assessment was to determine whether it was possible to generate relationships between the NRMM fuel use and other readily available data, to create a set of "indicators".

Fuel use data was compiled from Parties including this in their national submissions for NRMM categories, and also IIRs which provided an adequate explanation of the approaches taken. Two metrics were compared with commonly available datasets – the amount of liquid fuels consumed and the liquid fuels consumed as a fraction of the total (mobile and stationary components). The latter metric proved to be more challenging because changes to the stationary component that were independent of the fuel used by mobile machinery complicated the results.

In some cases it was possible to determine a strong relationship between fuel used by NRMM in selected sectors and a commonly available dataset (such as GVA). In other cases it was possible to derive an estimate for the fraction of total sector level fuel used in mobile machinery.

1.A.2.g vii Mobile combustion in manufacturing industries and construction

From the national datasets assessed, is has been possible to generate a relationship between the liquid fuel used in NRMM and GVA for manufacturing and construction. The follow linear relationship was determined:

$$F_{liquid} = 0.49 \times GVA$$

Where:

Fliquid is the amount of liquid fuel used for NRMM in manufacturing and construction (TJ)

GVA is the gross value added for manufacturing and construction (million Euros current value).

However, it should be noted that this represents an upper limit for the liquid fuel use (i.e. it is conservative with regards to determining emissions), and there is significant uncertainty associated with this relationship. Data from some national inventories suggest significantly less fuel used per unit of GVA (see Appendix D). The differences between national datasets are thought to be an artefact caused by different methodologies used to estimate the fuel used for NRMM. However, after reviewing the methodologies reported in IIRs, it has not been possible to explain the differences that arise.

So, whilst the relationship above does allow fuel use, and hence emissions, to be better resolved into the mobile and stationary components of manufacturing and construction, it should be used with caution.

Details of this analysis are included in Appendix D.

1.A.4.b ii Residential: Household and gardening (mobile)

It was not possible to determine a strong and consistent relationship between the fuel used for NRMM in the residential sector with commonly available datasets. However, as a first approximation, it can be assumed that 1-2% of the total liquid fuel used in the domestic sector is used for NRMM.

It should be noted that Sweden and Norway are clear outliers from this relationship, with higher and very variable fractions of the fuel used for NRMM (~ 5-10%). However this is strongly influenced by significant changes to the liquid fuel consumption in the residential sector as a whole (i.e. for stationary combustion), rather than the fuel consumed by NRMM.

Details of this analysis are included in Appendix D.

1.A.4.c ii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery

From the data assessed, there is a strong relationship between the liquid fuel used in NRMM and GVA for agriculture/forestry/fishing (obtained from Eurostat). The follow linear relationship was determined (R^2 of 0.95):

$$F_{liquid} = 3.4 \times GVA$$

Where:

F_{liquid} is the amount of liquid fuel used for NRMM in agriculture forestry and fishing (TJ)

GVA is the gross value added for agriculture forestry and fishing (million Euros current value).

It can be assumed that the fuel used is entirely diesel oil.

A strong relationship was also found between the fuel used for mobile machinery and agricultural land cover, but this was not used because GVA data is considered to be more readily available.

The relationships between fuel used and agricultural products showed a bimodal distribution, which was assumed to be due to the variable extent to which forestry is important compared to arable or livestock farming in different countries.

Details of this analysis are included in Appendix D.

Other NRMM Categories

Efforts were made to investigate relationships for other NRMM categories. But it was not possible to determine any useable relationships or indicators for:

- 1.A.4.a.ii Commercial/institutional: Mobile
- 1.A.4.c iii National fishing
- 1.A.5.b Other, Mobile (inc. military, land based and recreational boats)

This was primarily because there was a lack of fuel use data at the detailed sector level reported by Parties to the CLRTAP. In addition, the correlations with commonly available datasets such as GVA were not strong enough to justify their use as a method for estimating fuel consumption.

3.3 Tier 2 technology-dependent approach

3.3.1 Algorithm

The generic algorithm for calculating emissions for each category (industry, agriculture and forestry, military land-based and household and gardening) using the Tier 2 methodology is:

$$E_i = \sum_j \sum_t FC_{j,t} \times EF_{i,j,t}$$

where:

E_i	=	mass of emissions of pollutant i during the inventory period,
$FC_{j,t}$	=	fuel consumption of fuel type j by equipment category c and of technology type t,
$EF_{i,j}$	=	average emission factor for pollutant i for fuel type j for equipment category c and of technology type t,
i	=	pollutant type,
j	=	fuel type (diesel, four-stroke gasoline, LPG and two-stroke gasoline),
t	=	off-road equipment technology: < 1981, 1981–1990, 1991–Stage I, Stage I, Stage II, Stage IIIA, Stage IIIB, Stage IV, Stage V).

In essence this involves sub-dividing the fuel consumption of fuel type j used by the NFR sectors into the different technology types such that the summation in the Tier 2 algorithm is equal to the single term in the Tier 1 algorithm, i.e.

$$\sum_t FC_{j,t} = FC_j$$

3.3.2 Default Emission factors

Table 3-2 presents the emission factors for Tier 2. These are based on detailed information on EFs for NRMM from the TREMOD model, combined with fleet data from the Danish emissions inventory (Winther 2016). Updates from the previous version of the Guidebook relate to the inclusion of new Stage IIIB, IV and V diesel engine emission technology stages which enter into the fleet between 2011-2013, 2014-2015 and 2019-2020, respectively. Updated data (EFs and load factors) are also included for the technologies up to Stage IIIA. The approach for deriving the Tier 2 EFs is outlined in Appendix C.

For heavy metals and POPs, the emission factors for Tier 1 must be used (Table 3–1). The emission factors are grouped according to the EU emission legislation stages, and three additional layers are added to cover the emissions from engines prior to the first EU legislation stages.

For some pollutants (heavy metals, SO_2 and CO_2,) the emission factors are independent of the equipment technology, i.e. are fuel derived. The key species, which do vary with differing equipment technologies, are particulate matter, NO_x, NMVOC and CO.

Table 3-2 Tier 2 emission factors for off-road machinery

Tier 2 emission factors												
				Technology								
Fuel	NFR Sector	Pollutant	Units	< 1981	1981-1990	1991-Stage I	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Stage V
Diesel	1.A.4.c.ii: Agriculture	BC	g/tonnes fuel	3221	2221	1074	727	483	416	74	73	9
		CH4	g/tonnes fuel	191	158	110	38	29	29	13	13	13
		CO	g/tonnes fuel	19804	17566	14147	6463	6104	6035	6087	6024	6077
		CO2	kg/tonnes fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/tonnes fuel	122	129	137	138	138	139	139	139	139
		NH3	g/tonnes fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/tonnes fuel	7760	6439	4493	1544	1181	1173	544	530	526
		NOx	g/tonnes fuel	29901	37383	49002	30799	20612	12921	9318	1587	1861
		PM10	g/tonnes fuel	5861	4047	1974	947	624	550	99	99	59
		PM2.5	g/tonnes fuel	5861	4047	1974	947	624	550	99	99	59
		TSP	g/tonnes fuel	5861	4047	1974	947	624	550	99	99	59
	1.A.4.c.ii: Forestry	BC	g/tonnes fuel	3021	2052	1172	607	456	437	74	74	9
		CH4	g/tonnes fuel	183	143	121	35	29	29	13	13	13
		CO	g/tonnes fuel	19014	16045	14239	5919	5940	5947	5940	5947	6008
		CO2	kg/tonnes fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/tonnes fuel	123	131	137	138	139	139	139	139	139
		NH3	g/tonnes fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/tonnes fuel	7423	5827	4907	1420	1160	1161	514	515	542
		NOx	g/tonnes fuel	33028	44030	49963	31344	20593	12845	9454	1586	1915
		PM10	g/tonnes fuel	5493	3731	2130	789	595	573	99	99	59
		PM2.5	g/tonnes fuel	5493	3731	2130	789	595	573	99	99	59
		TSP	g/tonnes fuel	5493	3731	2130	789	595	573	99	99	59
	1.A.2.g.vii and	BC	g/tonnes fuel	3414	2369	2001	800	825	758	78	78	56

Tier 2 emission factors												
				Technology								
Fuel	NFR Sector	Pollutant	Units	< 1981	1981-1990	1991-Stage I	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Stage V
	1.A.4.a.ii	CH4	g/tonnes fuel	199	171	144	42	39	36	15	13	23
		CO	g/tonnes fuel	20690	18890	16258	6639	7135	6826	6445	6019	7352
		CO2	kg/tonnes fuel	3160	3160	3160	3160	3160	3160	3160	3160	3160
		N2O	g/tonnes fuel	121	128	135	137	136	136	137	137	136
		NH3	g/tonnes fuel	7	7	8	8	8	8	8	8	8
		NMVOC	g/tonnes fuel	8077	6962	5851	1725	1587	1470	625	536	930
		NOx	g/tonnes fuel	26552	33942	43552	31077	22101	15653	11933	1570	7663[A]
		PM10	g/tonnes fuel	6207	4308	3642	1005	1034	950	98	98	116
		PM2.5	g/tonnes fuel	6207	4308	3642	1005	1034	950	98	98	116
		TSP	g/tonnes fuel	6207	4308	3642	1005	1034	950	98	98	116
Gasoline: two-stroke	1.A.2.g.vii, 1.A.4.a.ii,	BC	g/tonnes fuel	352	239	193	184	215				214
	1.A.4.b.ii and	CH4	g/tonnes fuel	22483	19462	17284	16979	8517				8539
		CO	g/tonnes fuel	754523	699494	621083	620519	695237				694870
	1.A.4.c.ii	CO2	kg/tonnes fuel	3197	3197	3197	3197	3197				3197
		N2O	g/tonnes fuel	12	16	16	18	20				20
		NH3	g/tonnes fuel	2	3	3	4	4				4
		NMVOC	g/tonnes fuel	298703	258562	229630	225579	113157				111450
		NOx	g/tonnes fuel	1050	1682	1852	3445	2495				2490
		PM10	g/tonnes fuel	7037	4786	3869	3683	4299				4278
		PM2.5	g/tonnes fuel	7037	4786	3869	3683	4299				4278
		TSP	g/tonnes fuel	7037	4786	3869	3683	4299				4278
Gasoline: four-stroke	1.A.2.g.vii, 1.A.4.a.ii,	BC	g/tonnes fuel	7	7	8	8	8				8
	1.A.4.b.ii and	CH4	g/tonnes fuel	710	910	672	650	568				468
		CO	g/tonnes fuel	1214855	836966	768445	774457	804157				778282
	1.A.4.c.ii	CO2	kg/tonnes fuel	3197	3197	3197	3197	3197				3197
		N2O	g/tonnes fuel	56	55	59	59	60				59
		NH3	g/tonnes fuel	4	4	4	4	4				4
		NMVOC	g/tonnes fuel	20182	25852	19082	18469	16126				13293
		NOx	g/tonnes fuel	2429	5743	7129	7088	6676				5354
		PM10	g/tonnes fuel	148	147	157	159	159				159
		PM2.5	g/tonnes fuel	148	147	157	159	159				159
		TSP	g/tonnes fuel	148	147	157	159	159				159

Tier 2 emission factors												
				Technology								
Fuel	NFR Sector	Pollutant	Units	< 1981	1981-1990	1991-Stage I	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Stage V

Reference: Winther (2016) with Heavy Metals and POPs taken from EMEP/EEA Emissions Inventory Guidebook, 2006.

A: For industrial NRMM the aggregated Stage V NO_x emission factor increase significantly compared to the previous technology steps, due to the fact that the industrial NRMM fleet consist of relatively many small engines < 56 kW. Engines < 19 kW was never regulated in the EU emission legislation directives until Stage V (c.f. Table 2-3). Engines 19-37 kW and 37-56 kW were not subject to regulation after Stage IIIA and Stage IIIB, respectively, but are now included in Stage V. The Stage V NO_x emission factors for < 56 kW engines are much higher than the emission factor for 56-560 kW engines (c.f. Table 3-11) and this influences the aggregated Stage V factor. To a smaller extent the same emission factor tendencies are visible for other sectors and other pollutants in Table 3-2.

Emission factors for Agriculture and Forestry have been presented separately as there are significant differences in the emission factors for machinery in these two sectors. Where activity statistics are not available at this detail levels, an average of the emission factors for Agriculture and Forestry can be used.

Emission factors for LPG is not available at Tier 2 technology level. Please use the Tier 1 emission factors in this case for all technology levels.

For land-based military emissions, emission factors for 1.A.2.g.vii should be used as no other data are available. However, be aware that these emission factors may underestimate emissions from military sources.

For estimation of emissions of SO_2, heavy metals and POPs, use Tier 1 emission factors in Table 3-1.

Black carbon: For information on BC fractions of PM (f-BC), please refer to Appendix E.
PM: The PM emission factors represented in the table above represent total PM emissions (filterable and condensable fractions).

3.3.3 Activity data

Commonly available national statistics will typically provide the fuel consumption data for the different NFR categories as used for Tier 1. To apply Tier 2 emission factors these fuel consumption statistics will need to be split by the relative proportion of engine technology (e.g. < 1981, 1981–1990, 1991–Stage I, Stage I, Stage II, Stage IIIA, Stage IV, Stage V) in use in any particular inventory year. This can be done through country-specific studies (the preferable option) or by using expert judgement from experts in the field of the different off-road machinery categories from e.g. trade associations for manufacturers, engineers and distributors by either selecting a particular technology to represent a particular year or by building up year-specific age profiles. Basic data on the estimated lifetime of different machines is included in Appendix C. These lifetime data — combined with industry knowledge to aggregate and weight the contribution of the detailed types to fuel consumption and data on the year of implementation of the different standards — can be used to build a picture of the age profiles for the different categories and technologies.

