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Emissions from and Fuel Consumption Associated with Off-road Vehicles and Other Machinery

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Rialtas na hÉireann
Government of Ireland

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EPA RESEARCH PROGRAMME 2021–2030

Emissions from and Fuel Consumption Associated with Off-road Vehicles and Other Machinery

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EPA Research Report

Prepared for the Environmental Protection Agency

by

Technological University Dublin and National University of Ireland Galway

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Non-road mobile machinery (NRMM) is a large category that until recently had not been widely researched in terms of its contribution of exhaust emissions to overall air pollution. This category covers a considerable range of machinery, with or without bodywork and wheels, that include an installed combustion engine and that are not intended for carrying passengers or goods on the road.

The first regulation concerning these machines was introduced in 1997 in the form of Directive 97/68/EC, which specified stages I–IV of NRMM emission standards. The current regulation, Regulation (EU) 2016/1628, governs the emissions of NRMM in the EU and establishes emission limits for gaseous and particulate pollutants for engines; it also defines the administrative and technical requirements for EU approval. This regulation has applied since 1 January 2017. This type approval is a prerequisite for placing engines on the EU market. These EU regulations have been enacted into Irish legislation through numerous Statutory Instruments.

The lack of uniformity of the machines in this category and the fact that they are used in many and varied sectors, ranging from large-scale machines used in the construction sector to smaller handheld machines used in private gardens, render it difficult to form a full understanding of the number of these machines currently in operation in Ireland. In this research a range of data were collected from numerous sources in relation to NRMM, for example on ownership, type of NRMM and fuel used. Direct data collection proved difficult, however, and the use of supplementary data was required, including data from the National Oil Reserves Agency (relating to low-sulfur gas oil) and data from the Central Statistics Office. Emissions were calculated for both these data sets and results were then compared. The comparison revealed a discrepancy between the emissions calculated from fuel usage information received through the bottom-up data collection from NRMM users and the emissions calculated from national-level data. This discrepancy, however, is not large enough to account for the large deficit in the directly reported information, as a significant number of NRMM usage data are missing because data holders did not respond to our data collection request. The lack of data made available indicates that in the future data collection efforts will require cooperation from NRMM users, through voluntary agreements or, if necessary, through regulatory requirements, to achieve more accurate emission calculations. As there is no legislation requiring owners of NRMM to report on their fuel use at the national level, the collection of data proved difficult, as data were made available only at the discretion of the data holder. Based on the information received, emissions were calculated for the most common pollutants associated with certain types of NRMM [carbon dioxide, black carbon, methane, carbon monoxide, nitrous oxide, ammonia, non-methane volatile organic compounds, nitrogen oxides, particulate matter (PM_{10} and $PM_{2.5}$) and total suspended particles].

The data collected are intended to be used to improve the national emissions inventory for a range of machines in Ireland. From the data on NRMM activities provided by data holders, the emissions in Table ES.1 were calculated for 2019, using guidance from the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (published by the European Environment Agency in collaboration with the

Table ES.1. Pollutant emissions calculated for 2019 based on information received from NRMM holders

Pollutant	Emissions
CO_2	1605.1 kt
BC	572.7 t
CH_4	44.0 t
CO	5795.7 t
N_2O	69.0 t
NH_3	4.1 t
NMVOC	1792.0 t
NO_x	17,423.6 t
PM_{10}	979.9 t
$PM_{2.5}$	979.9 t
TSP	979.9 t

BC, black carbon; NMVOC, non-methane volatile organic compound; NO_x, nitrogen oxides; TSP, total suspended particles.

European Monitoring and Evaluation Programme; see also section 1.4.4.1 in this report).

To improve the ease and accuracy of future data collection it is recommended that an agreement is established between data holders and the agency receiving the data. This would help to assure data holders that the data will not be shared with competitors, and that the information received will be used only to establish details about the NRMM in Ireland and to compile an accurate pollutant emissions inventory. Furthermore, a mandatory registration form to be filled in at point of purchase of each machine, particularly those used for commercial activity, containing information on the manufacturer, EU approval number, type of machine, age of machine, type of fuel used, engine size and power output (kW), is recommended. When these machines are owned by a business, contractor or other commercial company, reporting annual fuel use and operating hours at the end of each year could also be made mandatory.

