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Review

Non-Road Mobile Machinery Emissions and Regulations: A Review

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Highlights:

What are the main findings?
- Non-Road Mobile Machinery are used in many sectors for various off-road activities.
- NRMM have the potential to overtake on-road vehicles as the biggest mobile polluter.
- Lack of available data can cause inaccuracy in estimated emissions and inventories.

What is the implication of the main finding?
- Emission inventories are needed to fully understand NRMM emissions.
- EU regulations benefit the environment and businesses and avoid unfair competition.

Abstract: Non-Road Mobile Machinery (NRMM) incorporate a wide range of machinery, with or without bodywork and wheels, and are installed with a combustion engine and not intended for carrying passengers or goods on the road. These are used in many different sectors including construction, agriculture, forestry, mining, local authorities, airport and port ground operations, railways, inland waterways and within the household and gardening sector. This article presents a review of the state of knowledge with regard to non-road mobile machinery, particularly focusing on their regulation and the atmospheric emissions associated with them. This was undertaken as there is currently a lack of this information available in the literature, which is an oversight due to the potential for Non-Road Mobile Machinery to form a greater part of atmospheric emissions in the future, as other areas of emissions are tackled by regulations, as is outlined in the article. Emissions such as particulate matter (PM), carbon oxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), nitrogen oxides (NO_x) and sulphur oxides (SO_x) from NRMM contribute considerably to total emissions released into the air. NRMM are diverse in application, engine type and fuel use, and are therefore difficult to categorise. This leads to numerous issues when it comes to the control and regulation of their emissions. The most recent European and international regulations are outlined in this article. Due to the divergent nature of NRMM, their emissions profiles are highly varied, and in-use emissions monitoring is challenging. This has led to a lack of data and inaccuracies in the estimation of total emissions and emission inventories. It was assumed in the past that emissions from non-road sources did not contribute as significantly to total emissions as those from on-road sources. This assumption was partly due to the difficulty in gathering relevant data, and it was disproven in the 1990s by studies in The Netherlands, Finland and Sweden. It is now understood that NRMM will eventually surpass on-road vehicles as the leading source of mobile pollution due to the continuing efforts to reduce emissions from other sources. Many states worldwide gather emissions data from NRMM, and EU member states are required to report their emissions. As of January 2017, a new European regulation establishing limits for gaseous and particulate pollutants from NRMM applies, and this regulation also defines administrative and technical requirements for EU approval. The exact number of NRMM and the total amount of fuel they use is currently not known. In Ireland,

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for example, their fuel use has been reported under stationary boilers and engines. However, this results in the underestimation of emissions of some pollutants (NO_x in particular) because emissions of air pollutants tend to be higher in mobile than in stationary machinery.

Keywords: non-road mobile machinery; NRMM; emissions; pollutants; air quality

1. Introduction

The term Non-Road Mobile Machinery (NRMM) covers a broad range of machinery, with or without bodywork and wheels, that are installed with a combustion engine, either a spark ignition (SI) petrol engine or a combustion ignition (CI) diesel engine, and that are not intended for carrying passengers or goods on the road. This type of machinery covers a large range of machines and are used in many different categories (Table 1). Pollutant emissions from these engines contribute significantly to air pollution by emitting carbon oxides (CO and CO_2), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM) [1,2].

Table 1. Examples of categories of NRMM and example machinery.

Agriculture and Forestry	Construction	Railway	Inland Waterway	Mines and Quarrying	Gardening and Handheld Equipment	Misc.
Harvesters Cultivators Tractors ATVs	Excavators Loaders Bulldozers Forklifts Cranes	Locomotives Railcars	Inland waterway vessels	Underground trucks Mining loaders Excavators	Lawnmowers Chain saws Hedge trimmers	Generators Side by side vehicles

Data from existing inventories show that compared to some other emissions, NRMM has a three times larger proportion of emissions compared to the proportion of energy consumption [3].

This article is a review of the current state of knowledge of NRMM in terms of current regulations and of emission studies conducted to date.

The numbers and types of NRMM in use and the impact this equipment and mobile machinery has on total emissions is in general not currently fully understood. However, EU countries are required to report their emissions under the Air Convention and National Emissions Ceiling Directive (NECD) [4]. Furthermore, this information is also useful for developing mitigation strategies. One of the challenges with studying these machines is that they are diverse in nature. They encompass a wide variety of different vehicles and machines which often have specialised applications. As a consequence of this, a number of different engine types and designs with varying fuel consumption profiles and power outputs exist, resulting in a diverse emissions profile.

The exact amount of fuel used in NRMM is not currently known; hence, it has previously been reported by some countries under stationary boilers and engines. However, this can result in an underestimation of emissions of some pollutants due to the differing emission factors for these subcategories. This underestimation can occur because emission of air pollutants (and NO_x in particular) tends to be higher for mobile machinery than for stationary plants. However, some data on emissions attributed to off-road sources are available for the EU-27 block and Great Britain. In these data, it is reported that 758.57 kt of NO_x (9.4% of the total 8047.48 kt), 50.17 kt of $PM_{2.5}$ (3.8% of the total 1321.95 kt) and 29.19 kt of black carbon (13.4% of the total 218.46 kt) were attributed to this category in 2015 [5].

2. Pollutants Emitted by NRMM Operation

An overview of the most common pollutants emitted by NRMM is listed in the below table (Table 2).

Table 2. Pollutants emitted by NRMM operation.

Particulate Matter, which is one of the most serious air pollution health risks in the EU, is divided into the following subcategories: TSP: Total suspended particles, which in practical terms covers all PM suspended in air, and they are measured by high-volume samplers applying standard measurement procedures PM_{10}: Inhalable particles with diameters that are 10 µm or smaller $PM_{2.5}$: Fine inhalable particles that are 2.5 µm or smaller UF: Ultrafine particles that are 0.1 µm or smaller BC: Black carbon, or soot, is a constituent of $PM_{2.5}$ formed from incomplete fuel combustion
Nitrogen Oxides, which are a health hazard for humans. They also cause eutrophication and acidification in waterbodies, and contribute to the formation of PM_{10}, $PM_{2.5}$ and ozone.
Carbon Monoxide, which is dangerous to human health and can be fatal. It is produced by the burning of any fuel caused by the incomplete combustion of fossil fuels and mostly oxidises to CO_2 in the atmosphere.
Carbon Dioxide, which is a heat-trapping greenhouse gas. It is released through burning of fossil fuels, among other human activities, as well as through natural processes such as respiration.
Hydrocarbons, which are dangerous to human health, especially to the health of the lungs. They react with nitrogen oxides in sunlight to produce photochemical smog. Both reactivity and quantity of hydrocarbon emissions must be measured in the assessment of the effect of emission of photochemical smog.
Sulphur Oxides, which are harmful for the respiratory system. They are produced by burning fossil fuels containing sulphur, but natural sources also exist, such as volcanoes. They can create secondary pollutants such as sulphate aerosols, PM and acid rain when released into the air.

Sources: [6–8].