Alternatively, data derived from Winther (2016) and Winther & Nielsen (2006) given in the following Tables 3–3 and 3-4 and 3-5 to 3–9 (Annex file accompanying this Guidebook chapter) can be used to split the total fuel consumption into engine technology layers for each inventory year.

In the Tables 3–3 and 3–4, the percentage split of total fuel consumption as a function of engine age are given for diesel machinery in 1.A.2.g.vii, 1.A.4.c.ii (Agriculture) and 1.A.4.c.ii (Forestry), and for gasoline two-stroke and four-stroke machinery.

The Tables 3–5 to 3–9 display the layer share of fuel consumption per engine age and inventory year for diesel-fuelled non-road machinery (Tables 3–5 to 3–7) and gasoline-fuelled non-road machinery (Tables 3–8 to 3–9). Only those inventory year/engine age combinations are listed for which fuel is consumed by more than one engine technology layer. For the remaining inventory year/engine age combinations, the engine technology layer which uses the fuel becomes self-explanatory.

See Appendix C for more description of the assumptions behind the aggregated fuel split data given in the Tables 3–3 to 3–9.

The following example explains how to combine the fuel shares per engine age from Table 3–3, with the inventory year specific fuel consumption shares disaggregated into engine ages and emission levels given in Table 3–5. For agricultural machinery, zero-year old engines use 8 % of the total fuel used in this sector. For the inventory year 2002, this 8 % share is further subdivided into fuel consumption shares for Stage 1 (8 %*65 % = 5.20 %) and Stage II (8 %*35 % = 2.80 %). For the inventory year 2001, fuel consumption shares of 8 %*58% = 4.64 % and 8 %*42 % = 3.36 %) are calculated for the 1991–Stage I and Stage I emission levels, respectively. For the inventory year intervals 1981–1990 and 1991–1998, the fuel used by zero-year old engines refer to the emission levels 1981–1990 and 1991–Stage I, respectively.

Table 3-3 Split (%) of total fuel consumption per engine age (irrespective of inventory year) for diesel-fuelled non-road machinery (1.A.2.g.vii (Industry), 1.A.4.c.ii (Agriculture), 1.A.4.c.ii (Forestry))

Engine age	1.A.4.c.ii Agriculture	1.A.4.c.ii Forestry	1.A.2.g.vii Industry
0	8.00	12.00	8.80
1	7.60	12.00	8.80
2	7.20	12.00	8.80
3	6.79	12.00	8.80
4	6.39	12.00	8.80
5	5.99	12.00	8.80
6	5.59	8.67	8.80
7	5.18	5.33	8.80
8	4.78	2.00	8.80
9	4.38	2.00	6.53
10	3.98	2.00	4.27
11	3.57	2.00	2.00
12	3.17	2.00	1.78
13	2.77	2.00	1.56
14	2.37	2.00	1.33
15	1.97		1.11

16	1.90		0.89
17	1.83		0.67
18	1.76		0.44
19	1.69		0.22
20	1.62		
21	1.55		
22	1.48		
23	1.41		
24	1.34		
25	1.28		
26	1.21		
27	1.14		
28	1.07		
29	1.00		
	100.0	100.0	100.0

Table 3-4 Share of total fuel consumption per engine age (irrespective of inventory year) for gasoline-fuelled two-stroke and four-stroke non-road machinery (1.A.2.g.vii (Industry), 1.A.4.c.ii (Agriculture), 1.A.4.c.ii (Forestry), 1.A.4.b.ii (Residential)

Engine age	two-stroke	four-stroke
0	29.00	14.70
1	29.00	14.70
2	29.00	14.70
3	5.80	14.70
4	1.20	12.00
5	1.20	8.00
6	1.20	8.00
7	1.20	8.00
8	1.20	1.30
9	1.20	1.30
10		1.30
11		1.30
Total	100	100

3.4 Tier 3 equipment-specific and technology-stratified approach

The Tier 2 methods outlined in the Section above use of fuel statistics, multiplied by technology specific emission factors. However, this method can be difficult to undertake because fuel consumption data are often not available at the required detail level.

A more detailed, Tier 3, methodology is described in the following sections. This methodology uses hours of operation as the main activity data and is primarily based on the US-EPA method for estimating off-road emissions (US-EPA 1991). The Tier 3 method presented here has been updated and includes detailed fuel consumption and emission information taken, to a large extent, from the German TREMOD NRMM model.

3.4.1 Algorithm

The basic algorithm used for the Tier 3 methodology is:

$$E = N \times HRS \times P \times (1 + DFA) \times LFA \times EF_{Base} \quad (5)$$

where:

E	=	mass of emissions of pollutant i during inventory period,
N	=	number of engines (units),
HRS	=	annual hours of use,
P	=	engine size (kW),
DFA	=	deterioration factor adjustment,
LFA	=	load factor adjustment,
EF_{Base}	=	Base emission factor (g/kWh).

In this methodology, the parameters N, HRS, P, DFA, LFA, EF_{Base} of the basic formula (5) mentioned above are split further by classification systems as follows:

N: the machinery/vehicle population - this is split into different technology levels and power ranges,

HRS: the annual working hour – this is a function of the age of the equipment/vehicles; therefore, for each sub category, individual age dependent usage patterns can be defined,

P: the power – this is a function of the power distribution of the vehicles/machinery; therefore, for each sub category an individual power distribution can be defined within given power ranges,

EF_{Base}: the emission factor – this is, for each pollutant, a function of technology levels and power output.

DFA: The deterioration factor adjustment – this is a function of the power range of the vehicles/machinery and the technology level.

LFA: The load factor adjustment – this is a function of technology level.

To use the approach above, it is necessary to stratify the machinery fleet numbers in terms of: technology level, power range, load, age, as well as the annual hours of operation for each of these classes.

In this Tier 3 approach, evaporative emissions of gasoline engines are quantified separately to exhaust emissions. In reality, evaporative emissions occur under all conditions, e.g. while the machine/vehicle is in operation or not in operation. However, the emissions from off-road machines and vehicles are not very well known. Therefore, only diurnal losses, based on US-EPA's methodology, are taken into account. That means that hot-soak, resting and running losses are not included.

The emissions are estimated using the formula:

$$E = N \times HRS \times EF_{eva} \quad (6)$$

The parameters N and HRS are identical to those used for the estimation of exhaust emissions. The emission factor EF_{eva} are presented in Table 3-20.

In principle, elements of the above described approach are used in many national studies and by industry (Utredning 1989, Achten 1990, Barry 1993, Puranen et al. 1992, Danish Environmental Protection Agency 1992, Caterpillar 1992, ICOMIA 1993).

3.4.2 Sensitivities and Points of Consideration

There are some parameters within the methodology which have a large influence on the resulting emissions, and others which do not.

For example, higher powered machinery may be used to complete a task faster than lower powered machinery. In many cases the total energy requirement for (i.e. the product of: Hrs x Power x Load factor) is very similar to achieve the same activity output. Consequently differentiating between the different powers of the NRMM machinery, and their usage pattern is not necessarily of high importance.

In contrast, some parameters are very important in determining accurate emissions estimates using the Tier 3 methodology. The following comments relate to estimating emissions of NO_x and PM, but are broadly true for many other pollutants:

Accurate assigning of equipment types according to whether they use constant speed or variable speed engines is important because the machinery types are required to comply with different emissions limits.

1. For NO_x emissions from non-road mobile sources fitted with variable speed CI engines, the important factors are:

    a. The fraction of the fuel used/activity occurring in engines of 56 kW or greater, rather than that used in engines of lower rated power;

    b. The fraction of the equipment having engines of 56 kW or greater that were built to meet Stage IV emissions standards, rather than the fraction that meet earlier emissions standards (the date of introduction of Stage IV was 01/01/2014 for engines whose power output is 130 kW of greater, and 01/10/2014 for engines whose power output is above 56 kW but less than 130 kW).

Above or below the 56kW threshold, the actual rated power of the non-road mobile machinery used has little impact on the resulting emissions. However to compile the inventory, the product of the total number of pieces of equipment x the average hours used x the average power is still needed to quantify the fraction of the fuel used for engines larger and smaller than 56 kW, even if the detailed disaggregation by power ranges is not important.

2. For PM emissions from non-road mobile sources fitted with variable speed CI engines, the important factors are:

    a. The fraction of the fuel used (or activity) occurring in engines of 37 kW or greater rated power, rather than that used in engines of lower rated power;

    b. The fraction of the equipment having engines of 37 kW or greater that were built to meet Stage IIB emissions standards, rather than the fraction that meet earlier emissions standards (the date of introduction of Stage IIIB was 01/01/2011 for many, but not all, engines whose power output is 37 kW of greater).

Above or below the 37kW threshold, PM emission factors are not affected by the detailed rated power of the non-road mobile sources used.

3.4.3 Tier 3 Emission Factors

In the Tier 3 approach the machinery/vehicle population is split into different machinery types, ages and power ranges. The detailed fuel consumption and emission information is to a large extent taken from the German TREMOD NRMM model (IFEU, 2004) and later updated in 2009 and 2014 by IFEU (2009, 2014). Fuel consumption and emission information for Stage V machinery is provided by Winther (2016).

Diesel machinery base emission factors

For diesel engines, EFs are presented here for each of the following technology levels: < 1981, 1981–1990, 1991–Stage I, Stage I, II, IIIA, IIIB, IV and V. The EFs for each of these technology levels are divided into engine size classes which correspond to the engine size classifications made in the EU emission directives for NRMM.

- **Up to Stage II:** The EFs for fuel consumption and NO_x, VOC, CO and TSP emissions for technology levels up to and including Stage II are reported in the TREMOD NRMM model (IFEU 2004). These are based on measured data from a range of different studies and data suggested from literature reviews (Euromot 1995; BUWAL 1996; FAT 2002; KBA 2002 as cited in IFEU 2004).
- **Stage IIIA Onwards:** Currently no measurement data have been sourced that allow the determination of EFs for the technology levels Stages IIIA, IIIB, IV and V. Consequently, EFs for these technology levels are estimated from the EU directive emission limits relevant for diesel NRMM and agricultural tractors. Table 3-5 below shows how the EFs have been derived from the corresponding emission limit values (IFEU, 2009; Winther, 2016).

Table 3-5 Derivation of EFs from Emission Limit Values for Technology Levels for Stages IIIA, IIIB, IV and V Technology Levels.

Stage	NO_x	VOC	PM	CO
Stage IIIA	(90 % of the NOx+HC) Limit value – 10%	(10 % of the NOx+HC) Limit value – 10%	Limit value – 10 %	Limit value – 40 %
Stage IIIB	Limit value – 10 %	Limit value – 30 %	Limit value	Limit value – 40 %
Stage IV	Limit value	Limit value – 30 %	Limit value	Limit value – 40 %
Stage V	Limit value	Limit value – 30 %	Limit value	Limit value – 40 %

Stage II EFs are used for CO, VOC and PM in the cases where the generic EFs exceed the Stage II EFs. For more explanation see IFEU (2009).

$PM_{2.5}$ is assumed to be 94% of PM. N_2O and NH_3 EFs are unchanged from the EMEP/EEA Emissions Inventory Guidebook, 2013 Edition. CH_4 is be assumed to be 2.4% of total VOC (IFEU, 2009).

In the TREMOD NRMM model, the 37-56 kW and 56-75 kW size classes are represented by one 37-75 kW size group. NO_x emission factors for Stage IIIA, IIIB and IV are reported as 3.8, 3.4 and 2.1 g/kWh, respectively. Stage V emission factors have been determined using the same approach as those for Stage IV.