With an increasing focus on air quality, policymakers require detailed evidence-based data to support the development of emission reduction measures, so it is imperative that all sources of air pollutants are well understood. The relative share of air pollutant and greenhouse gas emissions originating from NRMM is likely to increase as road emissions decline as a result of the move to lower-emission vehicles.

1 Introduction

1.1 Aim and Objectives

This research project aimed to evaluate in detail the state of the non-road mobile machinery (NRMM) currently in use in Ireland. The project involved the assessment of the amount of and emissions from NRMM in Ireland so that the contribution of these machines to Ireland's overall greenhouse gas and air pollution emissions inventory can be quantified.

The objectives of the project were to:

- conduct a detailed search of existing regulations, models, inventories and measurements of emissions from off-road vehicles and other machinery, and to carry out an extensive literature review of the existing information;
- collect information from current NRMM holders in an attempt to assess the size of the current NRMM fleet in Ireland;
- establish a suitable methodology for the estimation of the fuel use and air pollutant and greenhouse gas emissions associated with the use of NRMM in Ireland;
- use this methodology to add NRMM-specific information to Ireland's overall national emission inventories.

1.2 Non-road Mobile Machinery

The term NRMM covers a large range of machines, with or without bodywork and wheels, that have a combustion engine installed – either a spark ignition petrol engine or a compression ignition diesel engine – and that are not intended for carrying passengers or goods on the road. These engine emissions contribute significantly to air pollution by emitting carbon oxides (CO and CO_2), hydrocarbons (HCs), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter (PM) (Centre for Low Emissions Construction, 2019; European Commission, 2020).

The number and types of these machines in use, and the impact this equipment and mobile machinery has on total emissions, are not fully understood in Ireland at present. In December 2016 the National Emissions Reduction Commitments Directive (NECD) (2016/2284/EU) entered into force. This directive sets emission reduction commitments for 2020 and 2030 for five main air pollutants: NO_x, non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO_2), ammonia (NH_3) and fine particulate matter ($PM_{2.5}$). These pollutants can have considerable negative impacts on human health and the health of the environment (EEA, 2021).

Countries are required to report their emissions under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) (European Commission, no date) and the NECD. The Environmental Protection Agency (EPA) is responsible for submitting the report for Ireland. The information is also useful for developing emission mitigation strategies. One of the challenges of studying NRMM (see Table 1.1 for examples) is that the term encompasses a diverse range of vehicles and machines, which often have very

Table 1.1. Examples of categories of NRMM and types of machinery

Category	Machine
Agriculture and forestry	Harvesters
	Cultivators
	All-terrain vehicles
Construction	Excavators
	Loaders
	Bulldozers
	Forklifts
	Cranes
Railway	Locomotives
	Railcars
Inland waterway	Inland waterway vessels
Mines and quarrying	Underground – trucks
	Mining – loaders
	Excavators
Gardening and handheld equipment	Lawnmowers
	Chain saws
	Hedge trimmers
Miscellaneous	Generators
	Side-by-side vehicles

specialised applications. As a consequence, a number of different engine types and designs with varying fuel consumption profiles and power outputs exist, resulting in a diverse emissions profile.

The amount of fuel used by NRMM in Ireland is not currently known. Hence, the fuel used by these machines is reported together with the fuel used by stationary boilers and engines or the road transport sector. As a consequence of this, the total amount of fuel consumed reported by Ireland is accurate, but uncertainty about the amount of fuel allocated to the NRMM category currently exists. This results in an underestimation of the emissions of some pollutants because emissions of air pollutants per amount of fuel consumed tend to be higher for mobile machinery than for stationary plant. Some data on emissions attributed to off-road sources are available for the EU-27 block and the UK. It was reported that 758.6 kilotonnes (kt) of NO_x (9.4% of the total 8047.5 kt), 50.2 kt of $PM_{2.5}$ (3.8% of the total 1321.9 kt) and 29.2 kt of black carbon (13.4% of the total 218.5 kt) were attributed to this category in 2015, making it a significant source of some pollutants (EMEP Centre on Emissions Inventories and Projections, 2020). Box 1.1 provides

Box 1.1. Pollutants emitted by NRMM

PM

This is one of the most serious air pollution health risks in the EU. PM can affect both lung and heart health.