3. NRMM Emission Studies

The study of NRMM emissions in the literature has largely been overshadowed by their on-road counter parts due to data on NRMM not being as freely available [9]. It was assumed until the 1990s that emissions from non-road sources were not as significant as those from on-road sources, but studies in the early 1990s suggested otherwise [9,10]. Puranen and Mattila [9], for example, discovered in a study in 1990 that the total amount of diesel fuel consumed by work machines was 780,000 m^3, which equated to about 30% of all traffic consumption in Finland. In comparison the amount of gasoline consumed by them was only 69,000 m^3, equating to 3% of all traffic consumption. They also found that the NO_x emissions from work machines accounted for 15% of total NO_x emissions, and that PM, CO, CO_2 and HC emissions from the work machines accounted for between 4% and 10% of total such emissions.

As a consequence of this oversight and lag in emission standards, the concern about emissions from NRMM has risen considerably in recent decades as their relative contribution to anthropogenic emissions continues to increase while mitigation efforts for on-road vehicle emissions improve, leading to a decrease in their emissions. This means that NRMM will eventually surpass on-road vehicles as the leading source of mobile pollution [11]. This rise in the share of emissions for NRMM was predicted over two decades ago, yet fewer studies regarding emissions of NRMM sources have been conducted in the past twenty years compared to the number of studies conducted in relation to emissions from on-road vehicles [9–12].

Despite increased interest, many studies have highlighted the challenges faced when investigating NRMM emissions, the first being that there is still a considerable lack of off-road emission data available, particularly in-use emission data [13]. This lack of data and related statistics also leads to inaccuracies in estimating overall emissions and inventories from NRMM. Differences in engine design, operating conditions, engine load and fuel use result in varying exhaust compositions and amounts, making predictions of emissions difficult if data are limited [14]. Generally, emission tests were carried out in laboratory settings mimicking the in-use operation of NRMM engines. However, such tests have been shown to be inaccurate when compared to real-life emissions [15], a scenario highlighted by the 2015 Volkswagen scandal [16]. This brings to light the fact that real-life emissions are different from emissions created in laboratory settings. Laboratory testing often fails to accurately account for real-life factors such as the duration and intensity of tasks performed by an NRMM and the different levels of activity within that operation (e.g., idle, moving, etc.), as generally only the engine/chassis is tested [15]. To overcome the uncertainties in laboratory testing, legislators have called for the measurement of Real Driving Emissions (RDE). Unfortunately, collecting data from NRMM while in operation (real conditions) also encounters several challenges. Past studies have highlighted difficulties in quantifying exhaust emissions in comparison to on-road machinery due to the wide range of activities undertaken by NRMM and the operating cycles employed [17,18], as well as difficulties in installing the required instrumentation [19], and the general high cost associated with such tests. However, reliable results that cannot be replicated in laboratory settings are generated. For this reason, studies have moved towards the use of Portable Emission Measurement Systems (PEMS) and similar devices to obtain in-use exhaust emissions of NRMM [20,21]. Considerable work has been carried out in recent years using PEMS on a range of different NRMM [20,21], including several types of construction and agricultural machinery [11–13,17,22–29].

Although fewer in number than on-road machinery, NRMM have been shown to have considerable impact on the production and emission of NO_x and PM. Recent studies from China illustrated that NRMM produced the same concentrations of NO_x and PM as was produced by all on-road sources in 2018, which had a notable impact on air quality in the form of smog [12,30]. Many papers have also investigated the health impacts [31] and chemical composition of such emissions [30,32,33]. However, due to the diverse nature of NRMM, past literature has generally focussed on assessing the emissions of a few types of machinery within sectors of interest. Studies regarding emissions from construction and agricultural machinery are well documented, with additional studies also covering emissions from forestry, cargo, port and handheld and domestic gardening equipment, as discussed in Sections 3.1–3.3.

3.1. NRMM Emissions in Agriculture

Agriculture represents one of the oldest and most important global industries, and it is responsible for approximately 5% of global energy consumption [34]. Nowadays, a variety of NRMM are regularly employed for a range of agricultural tasks. The weighted contribution of agricultural NRMM to anthropogenic emissions has been thoroughly explored in past literature. A study from Poland compared the fuel consumption of farming machinery between 2012 and 2013, and suggested that emissions from agricultural NRMM had the biggest impact on the total emission of CO, NO_x, hydrocarbons and PM [33] (Figure 1). Similar trends were also observed throughout Europe and elsewhere [9,12,35,36]. Emissions of NRMM from agricultural sources in China have received much attention in the past decade due to their impact on the air quality, with a series of studies concluding that agricultural machinery is an important NRMM source that contributes significantly to these emissions [12,35].

Additionally, an investigation by the Swiss Federal Office for the Environment into the fuel consumption and emissions of NRMM found that agricultural machinery alone accounted for 300 tonnes of PM in 2010. Interestingly, this was more than four times higher than the PM produced by construction machinery, even though diesel consumption was nearly 20% lower for agricultural machinery. This was attributed to the long lifespan of agricultural NRMM and the lack of retrofitted PM filters [37]. Therefore, it is estimated that agricultural NRMM emissions will not reduce to the same, or greater, extent as the emissions of construction NRMM that already have such measures in place. Fortunately, a reduction in agricultural emissions was determined for the 1985–2050 period (the Swiss report covers the period from 1980 and includes forecasts up to 2050, with 2010 serving as reference year), with similar trends also observed by Winther and Nielsen [26] and Hou et al. [38]. This reduction is particularly true for NO_x and PM emissions due to improved diesel fuel standards, emission regulations and the proposed use of exhaust filters [38].