Table 3-6 Baseline emission factors and fuel consumption (FC) for diesel NRMM [g/kWh]

Engine Power (kW)	Technology Level	NO_x	VOC	CH_4	CO	N_2O	NH_3	PM	PM_{10}	$PM_{2.5}$	BC	FC
P<8	<1981	12.00	5.00	0.120	7.00	0.035	0.002	2.800	2.800	2.800	1.540	300
P<8	1981-1990	11.50	3.80	0.091	6.00	0.035	0.002	2.300	2.300	2.300	1.265	285
P<8	1991-Stage I	11.20	2.50	0.060	5.00	0.035	0.002	1.600	1.600	1.600	0.880	270
P<8	Stage V	6.08	0.68	0.016	4.80	0.035	0.002	0.400	0.400	0.400	0.320	270
8<=P<19	<1981	12.00	5.00	0.120	7.00	0.035	0.002	2.800	2.800	2.800	1.540	300
8<=P<19	1981-1990	11.50	3.80	0.091	6.00	0.035	0.002	2.300	2.300	2.300	1.265	285
8<=P<19	1991-Stage I	11.20	2.50	0.060	5.00	0.035	0.002	1.600	1.600	1.600	0.880	270
8<=P<19	Stage V	6.08	0.68	0.016	3.96	0.035	0.002	0.400	0.400	0.400	0.320	270
19<=P<37	<1981	18.00	2.50	0.060	6.50	0.035	0.002	2.000	2.000	2.000	1.100	300
19<=P<37	1981-1990	18.00	2.20	0.053	5.50	0.035	0.002	1.400	1.400	1.400	0.770	281
19<=P<37	1991-Stage I	9.80	1.80	0.043	4.50	0.035	0.002	1.400	1.400	1.400	0.770	262
19<=P<37	Stage II	6.50	0.60	0.014	2.20	0.035	0.002	0.400	0.400	0.400	0.320	262
19<=P<37	Stage IIIA	6.08	0.60	0.014	2.20	0.035	0.002	0.400	0.400	0.400	0.320	262
19<=P<37	Stage V	3.81	0.42	0.010	2.20	0.035	0.002	0.015	0.015	0.015	0.002	262
37<=P<56	<1981	7.70	2.40	0.058	6.00	0.035	0.002	1.800	1.800	1.800	0.990	290
37<=P<56	1981-1990	8.60	2.00	0.048	5.30	0.035	0.002	1.200	1.200	1.200	0.660	275
37<=P<56	1991-Stage I	11.50	1.50	0.036	4.50	0.035	0.002	0.800	0.800	0.800	0.440	260
37<=P<56	Stage I	7.70	0.60	0.014	2.20	0.035	0.002	0.400	0.400	0.400	0.320	260
37<=P<56	Stage II	5.50	0.40	0.010	2.20	0.035	0.002	0.200	0.200	0.200	0.160	260
37<=P<56	Stage IIIA	3.81	0.40	0.010	2.20	0.035	0.002	0.200	0.200	0.200	0.160	260
37<=P<56	Stage IIIB	3.81	0.28	0.007	2.20	0.035	0.002	0.025	0.025	0.025	0.020	260
37<=P<56	Stage V	3.81	0.28	0.007	2.20	0.035	0.002	0.015	0.015	0.015	0.002	260
56<=P<75	<1981	7.70	2.40	0.058	6.00	0.035	0.002	1.800	1.800	1.800	0.990	290

Engine Power (kW)	Technology Level	NO_x	VOC	CH_4	CO	N_2O	NH_3	PM	PM_{10}	$PM_{2.5}$	BC	FC
56<=P<75	1981-1990	8.60	2.00	0.048	5.30	0.035	0.002	1.200	1.200	1.200	0.660	275
56<=P<75	1991-Stage I	11.50	1.50	0.036	4.50	0.035	0.002	0.800	0.800	0.800	0.440	260
56<=P<75	Stage I	7.70	0.60	0.014	2.20	0.035	0.002	0.400	0.400	0.400	0.320	260
56<=P<75	Stage II	5.50	0.40	0.010	2.20	0.035	0.002	0.200	0.200	0.200	0.160	260
56<=P<75	Stage IIIA	3.81	0.40	0.010	2.20	0.035	0.002	0.200	0.200	0.200	0.160	260
56<=P<75	Stage IIIB	2.97	0.28	0.007	2.20	0.035	0.002	0.025	0.025	0.025	0.020	260
56<=P<75	Stage IV	0.40	0.28	0.007	2.20	0.035	0.002	0.025	0.025	0.025	0.020	260
56<=P<75	Stage V	0.40	0.13	0.003	2.20	0.035	0.002	0.015	0.015	0.015	0.002	260
75<=P<130	<1981	10.50	2.00	0.048	5.00	0.035	0.002	1.400	1.400	1.400	0.770	280
75<=P<130	1981-1990	11.80	1.60	0.038	4.30	0.035	0.002	1.000	1.000	1.000	0.550	268
75<=P<130	1991-Stage I	13.30	1.20	0.029	3.50	0.035	0.002	0.400	0.400	0.400	0.220	255
75<=P<130	Stage I	8.10	0.40	0.010	1.50	0.035	0.002	0.200	0.200	0.200	0.160	255
75<=P<130	Stage II	5.20	0.30	0.007	1.50	0.035	0.002	0.200	0.200	0.200	0.160	255
75<=P<130	Stage IIIA	3.24	0.30	0.007	1.50	0.035	0.002	0.200	0.200	0.200	0.160	255
75<=P<130	Stage IIIB	2.97	0.13	0.003	1.50	0.035	0.002	0.025	0.025	0.025	0.020	255
75<=P<130	Stage IV	0.40	0.13	0.003	1.50	0.035	0.002	0.025	0.025	0.025	0.020	255
75<=P<130	Stage V	0.40	0.13	0.003	1.50	0.035	0.002	0.015	0.015	0.015	0.002	255
130<=P<560	<1981	17.80	1.50	0.036	2.50	0.035	0.002	0.900	0.900	0.900	0.450	270
130<=P<560	1981-1990	12.40	1.00	0.024	2.50	0.035	0.002	0.800	0.800	0.800	0.400	260
130<=P<560	1991-Stage I	11.20	0.50	0.012	2.50	0.035	0.002	0.400	0.400	0.400	0.200	250
130<=P<560	Stage I	7.60	0.30	0.007	1.50	0.035	0.002	0.200	0.200	0.200	0.140	250
130<=P<560	Stage II	5.20	0.30	0.007	1.50	0.035	0.002	0.100	0.100	0.100	0.070	250
130<=P<560	Stage IIIA	3.24	0.30	0.007	1.50	0.035	0.002	0.100	0.100	0.100	0.070	250
130<=P<560	Stage IIIB	1.80	0.13	0.003	1.50	0.035	0.002	0.025	0.025	0.025	0.018	250
130<=P<560	Stage IV	0.40	0.13	0.003	1.50	0.035	0.002	0.025	0.025	0.025	0.018	250
130<=P<560	Stage V	0.40	0.13	0.003	1.50	0.035	0.002	0.015	0.015	0.015	0.002	250
P>560	Stage V	3.50	0.13	0.003	1.50	0.035	0.002	0.045	0.045	0.045	0.002	250

Gasoline machinery base emission factors

EFs for gasoline engines are resolved into 2-stroke and 4-stroke engines, for both hand held (SH) and not hand held (SN) equipment. The EFs are further grouped into the engine size classes (ccm) corresponding to the engine size classifications made in the EU emission directive 2002/88 for gasoline fuelled non-road machinery.

EFs and fuel consumption are available for each of the following technology levels: < 1981, 1981–1990, 1991–Stage I, Stage I, Stage II and Stage V. The EFs for fuel consumption and NO_x, VOC, CO and TSP (2-stroke only) emissions are provided by IFEU (2004). They are based on expert judgement, taking into account specific measurement data, type approval values, and estimated emission increases for the engines originating from 1990 and earlier (see IFEU, 2004). Fuel consumption and emission information for Stage V machinery is provided by Winther (2016).

4-stroke TSP emission factors in TREMOD NRMM come from the USEPA (USEPA, 1999). N_2O and NH_3 EFs are unchanged from the 2013 version of the EMEP/EEA Emissions Inventory Guidebook. CH_4 is assumed to be 7.0 % and 3.4 % of VOC for 2-stroke and 4-stroke engines respectively (IFEU, 2009).

Table 3-7 Emission factors and fuel consumption (FC) for gasoline 2 stroke non road engines (g/kWh)

Size code	Size class	Technology Level	NO_x	VOC	CH4	CO	N_2O	NH_3	TSP	BC	FC
SH2	20<=S<50	<1981	1.00	305	21.35	695	0.01	0.002	7.00	0.350	882
SH2	20<=S<50	1981-1990	1.00	300	21.00	579	0.01	0.002	5.30	0.265	809
SH2	20<=S<50	1991-Stage I	1.10	203	14.21	463	0.01	0.002	3.50	0.175	735
SH2	20<=S<50	Stage I	1.50	188	13.16	379	0.01	0.002	3.50	0.175	720
SH2	20<=S<50	Stage II	1.50	44	3.08	379	0.01	0.002	3.50	0.175	500
SH2	20<=S<50	Stage V	1.50	44	3.08	379	0.01	0.002	3.50	0.175	500
SH3	S>=50	<1981	1.10	189	13.23	510	0.01	0.002	3.60	0.180	665
SH3	S>=50	1981-1990	1.10	158	11.06	425	0.01	0.002	2.70	0.135	609
SH3	S>=50	1991-Stage I	1.20	126	8.82	340	0.01	0.002	1.80	0.090	554
SH3	S>=50	Stage I	2.00	126	8.82	340	0.01	0.002	1.80	0.090	529
SH3	S>=50	Stage II	1.20	64	4.48	340	0.01	0.002	1.80	0.090	500
SH3	S>=50	Stage V	1.20	64	4.48	340	0.01	0.002	1.80	0.090	500
SN1	S<66	<1981	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN1	S<66	1981-1990	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN1	S<66	1991-Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN1	S<66	Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN1	S<66	Stage II	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN1	S<66	Stage V	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	<1981	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	1981-1990	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	1991-Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	Stage II	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN2	66<=S<100	Stage V	0.03	10	0.70	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	<1981	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	1981-1990	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	1991-Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	Stage II	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN3	100<=S<225	Stage V	0.03	10	0.70	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	<1981	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	1981-1990	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	1991-Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	Stage I	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	Stage II	0.50	155	10.85	418	0.01	0.002	2.60	0.130	652
SN4	S>=225	Stage V	0.03	8	0.56	418	0.01	0.002	2.60	0.130	652

Table 3-8 Emission factors and fuel consumption (FC) for gasoline 4 stroke non road engines (g/kWh)

Size code	Size class	Technology Level	NO_x	VOC	CH4	CO	N_2O	NH_3	TSP	BC	FC
SH2	20<=S<50	<1981	2.40	33	1.12	198	0.03	0.002	0.08	0.004	496
SH2	20<=S<50	1981-1990	3.50	27.5	0.94	165	0.03	0.002	0.08	0.004	474
SH2	20<=S<50	1991-Stage I	4.70	22	0.75	132	0.03	0.002	0.08	0.004	451
SH2	20<=S<50	Stage I	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406

Size code	Size class	Technology Level	NO_x	VOC	CH4	CO	N_2O	NH_3	TSP	BC	FC
SH2	20<=S<50	Stage II	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406
SH2	20<=S<50	Stage V	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406
SH3	S>=50	<1981	2.40	33	1.12	198	0.03	0.002	0.08	0.004	496
SH3	S>=50	1981-1990	3.50	27.5	0.94	165	0.03	0.002	0.08	0.004	474
SH3	S>=50	1991-Stage I	4.70	22	0.75	132	0.03	0.002	0.08	0.004	451
SH3	S>=50	Stage I	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406
SH3	S>=50	Stage II	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406
SH3	S>=50	Stage V	4.70	22	0.75	132	0.03	0.002	0.08	0.004	406
SN1	S<66	<1981	1.20	26.9	0.91	822	0.03	0.002	0.08	0.004	603
SN1	S<66	1981-1990	1.80	22.5	0.77	685	0.03	0.002	0.08	0.004	603
SN1	S<66	1991-Stage I	2.40	18	0.61	548	0.03	0.002	0.08	0.004	603
SN1	S<66	Stage I	4.30	16.1	0.55	411	0.03	0.002	0.08	0.004	475
SN1	S<66	Stage II	4.30	16.1	0.55	411	0.03	0.002	0.08	0.004	475
SN1	S<66	Stage V	4.30	16.1	0.55	411	0.03	0.002	0.08	0.004	475
SN2	66<=S<100	<1981	2.30	10.5	0.36	822	0.03	0.002	0.08	0.004	627
SN2	66<=S<100	1981-1990	3.50	8.7	0.30	685	0.03	0.002	0.08	0.004	599
SN2	66<=S<100	1991-Stage I	4.70	7	0.24	548	0.03	0.002	0.08	0.004	570
SN2	66<=S<100	Stage I	4.70	7	0.24	467	0.03	0.002	0.08	0.004	450
SN2	66<=S<100	Stage II	4.70	7	0.24	467	0.03	0.002	0.08	0.004	450
SN2	66<=S<100	Stage V	4.02	5.98	0.20	467	0.03	0.002	0.08	0.004	450
SN3	100<=S<225	<1981	2.60	19.1	0.65	525	0.03	0.002	0.08	0.004	601
SN3	100<=S<225	1981-1990	3.80	15.9	0.54	438	0.03	0.002	0.08	0.004	573
SN3	100<=S<225	1991-Stage I	5.10	12.7	0.43	350	0.03	0.002	0.08	0.004	546
SN3	100<=S<225	Stage I	5.10	11.6	0.39	350	0.03	0.002	0.08	0.004	546
SN3	100<=S<225	Stage II	5.10	9.4	0.32	350	0.03	0.002	0.08	0.004	546
SN3	100<=S<225	Stage V	3.52	6.48	0.22	350	0.03	0.002	0.08	0.004	546
SN4	S>=225	<1981	1.30	11.1	0.38	657	0.03	0.002	0.08	0.004	539
SN4	S>=225	1981-1990	2.00	9.3	0.32	548	0.03	0.002	0.08	0.004	514
SN4	S>=225	1991-Stage I	2.60	7.4	0.25	438	0.03	0.002	0.08	0.004	490
SN4	S>=225	Stage I	2.60	7.4	0.25	438	0.03	0.002	0.08	0.004	490
SN4	S>=225	Stage II	2.60	7.4	0.25	438	0.03	0.002	0.08	0.004	490
SN4	S>=225	Stage V	2.08	5.92	0.20	438	0.03	0.002	0.08	0.004	490

LPG machinery base emission factors

Fuel use and EFs for CO, VOC and NO_x are taken from IFEU (2004), based on measurements from Miersch (1999). The TSP EF is from work undertaken by TNO (CEPMEIP, 2001). The CH_4 percentage share of total VOC is 5 % (USEPA, 2004). Due to lack of data, no distinction is made between technology levels.