TSP

In practical terms, total suspended particles (TSP) cover all PM suspended in air, including:

- PM_{10} (inhalable particles with diameters of 10 µm or smaller)
- $PM_{2.5}$ (inhalable particles with diameters of 2.5 µm or smaller)
- Ultrafine (UF) (ultrafine particles with diameters of 0.1 µm or smaller)
- BC (black carbon or soot; a constituent of $PM_{2.5}$ formed from incomplete fuel combustion).

NO_x

This is a health hazard for humans. NO_x can cause eutrophication and acidification in water bodies and contributes to the formation of PM_{10}, $PM_{2.5}$ and ozone.

CO

This is dangerous for human health and can be fatal. CO is produced by the burning of any fuel, particularly the incomplete combustion of fossil fuels, and mostly oxidises to CO_2 in the atmosphere.

HCs

These are dangerous for human health, especially the health of the lungs. HCs react with NO_x in sunlight to produce photochemical smog. Both the reactivity and the quantity of HC emissions must be measured when assessing their effect on the production of photochemical smog.

SO_x

These are harmful to the respiratory system. They are produced by burning fossil fuels containing sulfur. Natural sources of SO_x also exist, e.g. volcanoes. They create secondary pollutants, e.g. sulfate aerosols, PM and acid rain, when released into the air.

Sources: McReynolds *et al*. (1965), EGCSA (2019), Minnesota Pollution Control Agency (2020), NASA (2020), Gas Networks Ireland (no date).

an overview of the main pollutants that can be emitted by operating NRMM.

1.3 Pollutants of Most Concern

The pollutants of most concern that are emitted by NRMM are listed in Box 1.1.

1.4 NRMM Emission Studies

Emissions studies have largely focused on on-road vehicles, rather than NRMM, because data on NRMM emissions have not been as freely available (Puranen and Mattila, 1992). The assumption was that emissions from non-road sources are not as significant as those from on-road sources. However, studies in the early 1990s sought to assess fuel use and emissions from NRMM (Achten, 1990; Puranen and Mattila, 1992). Puranen and Mattila (1992), for example, calculated that work machines accounted for the consumption of 780,000 m^3 of diesel fuel in Finland in 1990, equivalent to about 30% of total diesel consumption by traffic. In comparison, the amount of petrol consumed by work machines was only 69,000 m^3, equating to 3% of total petrol consumption by traffic in Finland. 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 the total of such emissions.

As a consequence of these studies and the increase in the relative contribution of NRMM emissions (as mitigation measures for on-road vehicle emissions improve), concern about emissions from NRMM has risen considerably in recent decades. It is thought that non-road mobile machines will eventually surpass on-road vehicles as the leading source of mobile pollution (Zhang *et al*., 2020). This rise in the share of emissions accounted for by NRMM was predicted over two decades ago; however, fewer studies on the emissions from NRMM sources than from on-road vehicles have been conducted in the last 20 years (Puranen and Mattila, 1992; Wang *et al*., 2016).

Many studies have highlighted the challenges faced when investigating NRMM emissions. The first is that there is still a considerable lack of off-road emission data, particularly in-use emission data (Cao *et al*., 2016). This lack of data and related statistics has also led 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 (Athanassiadis, 2000). Generally, emission tests are carried out in laboratory settings mimicking the in-use operation of NRMM engines. However, the results of such tests have been shown to be inaccurate when compared with real-life emissions (Merkisz *et al*., 2016), a scenario highlighted by the 2015 Volkswagen scandal (Kwon *et al*., 2018). Laboratory testing often fails to accurately account for real-life factors such as the duration and intensity of tasks performed by NRMM and the different levels of activity within that operation (e.g. idling, moving), as generally only the engine or the chassis is tested (Merkisz *et al*., 2016). To overcome the uncertainties in laboratory testing, legislators called for the measurement of real driving emissions (RDE). This resulted in the entire testing scenario now being covered in Article 19 of Regulation (EU) 2016/1628 (EU, 2016). Collecting data from NRMM during operation (real conditions) encounters several challenges. Past studies have emphasised difficulties in quantifying exhaust emissions in comparison with on-road machinery because of the wide range of activities undertaken by NRMM, the operating cycles employed (Gietzelt *et al*., 2012; Desouza *et al*., 2020), difficulties in installing the required instrumentation (Lijewski *et al*., 2015) and the general high cost associated with such tests. However, reliable results are generated that cannot be replicated in laboratory settings. For this reason studies have moved towards the use of portable emission measurement systems (PEMS) and similar devices to obtain measurements of in-use exhaust emissions of NRMM (Frey *et al*., 2008; Mamakos *et al*., 2013). Considerable work has been carried out in recent years using PEMS on a range of different non-road machines (Frey *et al*., 2008; Mamakos *et al*., 2013), including several types of construction and agricultural machinery (Fu *et al*., 2012; Gis *et al*., 2012; Merkisz *et al*., 2015; Cao *et al*., 2016, 2018; Szymlet *et al*., 2018; Thuneke *et al*., 2016; Hou *et al*., 2019; Desouza *et al*., 2020; Guo *et al*., 2020; Zhang *et al*., 2020).