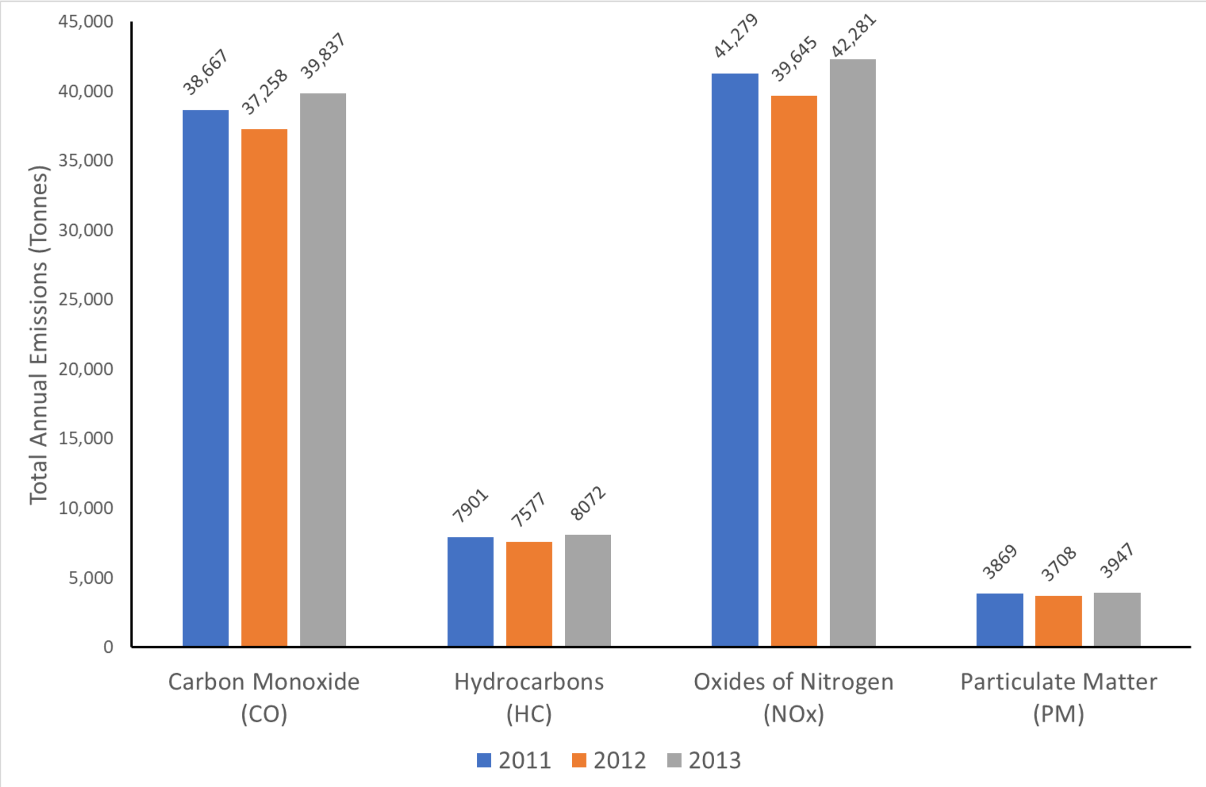

Figure 1. Total annual emissions of CO, HC, NOx and PM from agricultural machinery operated in Poland 2011–2013, adapted from [33].

Improved emission testing methods for agricultural NRMM constitute another topic that has been well documented in recent times. Several studies have investigated the deviations between exhaust emissions of NRMM in real-world and laboratory settings. Pirjola et al. (2017) [39] compared exhaust emissions emitted by a tractor in real-world conditions to those of a similar engine using a dynamometer. It was found that NO_x emission factors were approximately 50% higher in real-world conditions compared to laboratory tests. Deviations were also observed for the PM emissions with the production of nucleation mode particles in real-world conditions that were absent in laboratory testing, because of the absence of pollutants, e.g., ammonia, in the lab. With the introduction of RDE measurement, many studies have assessed the suitability of RDE devices for measuring the emissions of agricultural NRMM. PEMS are the most widely assessed RDE devices and have been included in many NRMM emission studies [22,26,28,29]. Szymlet et al. (2018) [28] even compared the emissions of a passenger car to a tractor using PEMS, illustrating emissions from NRMM to be several times higher than those from the on-road source.

Tractors are the most studied of the agricultural NRMM due to them being the most polluting of farming machinery [40]. Hou et al. (2019) [27] investigated the emission characteristics of 22 different types of agricultural NRMM including tractors, harvesters and micro-tillers and determined that tractors accounted for over 80% of agricultural NRMM emissions in Beijing in 2016. Many papers have focussed on assessing the engine performance of tractors and emissions during different operating modes in an effort to optimise the engine performance [29,40–43]. As a result, several simplified emission testing methods have also been developed for tractors. Janulevičius et al., 2013 [40], determined the suitability of measuring exhaust emissions during operation by using data collected in ECU load profiles of the tractors ECUs. Similarly, Ettl et al. [44] developed an alternative method based on torque data and ECU engine speed from long-term tractor operations. This method used a simplified test stand opposed to portable measurements to determine the real-world emissions and fuel consumption measurements of tractors.

As a result of the serious implications associated with the release of NRMM emissions in agriculture, many studies have also focussed on the mitigation and reduction of pollutants from exhaust gases. Lovarelli and Bacenetti, 2019 [45], describe some technological solutions suitable for agricultural tractors and self-propelled machines. Examples of these devices are Diesel Particulate Filters (DPF), Exhaust Gases Recirculation (EGR) and Selective Catalytic Reduction (SCR).

3.2. NRMM Emissions in Construction

Construction NRMM emissions have undergone many of the same studies as those for the agricultural NRMM. Both NRMM types generally utilise diesel engines, which have been shown to favour NO_x and PM production. However, unlike for agricultural NRMM, the literature on construction machinery shows that they have not seen the same decreasing trend in energy consumption. The Swiss Federal Office for the Environment carried out an investigation into the energy consumption and emission trends of NRMM for 1980–2050. The results showed that the energy consumption of construction NRMM from 1980 to 2010 almost trebled, with a further 20% increase expected by 2050 [37]. Notter et al. [36] also determined a 5% energy consumption increase between 2000 and 2015. This increase in energy consumption comes as a result of further urbanisation and resulting expansions of construction industries. Regarding greenhouse gas emissions, Notter et al. [36] determined that although agricultural machinery surpasses construction machinery in the production of NO_x and PM, construction machinery was found to contribute the most to the emission of CO_2. However, a decrease in emissions has been observed in recent years. For example, the Swiss Federal Office for the Environment [37] reported that PM emissions have fallen by 28% between 2005 and 2010, with similar reductions experienced for NO_x, as a result of strengthened regulations on air pollution and use of particle filters. This reducing trend has been predicted to continue due to improvements in engine and fuel standards, more stringent air pollution legislation and the eventual replacement of older (more polluting) machinery with newer more efficient models [36–38].

The characterisation of the emissions from construction machinery has received much attention due to its potential as an important source of air pollution, particularly in urban areas. The major urban centre of London introduced emission standards from construction machinery in 2015 by establishing a low emission zone [46]. In 2016, construction was responsible for 15% of $PM_{2.5}$ emissions and 34% of PM_{10} emissions in London [17]. Due to the health effects associated with the inhalation of PM and the likelihood of urban exposure, several investigations have specifically examined the measurement and composition of PM emissions from construction NRMM [11,19,30,32]. Zhang et al. [11] found similarities between construction exhaust particles and those of other diesel vehicles, containing similar proportions of water-soluble ions, organic and elemental carbon and polyaromatic hydrocarbons (PAHs). Similarly, Yu et al. [30] found that $PM_{2.5}$ emissions of construction NRMM were majorly composed of carbonaceous components. These carbonaceous particulates and PAH components represent a particular health risk to the human respiratory system.

Recent studies have also increasingly sought to measure exhaust emissions from construction NRMM under actual operating conditions. Desouza et al. [17] measured the exhaust emissions of 30 construction machines (including generators, excavators, dumpers, rigs, cranes and telehandlers) at active construction sites in London to evaluate the real-world emissions of construction NRMM using PEMS. Guo et al. [26] carried out an additional study on 50 construction machines and 37 tractors and harvesters using PEMS to determine emission factors. Similar investigations have been carried out for excavators [13,16,24,47], wheel loaders [23], forklifts [48] and motor graders [20]. Other real-time exhaust methods have been investigated in the literature. Muresan et al. [49] and Sennoune et al. [50] used similar systems to measure the exhaust emissions of earth work machines. The use of such equipment to determine real-life measures of exhaust emissions is important for the establishment of accurate NRMM emission factors and for the establishment of emission inventories. However, they have also highlighted other potential analytical applications. Desouza et al. [17] were able to detect the failure of the SCR on a telehandler that gave no warning of failure, while measuring exhaust emissions.