Table 3-9 Emission factors and fuel consumption (FC) for LPG non road engines (g/kWh)

NO_x	VOC	CO	NH_3	N_2O	TSP	FC
10[9]	2.2	1.5	0.003	0.05	0.07	311

Recreational craft base emission factors

Recreational craft are treated separately to other machinery types.

For newer engines complying with the EU Directive 2003/44 emission limits, the emission factors for CO, VOC, NO_x and TSP are estimated as 80 % of the relevant emission legislation value (IFEU, 2004). However, if the EF calculated using this approach exceeds the EF for "conventional craft" (i.e. the EF prior to the introduction of controls) then the latter value is used.

The EU Directive 2003/44 comprises the emission legislation limits for diesel engines, 2-stroke gasoline engines, and 4-stroke gasoline engines. For NO_x, a constant limit value is given for each of the three engine types. For TSP, the constant emission limit regards diesel engines only. The emission limits for CO and VOC are more complex, depending on engine size (kW) and parameters presented in the Directive 2003/44.

Table 3-10 below shows the technology specific fuel consumption and base emission factors for recreational craft for appropriate engine size categories used in the TREMOD NRMM model.

Table 3-10 Emission factors (g/kW hr) and fuel consumption (FC) for conventional and 2003/44 directive engines used by pleasure craft

	VOC	CO	NO_x	TSP	FC
2-Stroke outboard engines (conventional)					
0 - 3 kW	341	532	4	10	791
3 - 12 kW	257	427	2	10	791
> 12 kW	172	374	3	10	791
2-Stroke outboard engines (Directive 2003/44)					
0 - 3 kW	83	440	4	10	791
3 - 12 kW	42	184	2	10	791
> 12 kW	30	134	3	10	791
4-Stroke outboard engines (conventional)					
0 - 3 kW	121	585	5	0.08	426
3 - 12 kW	24	520	7	0.08	426
> 12 kW	14	390	10	0.08	426

[9] EMEP/EEA Emission Inventory Guidebook 2007

	VOC	CO	NO_x	TSP	FC
4-Stroke outboard engines (Directive 2003/44)					
0 - 3 kW	34	440	5	0.08	426
3 - 12 kW	14	184	7	0.08	426
> 12 kW	8	134	10	0.08	426
4-Stroke inboard engines (conventional)					
75 - 130 kW	10	346	12	0.08	426
4-Stroke inboard engines (Directive 2003/44)					
75 - 130 kW	6	125	12	0.08	426
Diesel inboard engines (conventional)					
< 15 kW	3.8	6	11.5	2.3	285
15 - 50 kW	2.2	5.5	18	1.4	281
> 50 kW	2	5.3	8.6	1.2	275
Diesel inboard engines (Directive 2003/44)					
< 15 kW	1.7	4	7.8	0.8	285
15 - 50 kW	1.5	4	7.8	0.8	281
> 50 kW	1.3	4	7.8	0.8	275

Deterioration factor adjustments

Engines wear with use. As a result, EFs for NRMM increase with time i.e. as the age of the machinery increases. It is therefore necessary to incorporate a deterioration adjustment into the emissions calculations.

Diesel and 2-Stroke Gasoline

The deterioration factor adjustment for a given machinery type at a given time depends on the engine-size class (only for gasoline), the emission level and the average engine life time. For diesel and gasoline 2-stroke engines the deterioration factor adjustment is generally expressed as:

$$DF_{D,2ST} = \frac{K}{LT} \cdot DF_{y,z} \qquad (18)$$

where $DF_{D,2ST}$ is the deterioration factor adjustment for diesel and 2-stroke gasoline machinery,

K is the engine age (between 0 and average life time)

LT is the average lifetime

y is the engine-size class, and

z is the technology level.

As can be derived from Equation 18, for diesel and gasoline 2-stroke engines younger than average engine life time a linear interpolation is made between zero and the maximum deterioration factor. For engines older than average engine life time the maximum deterioration factor is used.

Deterioration factors are shown in Table 3-11 and 3-17 below (IFEU, 2004) for: diesel engines, gasoline 2-stroke. The values express $DF_{y,z}$ i.e. the ratio representing the maximum emission increase for any specific type of equipment and technology level.

As an example from Table 3-16, the TSP emissions from a diesel engine becomes 47.3 % higher as the engine age reach average life time compared to the emissions from the engine as new. Reversely the NO_x emissions from 2-stroke SN1 engines up to Stage I decrease by 60 % compared to new engines when average engine life time is reached (Table 3-17). For newer engines (Stages I and II), the NOx emissions decrease by 33% when the average engine life time is reached.

Table 3-11 Deterioration factors for diesel machinery relative to average engine life time

Emission Level	NO_x	VOC	CO	TSP
Before Stage I	0.024	0.047	0.185	0.473
Stage I	0.024	0.036	0.101	0.473
Stage II	0.009	0.034	0.101	0.473
Stage IIIA, IIIB, IV, V	0.008	0.027	0.151	0.473

Table 3-12 Deterioration adjustment factors for gasoline 2-stroke engines relative to average engine life time

Engine	Size code	Size class	Technology Level	NO_x	VOC	CO	TSP
2-stroke	SH1	S<20	<1981	0	0.2	0.2	0
2-stroke	SH1	S<20	1981-1990	0	0.2	0.2	0
2-stroke	SH1	S<20	1991-Stage I	0	0.2	0.2	0
2-stroke	SH1	S<20	Stage I	0	0.24	0.24	0
2-stroke	SH1	S<20	Stage II	0	0.24	0.24	0
2-stroke	SH1	S<20	Stage V	0	0.24	0.24	0
2-stroke	SH2	20<=S<50	<1981	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	1981-1990	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	1991-Stage I	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	Stage I	0	0.29	0.24	0
2-stroke	SH2	20<=S<50	Stage II	0	0.29	0.24	0
2-stroke	SH2	20<=S<50	Stage V	0	0.29	0.24	0
2-stroke	SH3	S>=50	<1981	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	1981-1990	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	1991-Stage I	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	Stage I	0	0.266	0.231	0
2-stroke	SH3	S>=50	Stage II	0	0.266	0.231	0
2-stroke	SH3	S>=50	Stage V	0	0.266	0.231	0
2-stroke	SN1	S<66	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN1	S<66	Stage II	-0.33	0	1.109	5.103

Engine	Size code	Size class	Technology Level	NO_x	VOC	CO	TSP
2-stroke	SN1	S<66	Stage V	-0.33	0	1.109	5.103
2-stroke	SN2	66<=S<100	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN2	66<=S<100	Stage II	-0.33	0	1.109	5.103
2-stroke	SN2	66<=S<100	Stage V	-0.33	0	1.109	5.103
2-stroke	SN3	100<=S<225	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN3	100<=S<225	Stage II	-0.33	0	1.109	5.103
2-stroke	SN3	100<=S<225	Stage V	-0.33	0	1.109	5.103
2-stroke	SN4	S>=225	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	Stage I	-0.274	0	0.887	1.935
2-stroke	SN4	S>=225	Stage II	-0.274	0	0.887	1.935
2-stroke	SN4	S>=225	Stage V	-0.274	0	0.887	1.935

4-Stroke Gasoline

For gasoline 4-stroke engines the deterioration factor is calculated as:

$$DF_{4ST} = \sqrt{\frac{K}{LT}} \cdot DF_{y,z} \qquad (19)$$

Where DF_{4ST} is the deterioration factor adjustment for 4-stroke gasoline machinery.

No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and, hence, DF = 1 in these situations.

As explained in Equation 19, for gasoline 4-stroke engines younger than average engine life time the square root of a linear interpolation is made between zero and the maximum deterioration factor. For engines older than average engine life time the maximum deterioration factor is used.

Deterioration factors are shown in Table 3-13 below (IFEU, 2004; Winther, 2016) for gasoline 4-stroke engines. The values express $DF_{y,z}$ i.e. the ratio representing the maximum emission increase for any specific type of equipment and technology level.

Table 3-13 Deterioration adjustment factors for gasoline 4-stroke engines relative to average engine life time

Engine	Size code	Size class	Emission Level	NO_x	VOC	CO	TSP
4-stroke	SN1	S<66	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	Stage I	-0.3	1.753	1.051	1.753

Engine	Size code	Size class	Emission Level	NO_x	VOC	CO	TSP
4-stroke	SN1	S<66	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN1	S<66	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	Stage I	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	Stage I	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN4	S>=225	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	Stage I	-0.599	1.095	1.307	1.095
4-stroke	SN4	S>=225	Stage II	-0.599	1.095	1.307	1.095
4-stroke	SN4	S>=225	Stage V	-0.599	1.095	1.307	1.095
4-stroke	SH1	S<20	<1981	0	0	0	0
4-stroke	SH1	S<20	1981-1990	0	0	0	0
4-stroke	SH1	S<20	1991-Stage I	0	0	0	0
4-stroke	SH1	S<20	Stage I	0	0	0	0
4-stroke	SH1	S<20	Stage II	0	0	0	0
4-stroke	SH1	S<20	Stage V	0	0	0	0
4-stroke	SH2	20<=S<50	<1981	0	0	0	0
4-stroke	SH2	20<=S<50	1981-1990	0	0	0	0
4-stroke	SH2	20<=S<50	1991-Stage I	0	0	0	0
4-stroke	SH2	20<=S<50	Stage I	0	0	0	0
4-stroke	SH2	20<=S<50	Stage II	0	0	0	0
4-stroke	SH2	20<=S<50	Stage V	0	0	0	0
4-stroke	SH3	S>=50	<1981	0	0	0	0
4-stroke	SH3	S>=50	1981-1990	0	0	0	0
4-stroke	SH3	S>=50	1991-Stage I	0	0	0	0
4-stroke	SH3	S>=50	Stage I	0	0	0	0
4-stroke	SH3	S>=50	Stage II	0	0	0	0
4-stroke	SH3	S>=50	Stage V	0	0	0	0

Load adjustment factors

The adjustment factors due to engines operating under different load factors are included below in Table 3-14 (IFEU, 2014; Winther, 2016) ([10]).

Table 3-14 Transient operation adjustment factors for diesel engines

Technology Level	Load	Load factor	NO_x	VOC	CO	TSP	FC
Stage II and prior	High	>0.45	0.95	1.05	1.53	1.23	1.01
Stage IIIA	High	>0.45	1.04	1.05	1.53	1.47	1.01
Stage IIIB-V	High	>0.45	1	1	1	1	1
Stage II and prior	Middle	0.25≤LF≤0.45	1.025	1.67	2.05	1.6	1.095
Stage IIIA	Middle	0.25≤ LF≤0.45	1.125	1.67	2.05	1.92	1.095
Stage IIIB-V	Middle	0.25≤ LF≤0.45	1	1	1	1	1
Stage II and prior	Low	<0.25	1.1	2.29	2.57	1.97	1.18
Stage IIIA	Low	<0.25	1.21	2.29	2.57	2.37	1.18
Stage IIIB-V	Low	<0.25	1	1	1	1	1

Evaporative Emissions

Gasoline engines emit NMVOC via evaporative losses. Emissions are dependent on the machinery type, and whether the engine is 2-stroke and 4-stroke. 2-stroke gasoline engines use motor gasoline, whereas 4-stroke engines use a mixture of motor gasoline and lubrication oil.
Table 3-15 below presents EFs for evaporative emissions of NMVOC by machinery and engine type.

Table 3-15 NMVOC emission factors for evaporative losses in g/h

SNAP	Code	Vehicle/machinery type	2-stroke gasoline	4-stroke gasoline
0802	01	Shunting locomotives		
	02	Rail-cars		
	03	Locomotives		
0803	01	Sailing boats with auxiliary engines	0.75	
	02	Motorboats/workboats	11.0	11.0
	03	Personal watercraft	0.75	
	04	Inland goods carrying vessels		
0806	01	Two-wheel tractors	0.30	0.30
	02	Agricultural tractors		
	03	Harvesters/combiners		
	04	Others (sprayers, manure distributors, etc.)	0.3	0.30
0807	01	Professional chain saws/clearing saws	0.03	
	02	Forest tractors/harvesters/skidders		

([10]) Information presented in IFFEU 2014 is based on measurements for high and low engine loads from USEPA (2010) and supplementary emission information from TU Graz.

SNAP	Code	Vehicle/machinery type	2-stroke gasoline	4-stroke gasoline
	03	Others (tree processors, haulers, forestry cultivators, etc.)	0.07	
0808	01	Asphalt/concrete pavers		
	02	Plate compactors/tampers /rammers	0.11	0.12
	03	Rollers		
	04	Trenchers/mini excavators		
	05	Excavators (wheel/crawler type)		
	06	Cement and mortar mixers		1.20
	07	Cranes		
	08	Graders/scrapers		
	09	Off-highway trucks		
	10	Bulldozers (wheel/crawler type)		
	11	Tractors/loaders/backhoes		
	12	Skid steer tractors		
	13	Dumper/tenders		0.40
	14	Aerial lifts	2.30	
	15	Forklifts		2.25
	16	Generator sets	0.13	0.12
	17	Pumps	0.10	0.09
	18	Air/gas compressors		
	19	Welders		
	20	Refrigerating units		
	21	Other general industrial equipment (broomers, sweepers, etc.)	1.20	1.20
	22	Other material handling equipment (conveyors, etc.)		
	23	Other construction work equipment (paving/surfacing, etc.)	1.20	
0809	01	Trimmers/edgers/bush cutters	0.02	
	02	Lawn mowers	0.05	0.05
	03	Hobby chain saws	0.01	
	04	Snowmobiles/skidoos	1.00	1.00
	05	Other household and gardening equipment	0.05	0.05
	06	Other household and gardening vehicles	0.10	0.10

3.4.4 Tier 3 Activity Data

Many of the input data required for the application of this approach (e.g. the usage and the population data) are not part of general statistical yearbooks, or national energy balance tables. Therefore, specific data searches are needed to allow emission estimates of reasonable accuracy to be made. It may be necessary to draw extensively on expert judgement.