Although fewer in number than on-road machines, non-road mobile machines have been shown to have considerable impact on the production and emission of NO_x and PM. Recent studies from China (Wang *et al*., 2016; Yu *et al*., 2020) illustrate that NRMM sources produced the same concentrations of NO_x and PM as all on-road sources in 2018, which had a notable impact on the air quality in the form of smog. Many papers have also investigated the health impacts (Kagawa, 2002) and chemical composition of such emissions (Cui *et al*., 2017; Yu *et al*., 2020). However, because of the diverse nature of NRMM, past literature has generally focused on assessing the emissions of a few types of machinery within the sectors of interest. Studies regarding emissions from construction and agricultural machinery are well documented, with additional studies also covering emissions from forestry, cargo, port, handheld and domestic gardening equipment, some of which are discussed in sections 1.4.1–1.4.3.

1.4.1 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 (Dalgaard *et al*., 2001). Currently, a variety of NRMM is regularly employed for a range of agricultural tasks. The weighted contribution of agricultural NRMM to anthropogenic emissions has been well 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 emissions of CO, NO_x, HC and PM (Czechlowski *et al*., 2016). Similar trends were also observed throughout Europe and elsewhere (Puranen and Mattila, 1992; Notter *et al*., 2016; Wang *et al*., 2016). Emissions of NRMM from agricultural sources in China have received much attention in the past decade on account of their impact on air quality, with a series of studies concluding that agricultural machinery is an important source of these emissions (Wang *et al*., 2016; Lang *et al*., 2018). 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 more than the PM produced by construction machinery, despite the diesel consumption of agricultural machinery being 20% lower than that of construction machinery. This was attributed to the long lifespan of agricultural NRMM and the lack of retrofitted PM filters (Swiss Federal Office for the Environment, 2015). Therefore, it is estimated that emissions from agricultural NRMM will not decline to the same, or a greater, extent as the emissions from construction NRMM, as such measures are already in place for those machines. A reduction in agricultural emissions has been determined/forecast for the 1985–2050 period, and similar trends were observed by Winther *et al*. (2007) and Hou *et al*. (2019). This reduction is particularly marked for NO_x and PM emissions because of improved diesel fuel standards, emission regulations and the proposed use of exhaust filters (Winther *et al*., 2007).

Improved emission testing methods for agricultural NRMM is another topic that has been well documented in recent times. Several studies have investigated the differences between exhaust emissions of NRMM in real-world and laboratory settings. Pirjola *et al*. (2017) compared exhaust emissions emitted by a tractor in real-world conditions with those of a similar engine using a dynamometer in the laboratory. It was found that NO_x emission factors were approximately 50% higher in real-world conditions than in laboratory conditions. Differences were also observed for the PM emissions; nucleation mode particles ($< 0.01\,\mu m$) were produced in real-world conditions but not in laboratory conditions. These particles were absent in laboratory testing because of the absence of pollutants such as ammonia in the laboratory. With the introduction of RDE measurement, many studies have assessed the suitability of devices that measure RDE for measuring the emissions of agricultural NRMM. PEMS are the most widely assessed RDE devices and have been included in many NRMM emission studies (Merkisz *et al*., 2015; Thuneke *et al*., 2016; Szymlet *et al*. 2018; Hou *et al*., 2019). Szymlet *et al*. (2018) even compared the emissions of a passenger car with those of a tractor using PEMS; emissions from the tractor were shown to be several times higher than those from the car.