3.3. Other NRMM Emissions

Although NRMM from agriculture and construction contribute the most to anthropogenic emissions, NRMM from several other sectors have been studied. Several studies have focussed on emissions from forestry/logging NRMM [51–57]. Automated logging processes are more ecological than the use of more traditional chainsaw methods [56]; as such, many countries operate almost exclusively mechanised logging processes [58,59], the atmospheric emissions of which need to be accurately determined. Lijewski et al. [59] assessed the fuel usage and exhaust emissions of an entire logging process including harvesters, forwarders and transport using PEMS, illustrating once more the deviations between real-life emissions and traditional homologation tests. Harvesters were shown to contribute the most to NO_x and PM emissions due to the use of diesel engines, and forwarders contributed the most to CO and HC emissions (Figure 2).

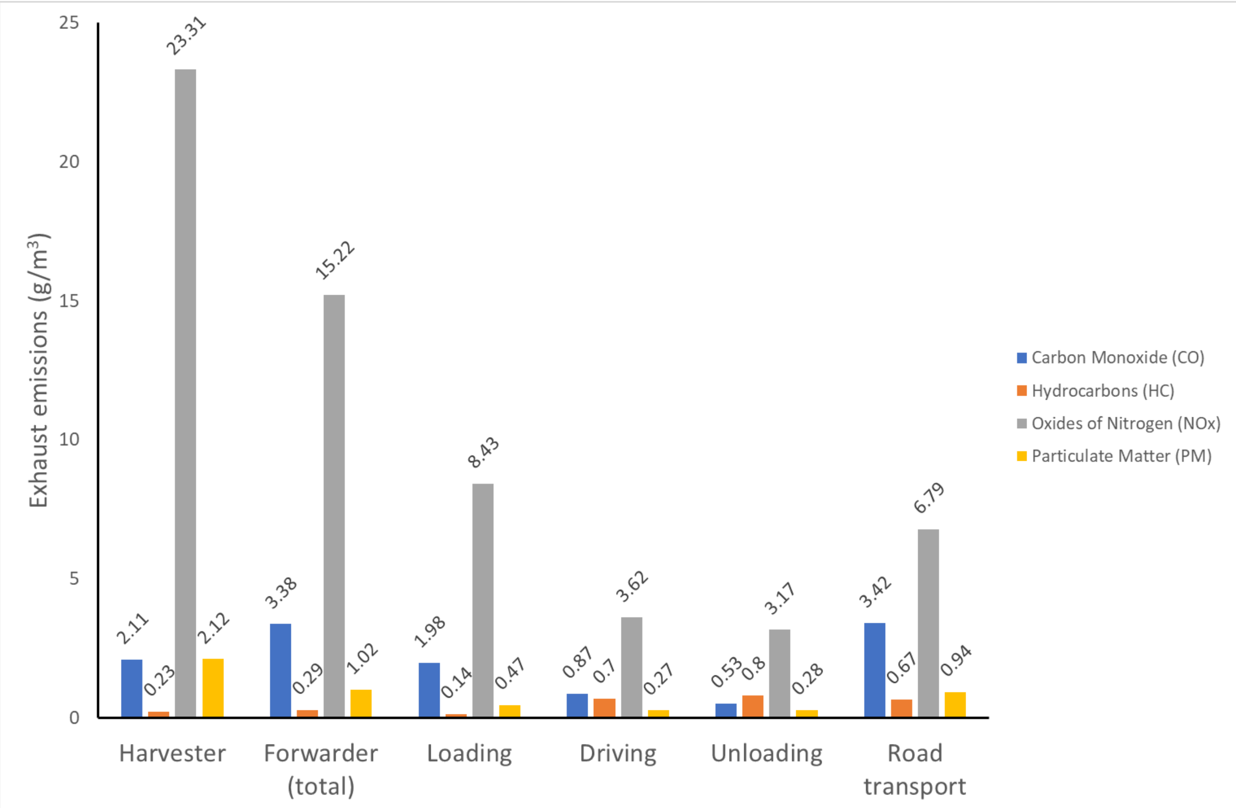

Figure 2. Exhaust emissions for individual timber extraction stages for 1 m^3 of timber adapted from [59].

The contribution of cargo and port handling equipment to regional/national emissions has also been investigated [60–62]. Generally, cargo handling equipment (CHE) is included in construction NRMM, but studies have suggested the separate management of such equipment. The first port emission inventory was constructed in the U.S. for the Port of Long Beach in 2004 [61,62]. Zhang et al. [62] developed a similar method for the estimation of CHE emissions in Nanjing Longtan Container Port, highlighting their contribution to NO_x, CO and PM emissions, with container trailers being the most polluting of the equipment.

Examples of emission testing of handheld and gardening NRMM can also be found in the literature. Lijewski et al. [59] used PEMS to measure the exhaust emissions from handheld generators and chainsaws. Emission testing of garden NRMM such as lawn mowers have also been conducted [63–65]. Priest et al. [65] assessed the CO, CO_2, CH_4, non-methane hydrocarbons (NMHC) and NO_x emissions from 16 in-use lawn mowers, the results of which were used to estimate the total emissions from lawn mowers in the Newcastle region of Australia. Similarly, Millo et al. [66] assessed the emission characteristics of 14 different types of common NRMM engines, including engines from lawn mowers, chainsaws, trimmers and snow removal equipment. Millo et al. [66] then compared these emissions with U.S. emission standards in an effort to form a basis for the European emission standards. Although most studies have focussed on industrial NRMM and measurement of their emissions, it is important to also note the contribution of more domestic handheld and gardening NRMM.

4. International Government Regulations for NRMM

4.1. European Union

European Regulation (EU) 2016/1628 [67] governs the emissions for NRMM in the European Union and establishes emission limits for gaseous and particulate pollutants for engines, as well as defines administrative and technical requirements for EU approval.

The regulation applies as of 1 January 2017 and defines emission limits for engines for different power ranges and applications, as well as laying down procedures that engine manufacturers have to follow for securing type-approval of their engines. This type-approval is a prerequisite for placing the engines on the EU market.

European emission standards for engines used in new NRMM have been broken down into stages I–V. The regulations for stages I–IV were specified by *Directive 97/68/EC* [68], as well as five amending Directives that were adopted from 2002 to 2012. As from Stage V, *Regulation (EU) 2016/1628* specifies emission requirements for all categories of compression ignition (diesel) and positive ignition (petrol) NRMM, replacing *Directive 97/68/EC* and its amendments.

Stages I/II were introduced in 1997. They concern diesel engines from a variety of sources, including industrial drilling rigs, compressors, construction wheel loaders, bulldozers, non-road trucks, highway excavators, forklift trucks, road maintenance equipment, snow ploughs, ground support equipment in airports, aerial lifts and mobile cranes. Agricultural and forestry tractors are also covered by this, but the implementation dates for these machines are different. Stages III–IV came into effect on 21 April 2004 for non-road engines, and on 21 February 2005 for agricultural and forestry tractors. Stage III standards are further divided into stages IIIA and IIIB, and these were phased in from 2006 to 2013. Stage IV came into effect from 2014. In addition to the Stage I–II engine categories, Stages III–IV also cover railroad locomotive engines and marine engines used for inland waterway vessels. The introduction of Stage V was proposed in 2014 and finalised in 2016. For engines below 56 kW and above 130 kW, the standards became effective from 2019, and for engines of 56 kW–130 kW from 2020. Stage V also includes compression ignition engines below 19 kW and above 560 kW, spark ignition engines above 19 kW and any other previously unregulated engines.