Data on the numbers of different machines and their age (technologies) can sometimes be obtained from sales statistics either from national statistical organisations or trade associations for suppliers or users of equipment.

Trade associations for suppliers or users of equipment can also provide data on the power ratings, usage (time in use) and load factors for these off-road machines.

In the absence of national data, data from the Danish inventory can be used to provide assumptions on annual hours of use and fractions of different, engine size, ages and types of machines in use for different NFR codes as well as assumptions on load factors (Winther & Nielsen, 2006).

In the absence of country-specific load factors for the different categories any number of different typical load factors (LF) can be applied. Weightings for time in mode for diesel and gasoline (> 20 kW) powered off-road industrial equipment (Cycle C), generators and mobile power plant (Cycle D) and utility, lawn and garden, typically < 20 kW (Cycle G), laid down in ISO DP 8178 can be used. These data are presented in Table 3-21. Weightings for time in mode for automotive vehicle applications such as forestry and agricultural tractors can be taken from Table 3-22.

However, it needs to be appreciated that the ISO DP 8178 standard, and the cycles for road vehicles, do change with time. For example, heavy-duty on-road vehicles are now tested to a different 13-mode cycle, and using a 30-minute duration transient cycle (the European Transient Cycle, ETC). It is proposed to add a new transient cycle (ISO 8178-11) to the suite of cycles for non-road mobile machinery. A full description of the Cycle classes A–G is provided in Table 3-23.

Table 3-16 Test points and weighting factors of ISO DP 8178 test cycles (11)

B-type mode number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Torque	**100**	**75**	**50**	**25**	**10**	**100**	**75**	**50**	**25**	**10**	**0**
Speed	**rated speed**					**intermediate speed**					**low idle**
Off-road vehicles											
Type C1	0.15	0.15	0.15		0.1	0.1	0.1	0.1			0.15
Type C2				0.06		0.02	0.05	0.32	0.30	0.10	0.15
Constant speed											
Type D1	0.3	0.5	0.2								
Type D2	0.05	0.25	0.3	0.3	0.1						

(11) Values in table checked against currently used version of ISO DP 8178, as given by table at web address http://www.dieselnet.com/standards/cycles/iso8178.html The changes made in first table are corrections to errors rather than the adoption of a new test matrix.

Locomotives (12)											
Type F	0.25							0.15			0.6
Utility, lawn and garden											
Type G1						0.09	0.2	0.29	0.3	0.07	0.05
Type G2	0.09	0.2	0.29	0.3	0.07						0.05
Type G3	0.9										0.1
Marine application											
Type E1	0.06 0.08	0.11					0.19	0.32			0.3
Type E2	0.2	0.5	0.15	0.15							
Marine application propeller											
Mode number E3	1					2		3		4	
Power % of rated power	100					75		50		25	
Speed % of rated speed	100					91		80		63	
Weighting factor	0.2					0.5		0.15		0.15	
Mode number E4	1					2		3		4	5
Speed % of rated speed	100					80		60		40	idle
Torque % of rated torque	100					71.6		46.5		25.3	0
Weighting factor	0.06					0.14		0.15		0.25	0.4
Mode number E5	1					2		3		4	5
Power % of rated p.	100					75		50		25	0
Speed % of rated speed	100					91		80		63	idle
Weighting factor	0.08					0.13		0.17		0.32	0.3

Table 3-17 Test cycle A (13 — mode cycle) used after July 2000 (13)

Mode number cycle A	1	2	3	4	5	6	7	8	9	10	11	12	13
Speed	Low idle speed	A	B	B	A	A	A	B	B	C	C	C	C
% Torque	0	100	50	75	50	75	25	100	25	100	25	75	50
Weighting factor	0.15	0.08	0.10	0.10	0.05	0.05	0.05	0.09	0.10	0.08	0.05	0.05	0.05

(12) These conditions are up to date — see for example definition given in 1a(v). of Annex 1 (page 8 of PDF file) using test cycle defined in Specification B, para 3.7.1.2 of Annex 2, p. 19 of PDF file.
(13) Engine speed A < B < C. For their definitions see EC Directive 1999/96/EC Appendix 1 of Annex III.

Table 3-18 Test cycles of ISO DP 8178 for industrial engine applications with typical examples

Cycle A	**Automotive, vehicle applications**	
	Examples:	forestry and agricultural tractors, diesel and gas engines for on-road applications
Cycle B	**Universal**	
Cycle C	**Off-road vehicles and industrial equipment**	
	C1:	diesel-powered off-road industrial equipment
	Examples:	industrial drilling rigs, compressors, etc.; construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, off-highway trucks, etc.; agricultural equipment, rotary tillers; forestry equipment; self-propelled agricultural vehicles; material handling equipment; fork lift trucks; hydraulic excavators; road maintenance equipment (motor graders, road rollers, asphalt finishers); snow plough equipment; airport supporting equipment; aerial lifts
	C2:	off-road vehicles with spark-ignited industrial engines > 20 kW
	Examples:	fork lift trucks; airport supporting equipment; material handling equipment; road maintenance equipment; agricultural equipment
Cycle D	**Constant speed**	
	D1:	power plants
	D2:	generating sets with intermittent load
	Examples:	gas compressors, refrigerating units, welding sets, generating sets on board of ships and trains, chippers, sweepers
	D3:	generating sets on-board ships (not for propulsion)
Cycle E	**Marine applications**	
	E1:	diesel engines for craft less than 24-m length (derived from test cycle B)
	E2:	heavy-duty constant speed engines for ship propulsion
	E3:	heavy-duty marine engines
	E4:	pleasure craft spark-ignited engines for craft less than 24-m length
	E5:	diesel engines for craft less than 24 m length (propeller law)
Cycle F	**Rail traction**	
	Examples:	locomotive, rail cars
Cycle G	**Utility, lawn and garden, typically < 20 kW**	
	G1:	non-handheld intermediate speed application

Examples:	walk behind rotary or cylinder lawn mowers, front or rear engine riding lawn mowers, rotary tillers, edge trimmers, lawn sweepers, waste disposers, sprayers, snow removal equipment, golf carts
G2:	non-handheld rated speed application
Examples:	portable generators, pumps, welders, air compressors; rated speed application may also include lawn and garden equipment which operates at engine rated speed
G3:	handheld rated speed applications
Examples:	edge trimmers, string trimmers, blowers, vacuums, chain saws, portable saw mills

3.5 Speciation

Tables 3-24 to 3-26 provide information as used by Veldt et al. (1993), Derwent, and Loibl et al. (1993) in their work on speciating NMVOC emission estimates for the road transport sector.

Table 3-19 Composition of VOC emission of motor vehicles (data as provided by Veldt et al.)

A) Non-methane VOCs (composition in weight % of exhaust)

Species or group of species	Exhaust four stroke (conventional)	Gasoline engine 3-way catalyst equipped	Evaporation	Diesel	LPG
Ethane	1.4	1.8		1	3
Propane	0.1	1	1	1	44
n-Butane	3.1	5.5	20	2	
i-Butane	1.2	1.5	10		
n-Pentane	2.1	3.2	15	2	
i-Pentane	4.3	7	25		
Hexane	7.1	6	15		
Heptane	4.6	5	2		
Octane	7.9	7			
Nonane	2.3	2			
Alkanes C> 10	0.9	3		30 (1)	
Ethylene	7.2	7		12	15
Acetylene	4.5	4.5		4	22
Propylene	3.8	2.5		3	10
Propadiene	0.2				
Methylacetylene	0.3	0.2			
1-Butene	1.7	1.5	1	)	
1,3 Butadiene	0.8	0.5		) 2	
2-Butene	0.6	0.5	2	)	
1-Pentene	0.7	0.5	2		
2-Pentene	1.1	1	3	1	
1-Hexene	0.6	0.4	)		
1,3 Hexene	0.6	0.4	) 1.5		
Alkanes C> 7	0.3	0.2	)	2 (1)	
Benzene	4.5	3.5	1	2	
Toluene	12.0	7	1	1.5	
o-Xylene	2.5	2		0.5	
M,p-Xylene	5.6	4	0.5	1.5	

Species or group of species	Exhaust four stroke (conventional)	Gasoline engine 3-way catalyst equipped	Evaporation	Diesel	LPG
Ethylbenzene	2.1	1.5		0.5	
Styrene	0.7	0.5			0.1
1,2,3-Trimethylbenzene	0.5	1			
1,2,4-Trimethylbenzene	2.6	4			
1,3,5-Trimethylbenzene	0.8	2			
Other aromatic	3.8	3			
Aromatic compounds	4.5	6		20 [(1)]	
Formaldehyde	1.7	1.1		6	4
Acetaldehyde	0.3	0.5		2	2
Other Aldehydes C4	0.3	0.2		1.5	
Acrolein	0.2	0.2		1.5	
2-Butenal				1.0	
Benzaldehyde	0.4	0.3		0.5	
Acetone	0.1	1		1.5	
	100	100	100	100	100

[(1)] C13.

B) Methane (composition in weight % of exhaust)

Gasoline		
— 2-stroke	7%	IFEU (2009)
— 4-stroke	3.4%	IFEU (2009)
Diesel	2.4%	IFEU (2009)
LPG	5%	USEPA(2004)

Table 3-20 Composition of VOC-emissions (data as used by Derwent)

		Percentage by mass speciation by source category, w/w %		
No	Species	petrol engine exhaust	diesel exhaust	petrol evaporation vehicles
0	Methane	8.00	3.7	
1	Ethane	1.30	0.5	
2	Propane	1.20		
3	n-butane	1.95	2.5	19.990
4	i-butane	0.93	2.5	10.480
5	n-pentane	2.78	2.5	7.220
6	i-pentane	4.45	2.5	10.150
7	n-hexane	1.76	2.5	2.020
8	2-methylpentane	2.14	2.5	3.020
9	3-methylpentane	1.49	2.5	2.010
10	2,2-dimethylbutane	0.28	2.5	0.600
11	2,3-dimethylbutane	0.54	2.5	0.740
12	n-heptane	0.74	2.5	0.703

No	Species	Percentage by mass speciation by source category, w/w %		
		petrol engine exhaust	diesel exhaust	petrol evaporation vehicles
13	2-methylhexane	1.39	2.5	0.924
14	3-methylhexane	1.11	2.5	0.932
15	n-octane	0.37	2.5	0.270
16	Methylheptanes	3.90	2.5	0.674
17	n-nonane	0.18	2.5	
18	Methyloctanes	1.58	2.5	
19	n-decane	0.37	2.5	
20	Methylnonanes	0.84	2.5	
21	n-undecane	2.75	2.5	
22	n-duodecane	2.75	2.5	
23	Ethylene	7.90	11.0	
24	Propylene	3.60	3.4	
25	1-butene	1.40	0.5	1.490
26	2-butene	0.50		2.550
27	2-pentene	0.90		2.350
28	1-pentene	0.70	0.7	0.490
29	2-methyl-1-butene	0.70		0.670
30	3-methyl-1-butene	0.70	0.5	0.670
31	2-methyl-2-butene	1.40	0.5	1.310
32	Butylene	0.50		
33	Acetylene	6.30	3.2	
34	Benzene	3.20	2.6	2.340
35	Toluene	7.20	0.8	5.660
36	o-xylene	1.58	0.8	1.590
37	a-xylene	2.06	0.8	1.880
38	p-xylene	2.06	0.8	1.880
39	Ethylbenzene	1.20	0.8	1.320
40	n-propylbenzene	0.16	0.5	0.410
41	i-propylbenzene	0.13	0.5	0.120
42	1,2,3-trimethylbenzene	0.40	0.5	0.310
43	1,2,4-trimethylbenzene	1.60	0.5	1.600
44	1,3,5-trimethylbenzene	0.50	0.5	0.390
45	o-ethyltoluene	0.38	0.5	0.370
46	a-ethyltoluene	0.63	0.5	0.640
47	p-ethyltoluene	0.63	0.5	0.640
48	Formaldehyde	1.60	5.9	
49	Acetaldehyde	0.35	1.0	
50	Proprionaldehyde	0.57	1.0	
51	Butyraldehyde	0.07	1.0	
52	i-butyraldehyde		1.0	
53	Valeraldehyde	0.03		
54	Benzaldehyde	0.39		

No	Species	Percentage by mass speciation by source category, w/w %		
		petrol engine exhaust	diesel exhaust	petrol evaporation vehicles
55	Acetone	0.14	2.0	

Table 3-21 Composition of VOC emissions from traffic and mobile sources (Loibl et al. 1993)

	Exhaust — conventional cars	Exhaust —catalyst cars	Exhaust cold start (all cars)	2 stroke engines	Diesel *engines*	Evaporation losses
Non-reactive						
Ethane	2	3	1	1	-	-
Acetylene	8	3	4	2	-	-
Paraffins						
Propane	-	-	-	1	-	2
Higher paraffins	32	48	45	72	52	85
Olefins						
Ethene	11	7	6	3	6	-
Propene	5	4	2	1	3	-
Higher olefins (C4+)	6	9	7	9	3	10
Aromatics						
Benzene	5	1	4	2	-	1
Toluene	10	11	140	3	-	1
Higher aromatics (C8+)	21	6	21	6	12	1
Carbonyls						
Formaldehyde	-	8	-	-	13	-
Acetaldehyde	-	-	-	-	3	-
Higher aldehydes (C3+)					4	
Cetones					1	
Other NMVOC						
Alcohols, esters, ethers						
Acids						
Halogenated Compounds						
Other/undefined					3	

4 Data quality

4.1 Inventory quality assurance/quality control (QA/QC)

Whichever Tier methodology is used, the approach to estimating emissions is a top-down approach. Consequently, there are likely to be assumptions included in the methodology associated with dividing data and allocating appropriately.