Tractors are the most studied of the agricultural NRMM category because they are the most polluting of farming machinery (Janulevičius *et al*., 2013). Hou *et al*. (2019) investigated the emission characteristics of 22 different types of agricultural NRMM, including tractors, harvesters and microtillers, and determined that tractors accounted for over 80% of emissions from agricultural NRMM in Beijing in 2016. Many papers have focused on assessing the engine performance of tractors and emissions during different operating modes in an effort to optimise the engine performance

(Lindgren and Hansson, 2002; Lindgren *et al*., 2011; An *et al*., 2013; Janulevičius *et al*., 2013; Thuneke *et al.*, 2016). As a result, several simplified emission testing methods have also been developed for tractors. Janulevičius *et al*. (2013) determined the suitability of measuring exhaust emissions during operation by using data collected in load profiles of the tractors' electronic control units (ECUs). Similarly, Ettl *et al*. (2018) developed an alternative method based on torque data and ECU engine speed from long-term tractor operations. This method used a simplified test stand rather than 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 emissions from NRMM in agriculture, many studies have also focused on the mitigation and reduction of pollutants from exhaust gases. Lovarelli and Bacenetti (2019) describe some technological solutions suitable for agricultural tractors and self-propelled machines. Examples of these devices are diesel particulate filters and exhaust gas recirculation and selective catalytic reduction devices.

1.4.2 NRMM emissions in construction

Emissions from construction NRMM have been the subject of many of the same studies as those on agricultural NRMM. Both NRMM types generally use diesel engines, which have been shown to favour NO_x and PM production. However, the literature shows that construction machinery has not seen the same decreasing trend in energy consumption as agricultural NRMM. The Swiss Federal Office for the Environment carried out an investigation into the energy consumption and emission trends of NRMM for the period 1980–2050. The results showed that the energy consumption of construction NRMM almost trebled between 1980 and 2010, with a further 20% increase expected by 2050 (Swiss Federal Office for the Environment, 2015). Notter *et al*. (2016) also determined a 5% energy consumption increase between 2000 and 2015. This increase in energy consumption is the result of further urbanisation and the resulting expansion of the construction industry. Regarding greenhouse gas emissions, Notter *et al*. (2016) determined that, although agricultural machinery surpasses construction machinery in the production of NO_x and PM, construction machinery contributed the most to the emissions of CO_2. However, a decrease in emissions has been observed in recent years. For example, the Swiss Federal Office for the Environment reported that PM emissions fell by 28% between 2005 and 2010, with similar reductions in NO_x emissions, as a result of strengthened regulations on air pollution and the use of particle filters (Swiss Federal Office for the Environment, 2015). This reducing trend has been predicted to continue because of 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 (Winther *et al*., 2007; Swiss Federal Office for the Environment, 2015; Notter *et al*., 2016).

Emissions from construction machinery have received much attention because they are potentially an important source of air pollution, particularly in urban areas. The major urban centre of London introduced emission standards for construction machinery in 2015 by establishing a low-emission zone (Faber *et al*., 2015). In 2016 construction was estimated to be responsible for 15% of $PM_{2.5}$ and 34% of PM_{10} emissions in London (Desouza *et al*., 2020). On account of 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 (Lijewski *et al*., 2015; Cui *et al*., 2017; Yu *et al*., 2020; Zhang *et al*., 2020). Zhang *et al*. (2020) found that exhaust particles from construction machinery and other diesel vehicles contained similar proportions of water-soluble ions and organic and elemental carbon and polyaromatic hydrocarbons (PAHs). Similarly, Yu *et al*. (2020) found that $PM_{2.5}$ emissions of construction NRMM were mainly composed of carbonaceous components. These carbonaceous particulates and PAH components represent a particular risk to the health of the human respiratory system.

Recent studies have also increasingly sought to measure exhaust emissions from construction NRMM under actual operating conditions. Desouza *et al*. (2020) 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*. (2020) 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 (Abolhasani *et al*., 2008; Fu *et al*., 2012; Cao *et al*., 2018; Kwon *et al*., 2018), wheel loaders (Fu *et al*., 2012), forklifts (Fuc *et al*., 2017) and motor graders (Frey *et al*., 2008). Other methods of measuring real-time exhaust emissions have been investigated in the literature. Muresan *et al*. (2015) and Sennoune *et al*. (2014) used similar systems to measure the exhaust emissions of earth work machines. The use of such equipment to measure real-life exhaust emissions is important for the establishment of emission inventories and accurate NRMM emission factors. However, it has also highlighted other potential analytical applications. Desouza *et al*. (2020) were able to detect the failure of the selective catalytic reduction device on a telehandler that gave no warning of failure while measuring exhaust emissions.