On 17 July 2020, *Regulation (EU) 2020/1040 of the European Parliament and of the Council* [69], amending *Regulation (EU) 2016/1628* with regard to its transitional provisions in order to address the impact of the COVID-19 crisis, was published. The regulation was backdated to take effect from 1 July 2020 to avoid any penalties being imposed on original equipment manufacturers who were previously expected to have their compliant NRMM engines produced by 30 June 2020. This amendment gives a 12-month extension to manufacturers of engines of between 56 kW and 130 kW to adhere to the emission limit values set out in Stage V. This extension was granted as the outbreak of COVID-19 caused delays in the supply chain of critical parts and components which further causes delays for engines and machinery fitted with those parts to be placed on the market as per *Regulation (EU) 2016/1628*.

The NRMM regulation has beneficial implications both for the environment and for business. While it protects the health of EU citizens, it also protects the environment and improves air quality in the EU. Additionally, it puts the internal EU market and the global market on the same level so as to avoid unfair competition from non-compliant low-cost products [2].

The regulation further establishes requirements for the market surveillance of all engines intended to be installed in NRMM that require EU type-approval. It is a stringent set of guidelines and regulations that aim to progressively reduce the emission of pollutants, and the intention is to have outdated non-compliant machines phased out and removed from circulation in due course. Manufacturers also need to comply with guidelines that outline a set of approval procedures for engines and associated machines dictated by this regulation. While these regulations will be effective in reducing harmful pollutants emitted by NRMM, some machinery that predates the regulation and as such is outside the scope of it, will still remain in operation for some time. However, according to Article 32 in *(EU) 2016/1628*, there are some exemptions. For inland waterway vessels, for example, - engines for lifeboat launchers Stage IIIA levels are exempt, and other engines that are intended for export to third countries only require marking but no type-approval [70].

4.2. United States of America

Since non-road engines are used in a wide range of applications with different characteristics, the United States Environmental Protection Agency [71] decided to apply separate emission standards for each of the following categories:

- Aircraft

  Regulations are separated by emission type:

  Nitrogen oxide emissions.
  Greenhouse gas emissions.
  Lead emissions.

- Heavy equipment

  Regulations are separated by engine type used in machines:

  Spark ignition engines over 19 kW (25 horsepower):

  Forklifts; generators; other farm, industrial and construction applications.
  May operate on propane, gasoline or natural gas.

  Compression ignition (diesel) engines:

  Excavators and other construction equipment, farm tractors and other agricultural equipment, forklifts, airport ground service equipment and utility equipment such as generators, pumps and compressors.
  The EPA has adopted multiple tiers of emission standards.

- Locomotives

  Three-part program to dramatically reduce emissions from all types of diesel locomotives finalised in 2008. When fully implemented it will:

  Cut particulate matter (PM) emissions by up to 90%.
  Cut nitrogen oxides (NO_x) by up to 80%.

- Marine

  Regulations are separated by engine type used in marine vessels:

  Spark ignition engines.
  Compression ignition (diesel) engines.

- Recreational vehicles

Snowmobiles, off-highway motorcycles (dirt bikes, all-terrain vehicles (ATVs)) and personal boats and watercraft.

- Small equipment and tools

Usually small spark ignition engines.

Evaporative emission standards address fuel permeation through fuel system components in addition to fuel venting during engine operation.

The NRMM regulations were structured in 1998 as a three-tiered progression. The phase-in was realised by horsepower rating:

- Tier 1 standards were phased in 1996–2000;
- Tier 2 was phased in 2001–2006;
- Tier 3 in 2006–2008; and
- Tier 4 in 2008–2015.

Source: [72].

4.3. United Kingdom

The U.K. has adapted the European regulations by introducing a legislation governing emissions produced by engines fitted in NRMM as the Non-Road Mobile Machinery (Emission of Gaseous and Particulate Pollutants) Regulations 1999, as amended. This sets emission standards for CO, HC, NO_x and—for diesel engines—PM.

The regulations were amended in 2004 to also cover small SI engines, such as those used in chainsaws and hedge trimmers, and constant-speed diesel engines. Imported engines and secondary engines mounted on road vehicles (for example, motorised winches fitted to breakdown recovery vehicles) are also included in this amendment. The regulations were further amended in 2006 to include engines used in rail cars, locomotives and inland water vessels. However, some exemptions apply depending on the size and the intended use of the equipment.

The following exclusions to the NRMM regulations apply:

- Aircraft.
- Certain specialist applications—military and recreational craft, road vehicles and ships for intended use at sea.
- Agricultural and tractor engines (these are excluded from NRMM regulations as they are covered by separate regulations).

A maximum fine of GBP 5000 for fitting an unapproved engine type is enforceable [73].

In 2020, the United Kingdom submitted their National Inventory Report (NIR) to the United Nations Framework Convention on Climate Change (UNFCCC). This report contained estimates for the national greenhouse gas emissions from 1990 to 2018. It also included descriptions of the methods that were used to produce these estimates. The report indicated that total GHG emissions have decreased since 1990. This decline is mainly due to reduced emissions from the energy sector. Emissions from NRMM are included under the energy sector, and these consist of an estimation of emissions for 77 different types of diesel- or petrol-powered engines in portable or mobile machinery. These are divided into the following categories: industrial off-road mobile machinery, aircraft support vehicles, house and garden machinery and agriculture/forestry/fishing mobile machinery. The relevant greenhouse gases pertaining to this category are CO_2, CH_4 and N_2O, and the fuel activities consist of DERV, gas oil and petrol. Emissions from individual types of mobile machinery are calculated using a Tier 3 methodology, and default machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from the EMEP/EEA Guidebook. Bottom-up data are used both for estimations and calculations, and in 2004, a study carried out on behalf of the Department for Transport was used as a basis for updating population, usage and lifetime of different types of off-road machinery. However, this was a once-off study, and other estimates were used for the years 1990–2003 and from 2005 onwards. There are, however, some uncertainties regarding these methods, estimated fuel consumption and activity rates being the main ones [74].

4.4. Japan

The former Ministry of Transport (MOT) and Ministry of Construction (MOC) were previously in charge of the emission regulations for new off-road engines and vehicles. The two ministries were amalgamated into the Ministry of Land, Infrastructure and Transport (MLIT) in 2001. The old emission regulations have been replaced by more recent ones by the MLIT together with the Ministry of the Environment (MOE) [75].

The emission standards apply to engines rated between 19 and 560 kW used in two types of vehicles:

1. Special motor vehicles, i.e., self-propelled non-road vehicles and machinery that are registered for operation on public roads (fitted with license plates).
2. Non-road motor vehicles, i.e., self-propelled and non-registered non-road vehicles and machinery.

Although the emission limits for the two vehicle categories are the same, they are introduced by separate regulatory acts.

- On 28 June 2005, the MOE announced a new set of standards for special vehicles based on the 2003 report of the Central Environment Council (CEC), and on 28 March 2006, these standards came into force for nonroad vehicles too. The emission limits here were based on the U.S. EPA Tier 3 standards effective from 2006 to 2008.
- In 2008, the CED recommended further tightening of nonroad emission regulations:

  In March 2010, regulations based on U.S. Tier 4i/EU Stage IIIB standards were introduced. They became effective from 2011 to 2013.
  New regulations based on U.S. Tier 4/EU Stage IIIB standards became effective from 2015 to 2016.