At the most basic level, the total fuel used by NRMM (diesel, petrol and LPG) will need to be resolved from the road transport sector. Increasing stratification will then be needed for increasingly detailed methodologies – stratification by machinery type, engine power rating, emission standard, hours of use and age. This stratification will vary in certainty depending on the supporting data.

The assumptions that underpin the stratification will need to be transparent and should be cross-checked with industry experts (e.g. trade associations) to the extent possible.

Care should also be given to ensuring that the approaches presented in this chapter are used appropriately. For example, the Tier 3 methodology requires suitable application of degradation factors to ensure that emissions are not underestimated for machinery in use (the emission factors given are for type approval and not for in-use vehicles).

4.2 Completeness

It is usually challenging to collect data that gives completeness both in terms of the machinery fleet and also hours of operation. However, where methods are based on power rating and hours of use, the calculated fuel consumption should be cross-checked with total fuel consumption data to ensure that the bottom up theoretical calculations are valid, and can account for all of the fuel consumption data in national statistics. A shortfall would suggest incompleteness.

4.3 Avoiding double counting with other sectors

There is the possibility that some double accounting could occur if the total amounts of petrol and diesel used by a nation are assumed to be combusted in road transport. Much of the equipment considered in this chapter is likely to be fuelled from the same sources and therefore calculating and adding these emissions to the road transport emissions would double count the emissions from this fuel because of this non-road mobile machinery.

However, in many countries there is a tax differential between fuel for road vehicles and that used for NRMM. Where this is the caser, there is typically reliable data on the division of the fuels for different uses.

4.4 Verification

National experts should check the overall fuel balance, e.g. whether the calculated fuel consumption corresponds to the statistical fuel consumption if such statistical information is available.

A central team should compare the main input parameters used by countries in order to identify major deviations. In cases where the following boundaries are exceeded, national experts should be contacted to check the correctness of the values and to learn about the reasons for their choice.

A) Tier 1 and Tier 2 methodologies

- The applied bulk emission factors for diesel, two-stroke gasoline, four-stroke gasoline, and LPG engines should not differ by more than 30 % for NO_x and fuel consumption, more than 50 % for CO and NMVOC, and more than a factor of 2 for N_2O, NH_3, CH_4 and diesel particulates from the all-country mean.

B) Tier 3 methodology

- The applied emission factors for the individual sub-categories should not differ by more than 30 % for NO_x and fuel consumption, more than 50 % for CO and NMVOC, and more than a factor of 2 for N_2O, NH_3, CH_4 and diesel particulates from the all-country mean.
- The applied average annual working hours should not differ by more than 50 % from the all-country mean.
- The applied average load factors should not differ by more than 25 % from the all-country mean.
- The applied average power output should not differ by more than 25 % from the all-country mean.

National statistical offices should check calculated energy consumption data in the greatest possible detail, or make available appropriate data for cross-checking. The (calculated) fuel consumed by categories should be incorporated in or cross-checked with the total national fuel balance.

4.5 Developing a consistent time series and recalculation

For Tier 2 and Tier 3 methodologies it is important to establish an understanding of the different age and technology types of machines so that the appropriate emission factors can be applied.

Furthermore, where possible, information should be incorporated into the methodology to reflect that fact that variables such as power ratings, average ages and hours of operation may exhibit trends across the time series.

4.6 Uncertainty assessment

For many subsectors, the estimation of emissions is still associated with quite large uncertainties due to the lack of information on vehicle and machinery population, emission factors, and conditions of use. Table 4-1 provides broad qualitative uncertainty estimates.

Table 4-1 Uncertainty estimates for input data required to apply the proposed methodologies

Sector	Subsector	Total fuel consump-tion	Parameter unit fuel consumption	Population	Load factor	Annual hours of use	Power range	Emission factor for the pollutants [1]									Age distribution	Engine design distribution
								CO_2	CO	NMVOC	CH_4	NO_x	N_2O	NH_3	SO_2	PM		
Agriculture	02 Tractors	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	03 Harvesters	D	B	C	D	C	B	B	B	B	C	B	E	E	B	B	D	D
	01/04 All others	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Forestry	02 Tractors	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	01/03 All others	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Industry	01, 04, 05, 07 to 13, 15 (All types of construction equipment)	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	02, 03, 06, 14, 16 to 22	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Military	All	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Household and gardening	All subsectors	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E

Note:
[1] As a rule, the emission factors to be used in the 'simple methodology' are one quality class worse.

Emitting activity rates:

Data quality A: very precise value, specifically known.

Data quality B: precise specific value.

Data quality C: approximate value, but sufficiently well estimated to be considered correctly representative.

Data quality D: approximate value, indicating good order of magnitude.

Data quality E: very approximate value, estimation of a possible order of magnitude.

Emission factors

Data quality A: data set based on a composite of several tests using analytical techniques and can be considered representative of the total population.

Data quality B: data set based on a composite of several tests using analytical techniques and can be considered representative of a large percentage of the total population.

Data quality C: data set based on a small number of tests using analytical techniques and can be considered reasonably representative of the total population.

Data quality D: data set based on a single source using analytical techniques or data set from a number of sources where data are based on engineering.

Data quality E: data set based on engineering calculations from one source; data set(s) based on engineering judgment; data set(s) with no documentation provided; may not be considered representative of the total population.

4.7 Gridding

The source categories covered by this chapter require to make use of somewhat different spatial allocation procedures:

- agricultural, forestry and military emissions should be disaggregated using land use data;
- emissions from the use of industrial NRMM are challenging to map. If information is available at the more detailed level, it may be possible to assign emissions from selected specific machinery types to industrial land coverages, and emissions from construction machinery to urban centres.
- household and gardening emissions can be disaggregated using general population density data. However, this over-allocates emissions to city centres. It is considerably better to be able to allocate emissions according to "green space" in residential locations, and it may be possible to determine a suitable coverage depending on the country specific information that is available;
- inland waterways should be allocated to the appropriate inland water surfaces.

Within each of the sectors further refinement is possible. However, since total emissions decrease with every further split, it is questionable whether the additional efforts are justified.

4.8 Reporting and documentation

Emissions for the categories in this chapter will need to be reported under a number of different NFR codes. Although agriculture and forestry have been split to help with the accuracy of calculations, these estimates will need to be combined for reporting.

4.9 Weakest aspects and priority areas for improvement in the current methodology

The Tier 3 methodologies proposed in this chapter generally require more input than is statistically available. Therefore, efforts should concentrate on data collection such as fuel use in sectors and subsectors, machinery population, conditions of use etc.

Section 3.4.2 includes comments on the methodology parameters which have smaller or larger impacts on the resulting emission estimates. Consideration should be taken of this when planning the efforts allocated to sourcing different datasets for estimating the emissions.

Also, much equipment does use transient, rather than steady state cycles. The current methodology takes virtually no account of this, and consideration should be given to appropriately revising the methodology and including detailed in-use emission factors for machinery. This improvement is likely to become more realistic as PEMS technology is increasingly used to measure emissions from machinery in use in real-world conditions.

5 Temporal disaggregation criteria

There are no relevant reports available about the temporal disaggregation of emissions from the source categories covered. Therefore, only 'common sense criteria' can be applied. Table 5-1 provides a proposal for the 'average' European disaggregation of emissions. In practice, the temporal disaggregation might differ considerably among countries.

Table 5-1 Proposal of the average European temporal disaggregation of emissions. The figures indicate percentages of the disaggregation of total seasonal, weekly, and hourly emissions to seasons, days, and hours

		Seasonal disaggregation (in %)			
Sector	**Subsector**	**Winter**	**Spring**	**Summer**	**Fall**
Agriculture	All	10	20	50	20
Forestry	All	10	20	50	20
Industry	All	20	30	30	20
Military		20	30	30	20
Household and gardening	all but 04 04, snowmobiles	10 90	40 5	30 0	20 5

		Seasonal disaggregation (in %)							Hourly disaggregation (%)			
Sector	**Subsector**	**M**	**T**	**W**	**T**	**F**	**S**	**S**	**6-12**	**12-18**	**18-24**	**24-6**
Agriculture	All	18	18	18	18	18	5	5	45	45	8	2
Forestry	All	18	18	18	18	18	5	5	45	45	8	2
Industry	All	19	19	19	19	19	2.5	2.5	50	45	4	1
Military		19	19	19	19	19	2.5	2.5	35	35	15	15
Household & Gardening	all but 04 04, Snowmobiles	5 10	5 10	5 10	5 10	10 10	35 25	35 25	35 35	35 35	4 4	1 1

6 Glossary

CC	Cylinder Capacity of the engine
COPERT	COmputer Programme to calculate Emissions from Road Transport
Corinair	Corinair emission inventory
CORINE	COoRdination INformation Environmentale
EIG	Emission Inventory Guidebook
IPCC	Intergovernmental Panel on Climate Change
NAPFUE	Nomenclature of Fuels
NUTS	Nomenclature of Territorial Units for Statistics (0 to III). According to the EC definition, NUTS level 0 is the complete territory of the individual Member States
SNAP	Selected Nomenclature for Air Pollution
TU	Territorial Unit

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8 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Transport. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Appendix A Reference list of off-road machinery

Several source category sub-splits have been proposed and used elsewhere and provided the starting point for the category split (e.g. Achten 1990, US-EPA 1991). The sub-split needs to be well balanced since, due to the large number of other mobile sources and machinery, there is a risk of going into too great a detail. On the other hand, all main activities and consequently all major sources need to be well covered. Therefore, a compromise has to be found.

A similar sub-split could be used with NFR codes, for example forming equipment based codes, e.g. of the form 1.A.2.g.vii (812) where the first digit of the three-digit code is the fourth digit of the SNAP code (e.g. 8 for 'Other mobile sources and machinery — Industry) and the second and third digits are the two-digit code given in Table 2–1. Hence 812 would be the code for 'Skid-steer tractors'.

Proposal for a reference list of off-road machinery, which should be covered under SNAP codes 0801 to 0803 and 0806 to 0809

SNAP	Name		Machinery included
080100	Military		
080300	Inland waterways:	01	Sailing boats with auxiliary engines
		02	Motorboats/workboats
		03	Personal watercraft
		04	Inland goods carrying vessels
080600	Agriculture:	01	Two-wheel tractors
		02	Agricultural tractors
		03	Harvesters/combines
		04	Others (sprayers, manure distributors, agriculture mowers, balers, tillers, swatchers)
080700	Forestry:	01	Professional chain saws/clearing saws
		02	Forest tractors/harvesters/skidders
		03	Others (tree processors, haulers, forestry cultivators, fellers/bunchers, shredders, log loaders, piling machines[14])
080800	Industry:	01	Asphalt/concrete pavers
		02	Plate compactors/tampers/rammers
		03	Rollers
		04	Trenchers/mini excavators
		05	Excavators (wheel/crawler type)

[14] Also used in industry (construction sites).