1.4.3 Other NRMM emissions

Although agriculture and construction NRMM is the biggest contributor to anthropogenic emissions, NRMM used in several other sectors has been studied. Several studies have focused on emissions from forestry/logging NRMM (Karjalainen and Asikainen, 1996; Berg and Karjalainen, 2003; Berg and Lindholm, 2005; Klvac and Skoupy, 2009; Engel *et al*., 2012; Lijewski *et al*., 2013; Wiśniewski and Kistowski, 2020). Automated logging processes are more ecological than the use of more traditional chainsaw methods (Lijewski *et al*., 2013); therefore, many countries operate almost exclusively mechanised logging processes (Karjalainen *et al*., 2001; Lijewski *et al*., 2017a), the atmospheric emissions of which need to be accurately determined. Lijewski *et al*. (2017a) assessed the fuel usage and exhaust emissions of an entire logging process, including forest harvesters, forwarders and transport, using PEMS, illustrating once more the differences between real-life emissions and traditional homologation tests. Forest harvesters were shown to contribute the most to NO_x and PM emissions because of their use of diesel engines, and forwarders contributed the most to CO and HC emissions.

The contribution of cargo- and port-handling equipment to regional/national emissions has also been investigated (Starcrest Consulting Group, 2015; López-Aparicio *et al*., 2017; Zhang *et al*., 2017). Generally, cargo-handling equipment is included in construction NRMM, but studies have suggested that such equipment should be included in a separate category. The first port emission inventory was constructed in the USA for the Port of Long Beach in 2004 (Starcrest Consulting Group, 2015; Zhang *et al*., 2017). Zhang *et al*. (2017) developed a similar method for the estimation of cargo-handling equipment 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*. (2017b) used PEMS to measure the exhaust emissions from handheld generators and chainsaws. Emission testing of garden NRMM, such as lawnmowers, has also been conducted (Gabele, 1997; Priest *et al*., 2000; Christensen *et al*., 2001). Priest *et al*. (2000) assessed the CO, CO_2, CH_4, non-methane hydrocarbons and NO_x emissions from 16 in-use lawnmowers, the results of which were used to estimate the total emissions from lawnmowers in the Newcastle region of Australia. Similarly, Millo *et al*. (2002) assessed the emission characteristics of 14 different types of common NRMM engines, including engines from lawnmowers, chainsaws, trimmers and snow removal equipment. Millo *et al*. (2002) compared these emissions with US emission standards in an effort to form a basis for the European emission standards. Although most studies have focused on industrial NRMM and measurement of its emissions, it is important to also note the contribution of more domestic handheld and gardening NRMM.

1.4.4 Emission inventories

Air quality is determined by the quantities of air pollutants that are discharged into the atmosphere from a variety of sources, both natural and anthropogenic, along with 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 (Davidson *et al.*, 2011). These inventories help determine significant sources of air pollutants and they also provide important data for air quality modelling. Thus, emission inventories are an important source of data for assessing compliance with regulations and informing the control and management of air pollution.

There are three fundamental methods of compiling emission inventories (Denby *et al.*, 2011):

1. bottom-up emissions (based on specific activity data and emission factors);
2. top-down emissions (based on aggregated data);
3. measurement of emissions data (usually only available for large point sources).

A bottom-up inventory is activity and location based, and 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 subnational totals into emissions resolved at a finer spatial scale.

The actual pollutant contribution from a source under conditions existing at the time of the test can be determined only by specific source measurement. The recommendation is that source-specific data be measured whenever possible (US EPA, 1997). However, as these data are usually available only for large point sources, this is currently not feasible for NRMM emissions.

Several countries, such as Switzerland and the USA, have established fully operational NRMM emission inventories (Zhang *et al.*, 2017), 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 with those on PEMS and RDE measurements, the last two of which represent the initial steps in developing a functional NRMM inventory. RDE studies generate data for the improvement of emission factors and subsequent inventories and models (Abolhasani *et al.*, 2008; Frey *et al.*, 2008). Several national/regional emission inventories documented in the literature are summarised below.