Voluntary emissions standards also exist for portable and transportable equipment which are not regulated under the special/nonroad vehicle standards. These standards provide recognition of low-emission engines for the designation of low-emission construction machinery [75].

4.5. China

The following timeline shows the development of NRMM regulations in China:

- 2007: First emission standards for mobile nonroad diesel engines were adopted.

  Based on European Stage I/II standards.
  Additionally covered small diesel engines (not subject to European standards).
- 2010: Emission standards for mobile nonroad spark ignition engines <19 kW were published in December. The limits were based on EU and U.S. standards.

  Stage I requirements became effective in March.
  Stage II had different implementation dates for non-handheld vs. handheld engines:

  Start dates for new engine types were January 2013/January 2015, respectively.
  Start dates for all new engines were January 2014/January 2016, respectively.
- 2014: China Stage III emission standards and proposed limits for Stage IV were published.

  Based on European Stage IIIA and IIIB requirements, respectively.
- 2018: A procedure for measuring smoke emissions from non-road equipment and vehicles came into effect in December.
- 2020: Stage IV implementation was postponed form January until December [76].

4.6. South Korea

South Korean emission standards are based on U.S. regulations. Standards for construction equipment were introduced in 2004, and standards for agricultural equipment were introduced in 2013.

- The first non-road emission standards came into effect in 2004/2005. These were based on U.S. Tier 1/Tier 2 standards, respectively. They applied to engines of between 19 kW and 560 kW rated power in machinery such as excavators, bulldozers, loader, cranes, graders, rollers and forklift trucks.
- In 2009, emission standards based on U.S. Tier 3 requirements came into effect for construction machinery, and in 2013 for agricultural equipment.
- In 2015, Tier 4-based standards came into effect.

The Korean Ministry of Environment and/or the National Institute of Environmental Research issue the emission certificates for the engines [77].

5. Emission Inventories

Air quality is determined by the quantities of air pollutants that are discharged into the atmosphere from a variety of sources and meteorological conditions. These sources vary in terms of type, pollutant discharged, activity level, geographical location and time period over which the emission is released. An emission inventory is a database comprising information collated for a specific pollutant originating from all source categories in a certain geographical area and within a specified time span [78]. These inventories help determine significant sources of air pollutants and they also provide important data for the generation of air quality modelling. Thus, emission inventories are an important source of data for keeping control on regulations with regard to air quality, which helps to inform the regulation of air pollution. Lončarević et al. [5] have, however, identified three main difficulties in creating a national NRMM emissions inventory. They are a lack of a comprehensive list of NRMM and their activity data, a lack of emission factor data and a lack of research. They further suggest that this general lack of data can be solved by creating national NRMM databases that are operated by a designated institution.

There are three fundamental methods of compiling emission inventories [79]:

- Bottom-up emissions (based on specific activity data and emission factors);
- Top-down emissions (based on aggregated data); and
- Measurement of data (usually only available for large point sources).

A bottom-up inventory is activity and location based; the necessary location, activity data and emission factor information must all be available to populate the inventory. This approach currently provides the highest level of information possible, and the resultant data are valuable both in air quality modelling applications and in the formulation of local abatement strategies.

A top-down approach generally relies on statistical or proxy data to disaggregate national or sub-national totals into emissions resolved at a finer spatial scale.

Measurement data give the most accurate emissions estimate. The actual pollutant contribution from a source under conditions existing at the time of the test can only be determined by specific source measurement. The recommendation is that source-specific data be measured whenever possible [80]. However, this is usually only available for large point sources, and therefore is currently not available for NRMM emissions.

Emission inventories are important for emission control and management. Several countries such as Switzerland and the U.S. have established fully operational NRMM emission inventories [62], whereas many other countries are still in the initial phases of development. This becomes apparent when comparing the number of literature studies on NRMM inventories to those on PEMS and Real Driving Emissions (RDE) measurements, the latter of which represent the initial steps in developing a functional NRMM inventory. RDE studies result in data generation for the improvement of emission factors and subsequent inventories and models [20,47]. Several national/regional emission inventories documented in the literature are summarised below.

The U.S. has been developing emission inventories since the early 1970s [81]. On-road sources have received much attention through the development of the former MOBILE emissions model, but it was not until the early 2000s that NRMM and other off-road machinery received equal attention through the development of the NONROAD model. These models estimate the emissions across a selected area and are reliant on exhaust emission data, fuel composition, location characteristics, etc. [81]. Emission models therefore require sufficient input data to calculate bottom-up emissions for a given location. However, past studies have illustrated the limitations of these models in comparison to real-life emissions [82–84]. The NONROAD model is now part of the MOVES model ("Nonroad Technical Reports | MOVES and Other Mobile Source Emissions Models | US EPA" [85]. Models such as the MOVES model require more detailed emission measurements taken in real-world conditions, forming a more robust foundation for emission inventories. This is particularly true for emission factors, as previous models were utilising emission factors that were decades old [81]. A similar point was made by Cadle et al. [86], in which the suitability of inspection and maintenance (I/M) programs were being evaluated to address this concern; in several cities, emissions data from these types of programs or assessments were being evaluated for suitability for providing MOVES emission rates.

Switzerland also has a fully operational NRMM emission inventory. Switzerland determined its first NRMM emission inventory in 1996 and has updated it twice since then (in 2008 and 2015). Notter et al. [36] described the updated inventory methodology employed in Switzerland. NRMM emissions are determined using a bottom-up approach in which operating hours segmented by machine type, motor type, size classes with respective nominal power, and age are multiplied with load factors. This provides an estimate of the energy demand, which is then multiplied by emission factors and fuel consumption. The result of this is then corrected for deviation of effective load from the standard load, dynamic utilisation of the machine, deterioration of the machine and for diesel particle filter. The required statistics and figures were obtained from a variety of sources, including previous NRMM emission inventories (1980–2000) and official or industry associations where possible, e.g., the Swiss Federal Motor Vehicle Inspection Office, the Swiss Master Builders Association, federal import/export statistics, agricultural census, etc. Using the updated emission inventory, Notter et al. [35] highlighted the increasing activity and fuel consumption of NRMM from 2000 to 2015 as well as the reduction in NRMM emissions due to the introduction of stricter legislation. In a related report, the Swiss Federal Office for the Environment studied the energy consumption and emissions of NRMM for the period 1980–2050 [37].

Winther and Nielsen [87] carried out similar studies in the construction of the NRMM emission inventory for Denmark in 1985–2004 and 1985–2020, including projections. They went on to present an updated NRMM emission inventory for Denmark, further advancing previous outdated NRMM inventory studies [88]. Data and figures were acquired from different professional bodies, machinery manufacturers, research bodies and statistical sources [87]. Diesel engines such as those used in a variety of NRMM were found to be the main contributor to PM and NO_x emissions, with future projections showing equivalent reductions to on-road vehicles. Emissions were calculated using a similar approach to Switzerland, including engine characteristics (type, age, size, etc.), working hours, load factor, emission factor, deterioration factor, transient factor, evaporation factor, etc. [87].