SNAP	Name		Machinery included
		06	Cement and mortar mixers
		07	Cranes
		08	Graders/scrapers
		09	Off-highway trucks
		10	Bull dozers (wheel/crawler type)
		11	Tractors/loaders/backhoes
		12	Skid-steer tractors
		13	Dumper/tenders
		14	Aerial lifts
		15	Forklifts
		16	Generator sets
		17	Pumps
		18	Air/gas compressors
		19	Welders
		20	Refrigerating units
		21	Other general industrial equipment (broomers, sweepers/ scrubbers, slope and brush cutters, pressure washers, pist machines, ice rink machines, scrapers, blowers, vacuums)
		22	Other material-handling equipment (conveyors, tunnel locs, snow-clearing machines, industrial tractors, pushing tractors)
		23	Other construction work equipment (paving/surfacing equipment, bore/drill rigs, crushing equipment, concrete breakers/saws, peat breaking machines, pipe layers, rod benchers/cutters)
080900	Household and gardening	01	Trimmers/edgers/bush cutters
		02	Lawn mowers
		03	Hobby chain saws
		04	Snowmobiles/skidoos
		05	Other household and gardening equipment (wood splitters, snow blowers, chippers/stump grinders, gardening tillers, leaf blowers/vacuums)
		06	Other household and gardening vehicles (lawn and garden tractors, all terrain vehicles, minibikes, off-road motorcycles, golf carts)

Appendix B Engine-types of off-road machinery

Engine-types of off-road machinery which should be covered under the Corinair 1990 SNAP codes 0801 to 0803

			Engine type			
SNAP	**Code**	**Vehicle/machinery type**	**D**	**2SG**	**4SG**	**LPG**
08 03	01	Sailing boats with auxiliary engines	x	x		
	02	Motorboats.workboats	x	x	x	
	03	Personal watercraft		x		
	04	Inland goods carrying vessels	x			
08 06	01	Two-wheel tractors	x	x	x	
	02	Agricultural tractors	x			
	03	Harvesters/combiners	x			
	04	Others (sprayers, manure distributors, etc.)	x	x	x	
08 07	01	Professional chain saws/clearing saws		x		
	02	Forest tractors/harvesters/skidders	x			
	03	Others (tree processors, haulers, forestry cultivators, etc.)	x	x		
08 08	01	Asphalt/concrete pavers	x			
	02	Plate compactors/tampers/rammers	x	x	x	
	03	Rollers	x			
	04	Trenchers/mini excavators	x			
	05	Excavators (wheel/crawler type)	x			
	06	Cement and mortar mixers	x		x	
	07	Cranes	x			
	08	Graders/scrapers	x			
	09	Off-highway trucks	x			
	10	Bull dozers (wheel/crawler type)	x			
	11	Tractors/loaders/backhoes	x			
	12	Skid-steer tractors	x			

			Engine type			
SNAP	**Code**	**Vehicle/machinery type**	**D**	**2SG**	**4SG**	**LPG**
	13	Dumper/tenders	x		x	
	14	Aerial lifts	x	x		
	15	Forklifts	x		x	x
	16	Generator sets	x	x	x	
	17	Pumps	x	x	x	
	18	Air/gas compressors	x			
	19	Welders	x			
	20	Refrigerating units	x			
	21	Other general industrial equipment (broomers, sweepers, etc.)	x	x	x	
	22	Other material handling equipment (conveyors, etc.)	x			
	23	Other construction work equipment (paving/surfacing, etc.)	x	x		
08 09	01	Trimmers/edgers/bush cutters		x		
	02	Lawn mowers	x	x	x	
	03	Hobby chain saws		x		
	04	Snowmobiles/skidoos		x	x	
	05	Other household and gardening equipment	x	x	x	
	06	Other household and gardening vehicles	x	x	x	

Legend:
D: diesel (fuel used: diesel oil for road transport)
2SG: two-stroke gasoline (fuel used: motor gasoline)
4SG: four-stroke gasoline (fuel used: mixture of motor gasoline and lubrication oil)
LPG: LPG (fuel used: liquefied petroleum gases)

Appendix C Background to Tier 1 and 2 emission factors for non-road machinery

1. Introduction

Section 3.4 explains the origin of the Tier 3 NRMM EFs, with information being primarily drawn from the TREMOD NRMM emissions model (IFEU 2014). The following sections explain the method used to calculate Tier 1 and Tier 2 EFs from the Tier 3 EFs.

The calculation of the Tier 1 and 2 factors, rely on the Danish inventory explained by Winther (20015b). The basis for fuel consumption and emission information is to a large extent taken from the German TREMOD NRMM emissions model, which takes data from extensive surveys made by Institut für Entsorgung und Umwelttechnik GmbH (IFEU,2004, 2009, 2014).

The baseline emission factors used in the Danish inventory — and the IFEU studies — are grouped into EU emission legislation categories. However, for engines older than directive first-level implementation dates, three additional emission level classes are added so that a complete matrix of fuel use and emission factors underpins the inventory.

In the following, a brief description is given of the baseline emission factors, and the approach to deriving aggregated EFs based on the Danish fuel consumption and emission results.

2. Aggregated emission factors

Chapter 3.4 explains the origin of the Tier 3 NRMM EFs, with information being primarily drawn from the TREMOD NRMM emissions model (IFEU 2014) and additional information for Stage V machinery provided by Winther (2016). EFs for the Tier 1 and Tier2 methodologies are generated by aggregating the Tier EFs in a way determined by information on the Danish NRMM fleet and usage.

Danish inventory uses the Tier 3 approach, and fuel consumption and emissions are found as the product of the number of engines, annual working hours, average rated engine size, load factor, and fuel use/emission factors. The emission effects of engine deterioration and engine loads, and gasoline fuel evaporation is not included in the aggregated emission factors. For further details, please refer to Winther (2015a and 2016).

For Tier 1, the results from the historical year 2006 are behind the aggregated emission factors. For Tier 2, the overall principle has been to assess the technology relevant emission factors from the 2014 inventory year point of view. In many cases the aggregated emission factors for the same technology level are more or less the same regardless of the inventory year. However, in some cases, the same technology level can have some variation in the emission factors as a function of inventory year, due to the specific Danish rates of penetration of new technology. However the differences that arise are within an acceptable range.

2.1 Diesel

The Danish inventory basis for stock is regarded as detailed enough to distinguish between agriculture, forestry and industry machinery types. Table C1 below shows the machinery types which contribute to the aggregated factors. The EFs are listed for Tier 1 and Tier 2 in the main body of the Chapter.

Table C1: Aggregation of Diesel Machinery Type to Tier 1 and 2 Categories

	Machinery type	Lifetime (yrs)
Agriculture	Self-propelled vehicles	15
Agriculture	Tractors	30
Agriculture	Harvesters	25
Agriculture	Tractors (machine pools)	7
Agriculture	Self-propelled vehicles (machine pools)	6
Agriculture	Harvesters (machine pools)	11
Forestry	Harvesters (forestry)	8
Forestry	Chippers	10
Forestry	Harvesters (forestry)	8
Forestry	Chippers	6
Forestry	Chippers	6
Forestry	Forwarders	8
Forestry	Forwarders	8
Forestry	Tractors (silvicultural)	6
Forestry	Tractors (silvicultural)	6
Forestry	Tractors (other)	15
Forestry	Tractors (other)	15
Industry	High pressure cleaners (diesel)	10
Industry	Motor graders	10
Industry	Airport GSE and other (light duty)	10
Industry	Asphalt pavers	10
Industry	Pumps (diesel)	15
Industry	Tractors (transport, industry)	30
Industry	Airport GSE and other (medium duty)	10
Industry	Generators (diesel)	15
Industry	Forklifts 2–3 tons (diesel)	20
Industry	Sweepers (diesel)	10
Industry	Aerial lifts (diesel)	10
Industry	Tampers/land rollers	14
Industry	Refrigerating units (long distance)	7
Industry	Refrigerating units (distribution)	6
Industry	Vibratory plates	10
Industry	Compressors (diesel)	13
Industry	Excavators/loaders	10
Industry	Track-type dozers	10
Industry	Track-type loaders	10

	Machinery type	Lifetime (yrs)
Industry	Wheel loaders (0–5 tons)	10
Industry	Wheel loaders (> 5,1 tons)	10
Industry	Wheel type excavators	10
Industry	Track type excavators (0–5 tons)	10
Industry	Refuse compressors	10
Industry	Telescopic loaders	14
Industry	Airport GSE and other (heavy duty)	10
Industry	Dump trucks	10
Industry	Mini loaders	14
Industry	Forklifts > 10 tons (diesel)	20
Industry	Forklifts 5–10 tons (diesel)	20
Industry	Forklifts 3–5 tons (diesel)	20
Industry	Forklifts 0–2 tons (diesel)	20
Industry	Track-type excavators (> 5,1 tons)	10

2.2 Gasoline

For gasoline engines the Danish stock and operational data available is for agriculture and forestry considered to be too scarce to underpin the calculation of sector specific emission factors, for two-stroke and four-stroke engines, respectively. Therefore, the decision has been to distinguish only between two-stroke and four-stroke engine-related factors. These factors are then repeated for all four land-based non-road sectors.

Tables 2 and 3 list the machinery types which are behind the aggregated factors. Emission factors are listed for Tier 1 and Tier 2 in the main chapter.

Table C2: Aggregation of 2-Stroke Gasoline Machinery Type to Tier 1 and 2 Categories

Sector	Fuel type	Engine	Machinery types	Lifetime (yrs)
Forestry	Gasoline	2-stroke	Chain saws (forestry)	3
Industry	Gasoline	2-stroke	Drills	10
Industry	Gasoline	2-stroke	Slicers	10
Industry	Gasoline	2-stroke	Rammers	10
Residential	Gasoline	2-stroke	Trimmers (professional)	4
Residential	Gasoline	2-stroke	Shrub clearers (private)	10
Residential	Gasoline	2-stroke	Shrub clearers (professional)	4
Residential	Gasoline	2-stroke	Hedge cutters (private)	10
Residential	Gasoline	2-stroke	Trimmers (private)	10
Residential	Gasoline	2-stroke	Other (gasoline)	10
Residential	Gasoline	2-stroke	Garden shredders	10
Residential	Gasoline	2-stroke	Suction machines	10
Residential	Gasoline	2-stroke	Chippers	10
Residential	Gasoline	2-stroke	Chain saws (private)	10
Residential	Gasoline	2-stroke	Chain saws (professional)	3
Residential	Gasoline	2-stroke	Hedge cutters (professional)	4

Table C3: Aggregation of 4-Stroke Gasoline Machinery Type to Tier 1 and 2 Categories

Sector	Fuel Type	Engine	Machinery types	Lifetime (yrs)
Agriculture	Gasoline	4-stroke	Tractors (gasoline-certified)	31
Agriculture	Gasoline	4-stroke	Tractors (gasoline non-certified)	31
Agriculture	Gasoline	4-stroke	Fodder trucks	10
Agriculture	Gasoline	4-stroke	Scrapers	10
Agriculture	Gasoline	4-stroke	Other (gasoline)	10
Agriculture	Gasoline	4-stroke	Sweepers	10
Agriculture	Gasoline	4-stroke	Bedding machines	10
Industry	Gasoline	4-stroke	Pumps (gasoline)	5
Industry	Gasoline	4-stroke	Compressors (gasoline)	8
Industry	Gasoline	4-stroke	Aerial lifts (gasoline)	10
Industry	Gasoline	4-stroke	Vibratory plates (gasoline)	10
Industry	Gasoline	4-stroke	High pressure cleaners (gasoline)	10
Industry	Gasoline	4-stroke	Generators (gasoline)	10
Industry	Gasoline	4-stroke	Other (gasoline)	10
Industry	Gasoline	4-stroke	Sweepers (gasoline)	10
Industry	Gasoline	4-stroke	Cutters	10
Residential	Gasoline	4-stroke	Riders (professional)	5
Residential	Gasoline	4-stroke	Wood cutters	10
Residential	Gasoline	4-stroke	Lawn movers (private)	8
Residential	Gasoline	4-stroke	Lawn movers (professional)	4
Residential	Gasoline	4-stroke	Cultivators (private-large)	15
Residential	Gasoline	4-stroke	Cultivators (private-small)	5
Residential	Gasoline	4-stroke	Cultivators (professional)	8
Residential	Gasoline	4-stroke	Riders (private)	12

2.3 LPG

For LPG, the fuel use factor and the emission factors of CO, VOC, NO_x and TSP are taken from IFEU (2014). The only LPG machinery type using LPG in the Danish inventory is forklifts, and due to lack of data, there is no distinction between technology levels. The emission factors are listed for LPG machinery in the main body of the chapter.

2.4 Recreational craft

For recreational craft, the distinction is given between diesel-fuelled engines, and two-stroke and four-stroke gasoline engines. For Tier 2, conventional technologies and engines complying with Directive 2003/44/EC are considered.

Table 4 lists the machinery types which are behind the aggregated factors. The emission factors for Tier 1 and Tier 2 are listed in the main body of the chapter.

Table C4: Aggregation of Boat Types to Tier 1 and 2 Categories

Fuel type	Boat type	Engine	Engine type	Lifetime
Gasoline	Other boats (< 20 ft)	Out-board engine	2-stroke	10
Gasoline	Yawls and cabin boats	Out-board engine	2-stroke	10
Gasoline	Sailing boats (< 26 ft)	Out-board engine	2-stroke	10
Gasoline	Speed boats	Out-board engine	2-stroke	10
Gasoline	Water scooters	Built in	2-stroke	10
Gasoline	Other boats (< 20 ft)	Out-board engine	4-stroke	10
Gasoline	Yawls and cabin boats	Out-board engine	4-stroke	10
Gasoline	Sailing boats (< 26 ft)	Out-board engine	4-stroke	10
Gasoline	Speed boats	In-board engine	4-stroke	10
Gasoline	Speed boats	Out-board engine	4-stroke	10
Gasoline	Water scooters	Built-in	4-stroke	10
Diesel	Motor boats (27–34 ft)	In-board engine		15
Diesel	Motor boats (> 34 ft)	In-board engine		15
Diesel	Motor boats (< 27 ft)	In-board engine		15
Diesel	Motor sailors	In-board engine		15
Diesel	Sailing boats (< 26 ft)	In-board engine		15

3. Fuel consumption split by engine age and engine technology level for diesel machinery (agriculture, forestry, industry) and gasoline two-stroke/four-stroke machinery

In Tables 3–3 and 3–4, the percentage split of total fuel consumption as a function of engine age is given for diesel machinery in 1.A.2.g.vii, 1.A.4.c.ii (agriculture) and 1.A.4.c.ii (forestry), and for gasoline two-stroke and four-stroke machinery.

Tables 3–5 to 3–9 (Annex file accompanying this Guidebook chapter) display the year specific fuel consumption percentages per engine age and inventory year for diesel-fuelled non-road machinery (Tables 3–5 to 3–7) and gasoline-fuelled non-road machinery (Tables 3–8 to 3–9). Only those inventory year/engine age combinations are listed for which fuel consumption for more than one engine technology is actually estimated. For the remaining inventory year/engine age combinations, the engine technology which uses the fuel becomes self-explanatory.