The USA has been developing emission inventories since the early 1970s (Miller *et al.*, 2006). On-road sources have received much attention through the development of the former Mobile Source Emissions Factor (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 (Non-road Engines, Equipment and Vehicles) model. These models estimate the emissions across a selected area and are reliant on exhaust emission data, fuel composition, location characteristics, etc. (Miller *et al.*, 2006). Emission models therefore require sufficient inputted data to calculate bottom-up emissions for a given location. However, past studies have illustrated the limitations of these models in comparison with real-life emissions (Sawyer *et al.*, 2000; Giannelli *et al.*, 2010). The NONROAD model is now part of the MOVES (Motor Vehicle Emission Simulator) model (US EPA, 2018). Models such as MOVES require more detailed emission measurements taken in real-world conditions to form a more robust foundation for emission inventories. This is particularly true for emission factors, as previous models were using emission factors that were decades old (Miller *et al.*, 2006). A similar point was made by Cadle *et al.* (2008), who evaluated the suitability of inspection and maintenance programmes to address this concern; in several cities emissions data from these types of programmes or assessments were being evaluated for suitability for providing MOVES emission rates.

Switzerland also has a fully operational NRMM emission inventory, first developed in 1996 and updated twice since then (in 2008 and 2015). Notter *et al.* (2016) described the updated inventory methodology being 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 by 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 use of the machine, and deterioration of the machine and the diesel particulate filter. The required statitistics 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 and an agricultural census. Using the updated emission inventory, Notter *et al*. (2016) highlighted the increasing activity and fuel consumption of NRMM from 2000 to 2015 and the reduction in NRMM emissions because of 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 (Swiss Federal Office for the Environment, 2015).

Winther *et al*. (2007) and Winther and Nielsen (2006) carried out similar studies in the construction of the NRMM emission inventory for Denmark between 1985 and 2004 and between 1985 and 2020, which included projections. Winther *et al*. (2007) presented an updated NRMM emission inventory for Denmark, further advancing previous outdated NRMM inventory studies (Bak *et al*., 2003). Data and figures were acquired from different professional bodies, machinery manufacturers, research bodies and statistical sources (Winther *et al*. 2007). 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 reductions equivalent to those of 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 and evaporation factor (Winther and Nielsen, 2006).

Several NRMM studies from China also focused on the development of emission inventories from different areas (Zheng *et al*., 2009; Wang *et al*., 2016; Zhang *et al*., 2017; Lang *et al*., 2018; Hou *et al*., 2019; Guo *et al*., 2020; Zhang *et al*., 2020). Hou *et al*. (2019) studied emissions from various types of agricultural machinery in real-world conditions to calculate suitable emission factors and emissions for an emission inventory for Beijing from 2006 to 2016. This study illustrated higher emissions in the north of Beijing than in the south as a result of differences in land use, highlighting the importance of regional inventory development for the detection of such deviances (Hou *et al*., 2019). Lang *et al*. (2018) 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*. (2016) developed an emission inventory for five types of NRMM using information on population, emission factors, etc., from technical reports, literature studies and national statistics (Wang *et al*., 2016). In addition, Zhang *et al*. (2017) developed an emission inventory for cargo-handling NRMM using a bottom-up approach, and Guo *et al*. (2020) 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 arising from the 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 (Symeonidis *et al*., 2004; López-Aparicio *et al*., 2017; Richmond *et al*., 2019), little has been covered in the literature on the development of such inventories. Additionally, several countries are still in the very early stages of developing NRMM emission inventories, due to the difficulty of data acquisition. One limitation of NRMM emission inventories is the incompleteness of some bottom-up inventories as a result of outdated or lacking regional/national data. To help overcome this, Kuenen *et al*. (2014) introduced an alternative to official emission data using the TNO-MACC-II database. TNO-MACC-II is a spatially explicit, high-resolution European emission inventory for the period 2003–2009. The aim of this database was to provide modellers with the inputs required, and it was constructed using available national emission totals per sector. When emissions were not available, emissions at the country level were acquired from EDGAR (Electronic Data Gathering, Analysis and Retrieval System) or the GAINS (Greenhouse Gas–Air Pollution Interactions and Synergies) model. EDGAR is a database in which global past and present-day anthropogenic emissions of air pollutants and greenhouse gases are listed by country on a 0.1×0.1 grid (EEA, 2020a). The GAINS model was launched in 2006 to assess cost-effective response strategies for combating air pollution and minimising its negative effect on human health, ecosystems and climate change (IIASA, 2018). However, López-Aparicio *et al*. (2017) and Kuenen *et al*. (2014) documented the difficulties in compiling the large number of data required and the discrepancies 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, the establishment of robust emission factors, and improved data documentation and NRMM register management.