Several NRMM studies from China have also focussed on the development of emission inventories from different areas [11,12,26,27,35,62,89]. Hou et al. [27] studied emissions from various agricultural machinery in real-world conditions to calculate suitable emission factors and emissions for an emission inventory of Beijing from 2006 to 2016. This study illustrated higher emissions in the north of Beijing than for the south due to land usage, highlighting the importance of regional inventory development for the detection of such deviances [27]. Lang et al. [35] carried out a similar inventory for agricultural NRMM for the entirety of China in 2014 using an engine power-based approach to calculate emissions. Wang et al. [12] developed an emission inventory for five types of NRMM using information on population, emission factors, etc., from technical reports, literature studies and national statistics [12]. In addition, Zhang et al. [62] developed an emission inventory for cargo handling NRMM using a bottom-up approach and Guo et al. [26] developed an emission inventory for agricultural and construction diesel machinery in the Beijing–Tianjin–Hebei region of China for 2015. However, the majority of these studies stressed the limitation introduced with lack of real-life emission and emission factor data, and the importance of RDE measurements.

Although other countries also include NRMM in their national/regional emission inventories [60,90,91], little has been covered in the literature on the development of such inventories. Additionally, several countries are still in the early stages of developing NRMM emission inventories due to difficulty in data acquisition. One limitation of NRMM emission inventories is the incompleteness of some bottom-up inventories due to outdated or lacking regional/national data. To help overcome this setback, Kuenen et. al. [92], introduced an alternative to official emission data using the TNO-MACC-II database. The TNO-MACC-II is a spatially explicit, high-resolution European emission inventory for 2003–2009. The aim of this database was to provide modellers with the inputs required and was constructed using available national emission totals per sector. When emissions were not available, emissions at the country level were acquired from EDGAR or the GAINS model. EDGAR is a database where global past and present-day anthropogenic emissions of air pollutants and greenhouse gases are listed by county on a $0.1^\circ \times 0.1^\circ$ grid [93], whereas the GAINS model was launched in 2006 to assess cost-effective response strategies for combating air pollution and minimise the negative effect of them to human health, ecosystems and climate change [94]. However, López-Aparicio et al. [60] and Kuenen et al. [92] clarified the difficulties in compiling the magnitude of required data and discrepancies that were found between such high-resolution gridded databases, downgraded inventories and observed concentrations. Future inventories and models will undoubtedly aim to account for such limitations through increased RDE sampling, establishment of robust emission factors and improved data documentation and NRMM register management.

EMEP/EEA Air Pollutant Inventory Guidebook

Information about how to estimate emissions from both anthropogenic and natural emission sources, in accordance with European regulatory requirements, can be found in the EMEP/EEA Air Pollutant Inventory guidebook. It provides a methodology for the estimation of combustion and evaporative emissions from selected NRMM sources. The aim of the guidebook is to facilitate the reporting of emission inventories by countries to the UNECE Convention on Long-range Transboundary Air Pollution and the EU National Emission Ceilings Directive.

(I) The first edition of this guidebook was published in 1996 as the EMEP/CORINAIR Atmospheric Emission Inventory guidebook [95].

"Council Decision 85/338/EEC established a work programme concerning an 'experimental project for gathering, coordinating and ensuring the consistency of information on the state of the environment and natural resources in the community'. The work programme was given the name CORINE—CO-oRdination d'INformation Environmentale—and includes a project to gather and organise information on emissions into the air relevant to acid deposition—Corinair. This project started in 1986 with the objective of compiling a coordinated inventory of atmospheric emissions from the 12 member states of the Community in 1985 [95].

It covered three pollutants—SO_2, NO_x and volatile organic compounds (VOC)—and recognised eight main source sectors:

- Combustion (including power plants, but excluding other industry);
- Oil refineries;

- Industrial combustion;
- Processes;
- Solvent evaporation;
- Road transportation;
- Nature; and
- Miscellaneous.

The Corinair 1985 inventory was developed in collaboration with the Member States, Eurostat, OECD and UNECE/EMEP and was completed in 1990. This inventory was made available to five EFTA countries, three Baltic States, nine Central and Eastern European countries and Russia, as well as to the Member States. This widening resulted in a more developed nomenclature—SNAP90—and increased the list of pollutants it covered to eight (SO_2, NO_x, non-methane volatile organic compounds (NMVOC), ammonia (NH_3), CO, methane (CH_4), NO and CO_2).

In agreement with EMEP, it further amended the main source sectors to 11:

- Public power, cogeneration and district heating plants;
- Commercial, institutional and residential combustion plants;
- Industrial combustion;
- Production processes;
- Extraction and distribution of fossil fuels;
- Solvent use;
- Road transport;
- Other mobile sources and machinery;
- Waste treatment and disposal;
- Agriculture; and
- Nature.

The goal for Corinair90 was to provide a complete, consistent and transparent air pollutant inventory for Europe in 1990. The Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) developed guidelines for estimating and reporting data from SO_x, NO_x, NMVOCs, CH_4, NH_3 and CO. These guidelines included a recommendation that emissions data should be reported at least for the 11 major source categories agreed with Corinair and other experts for the Corinair90 inventory and that the reporting should be realised as totals [95].

Section 8 of the guidebook concerns "Other Mobile Sources and Machinery". The term Non-Road Mobile Machinery (NRMM) is not specifically used, but this section encompasses all activities that are included within NRMM regulations. There is a slight risk of overlapping with other sectors, but the main subsections included in this section are:

- Military (engines for use by the armed forces are exempt as per Article 34.2 in *EU 2016/1628*);
- Railways;
- Inland waterways;
- Agriculture;
- Forestry;
- Industry; and
- Household and gardening.

The estimates for fuel consumption for the EC12 nations are based on figures from data collected in 1990. National estimates for VOCs, NO_x and SO_2 emissions from Norway, Denmark, Finland, Sweden, Switzerland and The Netherlands are also included in these estimates, even though only The Netherlands and Denmark were part of the EC 12 at the time. Finland and Sweden joined in 1995, and Norway and Switzerland are still not members of the EU.

Emissions estimates in Europe at the time were provided by the European Association of Internal Combustion Engine Manufacturers (EUROMOT) and the International Council of Marine Industry Associations (ICOMIA). Formulae were to be introduced for the purpose of emissions estimation for both simple and more advanced methods depending on the circumstances and requirements. Several warnings are present throughout this edition of the guidebook, highlighting that many emissions factors, equations and estimations are still uncertain and will require updating once more data and information becomes available. Baseline emissions factors for many fuel and engine types are provided, but they are only proposals, and as of the time of publication of this document, no emissions limiting regulations were in force yet (apart from for smoke from agricultural tractors). Sections within this guidebook outline verification procedures and proposed disaggregation criteria. This highlights the fact that the objective of the EMEP/CORINAIR guidebook is to be clear and transparent with their data collection and processing [95].

(II) 1999 Edition

Most of this edition of the EMEP/CORINAIR guidebook is exactly the same as the previous version. The emissions estimations values are still using estimations from 1990. The only changes to Section 8 are updates to the Shipping and Air Traffic subsections, but as they do not pertain to NRMM emissions, they are not relevant in this context [96].