Gasoline agricultural tractors are excluded from the aggregated figures presented in the Tables 3–4, 3–8 and 3–9. Even though these machinery types may be an important part of a country's VOC and CO emission inventory for gasoline machinery in the 1980's (and to a smaller extent also in the 1990's), the data which are examined for the Danish situation in this case may become too uncertain to apply for other countries.

One major reason for leaving out gasoline tractors from the aggregated figures is that the life time for these machinery types is regarded as very long and hence the relative amount of the fuel consumption for Denmark may be very different from the situation in other countries. If gasoline agricultural tractors are regarded as a major source of fuel consumption and emissions, countries are encouraged to make a separate Tier 3 calculation of the fuel consumption for gasoline agricultural tractors. This latter fuel consumption estimate can then be subtracted from the total fuel consumption given in the statistics, in order to obtain a new total fuel consumption base which underpins the emission inventory for gasoline non-road machinery in general.

Furthermore, no attempt has been made to derive a fuel consumption split for gasoline two-stroke and four-stroke machinery based on the Danish inventory. It is regarded as very uncertain, if such a fuel consumption split found for Denmark can be used for other countries in general. Just as an indication, the Danish fuel consumption percentage split between two-stroke and four-stroke gasoline machinery is found to be roughly 25/75 (in all inventory years).

4. Specific issues

4.1 SO_2

The emission factors for SO_2 are constant and rely on the sulphur content used in the Danish inventory. If the sulphur content for a specific country deviates from this, the emission factors must be scaled accordingly.

4.2 CO_2

The emission factors for CO_2 are constant and rely on the figures proposed by the Danish Energy Authority (DEA). If the emission factors for a specific country deviate from this, the country is encouraged to use country-specific data.

4.3 N_2O and NH_3

The emission factors are constant in terms of g/kg fuel. As engine technology gradually becomes more and more modern, the specific fuel consumption goes down, and hence the g/GJ derived emission factors increase.

5. References

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Appendix D Estimating fuel used by NRMM

The analysis by Dore et al (2015) investigates whether it is possible to establish relationships between NRMM fuel use data reported by Parties to the CLRTAP with other commonly available datasets. The intention of the analysis was to determine whether it is possible to generate “indicators” that would allow Parties to better estimate the amount of fuel being used by NRMM in different source categories.

Input Data

Emissions and fuel data were retrieved from the Centre on Emission Inventories and Projections (CEIP) WebDab database. The data sourced included the years 1990-2013. Choosing countries with accurate data towards emissions and fuel was essential and hence countries were selected according to the NRMM methodology shown in their respective IIRs (informative inventory reports). The majority of the countries selected corresponded to a tier 3 methodology. The countries selected for inclusion in the assessment were:

- Belgium
- Denmark
- France
- Italy
- Germany
- Netherlands
- Sweden
- The United Kingdom

In some cases fuel or emissions data were not reported by all of these countries for the entire time series. Hence the size of data sets varies across the different NRMM source categories.

A number of other datasets were retrieved from various different sources and are listed below:

Table D1: Data used in the investigation of generating NRMM indicators

Indicator Dataset:	Source:	Units:
Population EU 1990-2013	European Commission Eurostat database	Number
Gross Value Added (GVA) A/F/F (agriculture/forestry/fishing) 1990-2013	European Commission Eurostat Database	Current prices, million euro (€)
Gross Value Added (GVA) manufacturing and construction 1990-2013	European Commission Eurostat Database	Current prices, million euro (€)
Agricultural Land as a % of total land area 1990-2013	The World Bank Databank	Percentage (%)
Agricultural Land 1990-2013	The World Bank Databank	Square Kilometres (km^2)

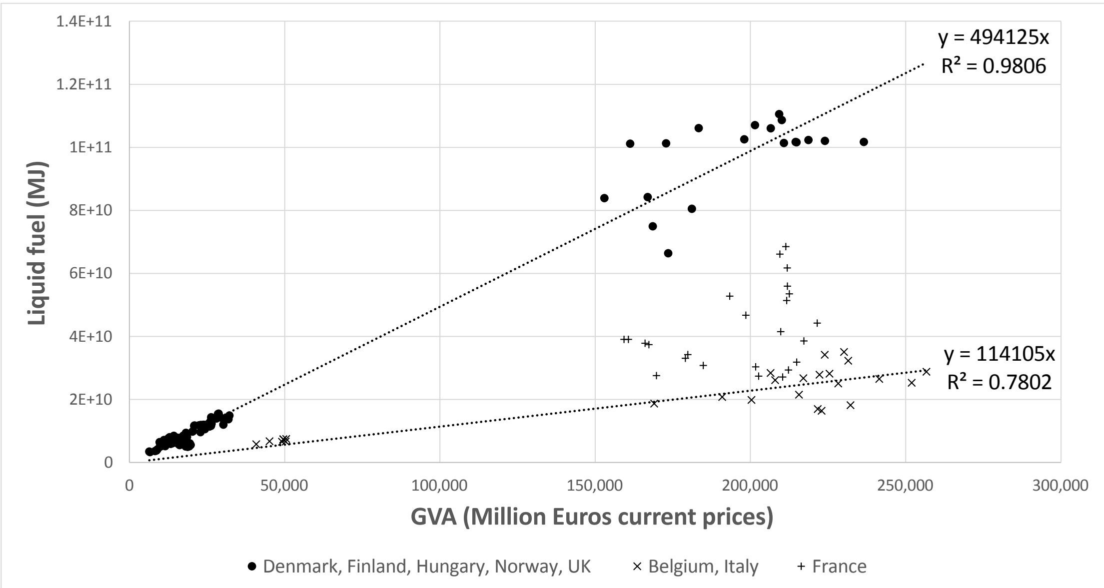
Total Forest products	FAOstat (Food and Agriculture Organization of the United Nations) (aggregated from dataset containing forest products in tons split by category)	Tonnes

These datasets were combined with either NRMM fuel use data or NRMM emissions data to test for the strength of the relationship. Those combinations considered to give a strong enough relationship to justify use as an indicator are presented below.

1.A.2.g vii Mobile Combustion in manufacturing industries and construction

Liquid fuel used in NRMM in the manufacturing and construction industries was plotted against the GVA for the countries where fuel data were available from the CLRTAP submissions.

Figure D1: The relationship between fuel use and GVA in the manufacturing and construction industries



The resulting data do indicate a relationship between liquid fuel use and GVA, but this is difficult to interpret with any certainty. A linear relationship is evident for Denmark, Finland, Hungary, Norway and the UK, but Belgium Italy and France show significantly different results.

Differences might be explained by genuine differences between countries, including the use of gas for NRMM, or the different make-up of NRMM activities within the manufacturing and construction sectors in different countries. However it is more likely that the differences are an artefact of the different methods that have been used to determine fuel consumption for each of the countries.

Time has been spent reviewing the methodologies given in the Informative Inventory Reports from the different countries, but no clear explanations have been found that allow interpretation of the results with any certainty.

The linear relationship between liquid fuel used and GVA for Denmark, Finland, Hungary, Norway and the UK is proposed for use because it provides an upper limit for the fuel used in NRMM, and therefore a conservative approach to estimating emissions from the manufacturing and construction sector as a whole. However, it is clear that there is significant uncertainty associated with this relationship and more work is needed to better understand differences between countries.

1.A.4.b ii Residential: Household and gardening (mobile)

The fuel used for residential NRMM as a fraction of the total liquid fuel use was determined. The following table shows maximum and minimum values for each country.

Table D2: Fuel used for residential NRMM, expressed as a fraction of the total country liquid fuel use

	Belgium	Denmark	Finland	France	Hungary	Italy	Norway	Sweden	UK
Minimum (%)	0.2	0.6	1.3	0.3	0.04	0.01	7.1	2.7	1.2
Maximum (%)	0.4	1.2	1.7	0.3	0.3	0.1	10.5	14.1	1.2

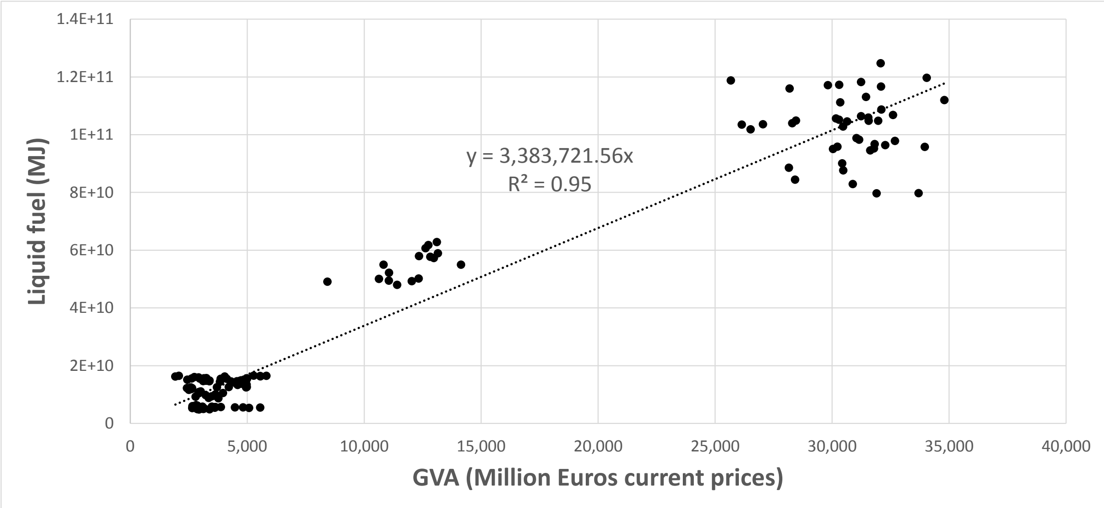
The high values in Norway and Sweden can be attributed to significant changes in the liquid fuel used for stationary combustion (both counties undergoing significant change in the energy mix used in the residential sector). However it is possible that this may mask a generally higher use of fuel for NRMM in the residential sector in two countries which anecdotally have higher levels of outdoor machinery use (e.g. snowmobiles, residential level forestry activities etc.).

As a guide, a figure of 1-2% is proposed for the NRMM fuel use percentage of the total liquid fuel used in the residential sector.

1.A.4.c ii Agriculture/Forestry/Fishing: Off-road vehicles & other machinery

The following relationship was determined between NRMM fuel use Agriculture, Forestry and Fishing and GVA.

Figure D2: The relationship between fuel use and GVA in Agriculture, Forestry and Fishing NRMM



The high R^2 value suggests that it is appropriate for this to be used as an indicator.

Other NRMM source categories

Efforts were made to investigate relationships for other NRMM categories. But it was not possible to determine any useable relationships or indicators for:

- 1.A.4.a.ii Commercial/institutional: Mobile
- 1.A.4.c iii National fishing
- 1.A.5.b Other, Mobile (including military, land based and recreational boats)

This was primarily because there was a lack of data detailed sector level data reported on fuel used in these categories by Parties to the CLRTAP. But, in addition, but also relationships with e.g. GVA were found to be not as strong as for other NRMM source categories.

References

Dore C. and Smith, H. (2015) Generating Indicators for Estimating NRMM Fuel Consumption. Continued Improvements of Inventory Methodologies, Chapter 2.2, EU Project Report 070201/2014/693666/FRA/ENV.C.3

Appendix E BC fractions of PM for non-road engines

In general the same diesel engine technologies are used by non-road working machinery and road transport vehicles, however, measurement data for BC and PM are scarce for non-road engines as such. Hence, for non-road diesel engines the decision is to use the f-BC fractions and +/- uncertainty ranges proposed for road transport engines, as the f-BC figures for these engines are derived from a comprehensive literature survey of EC and OC fractions of total exhaust PM made by Ntziachristos et al. (2007). This is also explained in Annex 3 in the guidebook chapter for road transport. The examined OC data from Ntziachristos et al. (2007) can be input for the further assessment of OC fractions of PM (f-OC).

For diesel engines < 130 kW f-BC fractions for diesel cars are used, and for diesel engines >= 130 kW f-BC fractions for heavy duty trucks are used (c.f. road transport Annex 3). In the case of gasoline 2-stroke and 4-stroke engines data from Kupiainen and Klimont (2004) is used. The same source is behind the average factor of 0.15 for LPG (+/- range = 50 %).

Table E.1 Proposed f-BC fractions for Tier 3 and used as an input for aggregated Tier 1 and 2 f-BC fractions for non-road engines

Technology	Diesel < 130 kW		Diesel >= 130 kW		Gasoline (2/4 stroke)	
	f-BC	+/- (%)	f-BC	+/- (%)	f-BC	+/- (%)
<1981	0.55	10	0.5	20	0.05	50
1981-1990	0.55	10	0.5	20	0.05	50
1991-Stage I	0.55	10	0.5	20	0.05	50
Stage I	0.8	10	0.7	20	0.05	50
Stage II	0.8	10	0.7	20	0.05	50
Stage IIIA	0.8	10	0.7	20		
Stage IIIB, no DPF	0.8	50	0.7	20		
Stage IIIB, DPF	0.15	50	0.15	20		
Stage IV, no DPF	0.8	50	0.7	30		
Stage IV, DPF	0.15	50	0.15	30		
Stage V	0.15	50	0.15	30		

Using the proposed f-BC fractions from Table D.1, the Tier 1 and 2 C emission factors shown in Table 3-1 and Table 3-2 are derived from the PM Tier 3 non road emission calculations made for Denmark in 2006 (Winther, 2016).

References

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