(III) 2001 Edition

This is still for the most part the same as the previous version [97].

(IV) 2002 Update

No further changes relevant to NRMM [98].

(V) 2006 Edition

A large portion of the guidebook is still identical to the 1996 edition. One major change is the addition of "EU Emission directives pertinent to various source categories of mobile sources and machinery". Previously, all the "other mobile sources and machinery" used the same emissions factors irrespective of engine type or year of manufacture. As of this update, baseline emission factors are divided into their NRMM stage, year of manufacture and their purpose. For example, one table may be for "Agriculture tractors NRMM Stage II", with different values listed for each successive implementation date [99].

(VI) 2007 Edition

No further changes relevant to NRMM [100].

(VII) 2009 Edition

The name has now changed to "EMEP/EEA Air Pollutant Emissions Inventory Guidebook". A further change is that it is now organised by the Nomenclature For Reporting (NFR) source code, whereas it was previously organised by the Selected Nomenclature for Air Pollutants (SNAP) code (Section 8). NFR refers to the format of reporting of national data in accordance with CLRTAP It is divided into seven categories: energy, industrial processes, use of solvents and other products, agriculture, changes in land use and silviculture, wastes and imported electrical energy. Each category is further divided into relevant subcategories [101,102].

The SNAP code was developed in the EMEP/EEA guidebook project and is synchronised with the IPCC/OECD nomenclature of source categories for activities resulting in emissions. It is divided into 11 categories: combustion in the production and transformation of energy, non-industrial combustion plants, industrial combustions plants, industrial processed without combustion, extraction and distribution of fossil fuels and geothermal energy, use of solvents and other products, road transport, other mobile sources and machinery, waste treatment and disposal, agriculture and other sources and sinks (nature) [102].

While this edition of the guidebook has been re-categorised and rearranged, many of the same tables with the same emissions values remain from the previous versions. However, a major expansion to the calculation of emissions factors and activity data has been made. It is now divided by fuel, NFR sector, pollutant and technology. The same emissions algorithms as in previous versions of the guidebook are used. Large fuel consumption estimation tables have been added, clearly showing the change in fuel consumption over the lifetime of NRMM [103].

(VIII) 2013 Edition

No further changes relevant to NRMM [104].

(IX) 2016 Edition

Proposed EU Commission Stage V limits in preparation of its use from 2019 onwards have been added. This is on the condition that legislation has been put in place before then. The legislation now takes PEMS into account as a new alternative to lab testing, but this has not yet resulted in any changes to measurement estimates.

Where applicable, PM emissions factors have been separated into filterable PM fractions and total PM. Unlike previous versions that have used the EMEP 2004 database, this edition of the guidebook used the EMEP 2015 database for PM emissions values from the EU countries. As a result, the guidebook included newly updated reports from a larger number of countries.

For Tier I, equations for estimating national NRMM fuel usage when data are unavailable were devised and tested for accuracy [105].

(X) 2019 Edition

This edition does not include any further changes relevant to NRMM [106].

6. Emission Trends for the Main Air Pollutants between 1990 and 2019

The EU has set a target of 20% emission reduction by 2020 compared to 1990; further plans are made for a reduction of 40% by 2030 and an 80–95% reduction by 2050. Another proposal exists for further emission reduction for the EU to reach climate neutrality by 2050 [3].

The total greenhouse gas emissions in the EU decreased by 28.3% between 1990 and 2019. Between 2018 and 2019, the decrease was 3.9%. A variety of factors have had an effect on this reduction, some of which are the growing use of renewables, the use of less carbon-intensive fossil fuels, improvements in energy efficiency and structural changes in the economy. During this period, greenhouse gas emissions decreased in most sectors except transport.

The largest reduction since 1990 is in CO_2 emissions, with considerable reductions also in N_2O and CH_4 emissions. The reductions in the latter two are probably consequences of lower levels of mining activity and lower agricultural livestock populations, as two examples. Key agricultural and environmental policies in the 1990s and climate energy policies in the 2000s have also played a part in the reduction in the overall greenhouse gas emissions.

According to the EU emission inventory reports from 1990 to 2019, there is an overall downward trend in emissions for the main air pollutants. In 2019, SO_x emissions were 92% lower than in 1990, for example. This is the greatest reduction in a main pollutant, and it can be attributed to a combination of measures, such as:

- Moving away from solid and liquid fuels with high sulphur content in energy-related sectors towards low-sulphur fuels such as natural gas;
- Using flue gas desulphurisation techniques in industrial facilities; and
- Implementing EU directives relating to the sulphur content of certain liquid fuels.

Emissions of the other main pollutants have also declined significantly since 1990: CO by 73%, NO_x by 64% and NMVOCs by 64%. However, most pollutant emissions reduced at a slower rate from 2007 to 2018, with NH_3 emissions reducing less than other pollutants overall and even increasing from 2013 to 2017.

The CLRTAP requires parties to report emissions of PM from the year 2000 onwards. The emissions of all subcategories in reported PM have fallen, and this is mainly due to abatement measures within the road transport, energy and industry sectors. Furthermore,

SO_x, NO_x and NH_3 are also involved in producing secondary PM. Hence, if there is a reduction in these pollutants, it follows that there will also be a reduction in PM. Heavy metals and persistent organic pollutants have also reduced significantly since 1990. This is, for the most part, the result of reducing point source emissions for these substances, mainly from industry [107].

7. Conclusions

Emissions from, and fuel consumption associated with, non-road vehicles and other machinery contribute largely to the total amount of emissions. Numerous studies have highlighted the various difficulties surrounding the calculation of the emissions from NRMM and their effects, due to the large variety of these machines and vehicles as well as the difficulty in measuring their in-use emissions. Currently, three methods of compiling emission inventories are used: bottom-up emissions that are based on specific activity data and emission factors, top-down emissions that are based on aggregated data and actual measurement of data, but this is usually only available for large point sources. Accordingly, a full and comprehensive understanding of the numbers and types of NRMM in existence as well as the impact they have on total emissions does not generally yet exist. Underestimation of some pollutants can take place if the fuel use and emissions of these machines are reported under stationary machinery, because the emission of air pollutants tends to be higher for mobile machinery than that for stationary plants.

As of 1 January 2017, *European Regulation (EU) 2016/1628* applies governing the emissions for NRMM and establishing emission limits for gaseous and particulate pollutants for engines. It also defines administrative and technical requirements for EU approval. This type-approval is a prerequisite for placing new engines on the EU market. In these regulations, European emission standards for engines used in new NRMM have been broken down into stages I–V and have been implemented incrementally. Although some overlapping between the EU and USA occur, major differences still exist in worldwide regulations, and engine and equipment manufacturers have called for a coordination of worldwide emission standards to make type-approval and certification more efficient.

EU countries are required to report their emissions under the Air Convention and National Emissions Ceiling Directive (NECD), and the first edition of the EMEP/EEA Air Pollutant Inventory Guidebook came out in 1996 to give information about how to estimate emissions from both anthropogenic and natural emission sources in accordance with European regulatory requirements.

According to the latest EU emission inventory report (1990–2019), there has been a downward trend for the main air pollutants. While this is good news, further research on NRMM is still needed to fully comprehend the role the emissions of this complex group of machines and vehicles plays in the total worldwide emissions.

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