1.4.4.1 EMEP/EEA Air Pollutant Emission Inventory Guidebook

Information about how to estimate emissions from both anthropogenic and natural emission sources, in accordance with EU regulatory requirements, can be found in the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (see EEA, 2019). It provides a methodology for the estimation of combustion and evaporative emissions from selected NRMM sources. The aim of this guidebook is to facilitate countries to report emission inventories to the UNECE CLRTAP and the EU NECD. The first edition of the guidebook was published in 1996 as the *EMEP/CORINAIR Atmospheric Emission Inventory Guidebook* (EEA, 1996). Council Decision 85/338/EEC (EU, 1985) 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". This work programme was given the name CORINE (Coordination of Information on the Environment) and included a project called Corinair, which sought to gather and organise information on emissions into the air relevant to acid deposition. This project started in 1986 with the objective of compiling a coordinated inventory of atmospheric emissions from the 12 Member States of the European Community in 1985 (Corinair). It covered three pollutants, namely SO_2, NO_x and volatile organic compounds (VOC); it also recognised the following eight main source sectors: combustion (including power plants, but excluding other industry), oil refineries, industrial combustion, processes, solvent evaporation, road transport, nature and miscellaneous. This inventory was completed in 1990 and was made available to a larger audience. This widening resulted in a more developed nomenclature – selected nomenclature for air pollutants (SNAP) code SNAP90 – and increased the list of pollutants it covered to the following eight: SO_2, NO_x, NMVOCs, NH_3, CO, CH_4, NO and CO_2. The main source sectors were expanded to the following 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; and agriculture and nature. 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 the NRMM regulations. There is a slight risk of overlap with other sectors, but the main subsections included in this section are military (engines for use by the armed forces are exempt, according to Article 34.2 in Regulation EU 2016/1628), railways, inland waterways, agriculture, forestry, industry, and household and gardening. The guidebook has been updated several times over the years. In 2009 the name changed to the current *EMEP/EEA Air Pollutant Emissions Inventory Guidebook* and a further significant change was that it is now organised by nomenclature for reporting (NFR) source code (Eustat, 2020a); previously it was organised by the SNAP code (Eustat, 2020b). The latest update of the guidebook was released in 2019.

1.5 International Government Regulations for NRMM

1.5.1 EU regulations

Regulation (EU) 2016/1628 (EU, 2016) governs NRMM emissions in the EU and establishes emission limits for gaseous and particulate pollutants for engines, as well as defining the administrative and technical requirements for EU approval (EU, 2016). The regulation has applied since 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 engines on the EU market. Agriculture and forestry vehicles are further governed by Regulation (EU) No. 167/2013 of the European Parliament and of the Council of 5 February 2013 on the approval and market surveillance of agricultural and forestry vehicles (EU, 2013).

European emission standards for engines used in new NRMM have been broken down into five stages. These stages were introduced incrementally between

1997 and 2016. However, in 2020 an amendment granted an extension to the deadline for manufacturers of certain engines to adhere to the emission limit values of stage V because of delays caused by the COVID-19 crisis (EU, 2020).

The NRMM regulation has beneficial implications for both the environment and business. It protects the health of EU citizens, and 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 (European Commission, 2020).

The regulation further establishes requirements for the market surveillance of all engines that require EU type approval and which are intended to be installed in NRMM. It is a stringent set of guidelines 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. Thus, manufacturers are required to comply with the guidelines that outline a set of approval procedures for engines and associated machines (European Commission, 2017).

1.5.2 Implementation of EU regulations in Ireland

Technical specifications for gas oils, petrol and diesel in Ireland are set out by the Minister for the Department of the Environment, Climate and Communications (DECC, 2020). The National Standards Authority of Ireland (https://www.nsai.ie) is the country's official standards body and is responsible for issuing type approval under these regulations. The following Statutory Instruments (S.I.s) are relevant for the regulation of NRMM under Irish law.

S.I. No. 396/1999 – European Communities (Control of Emissions of Gaseous and Particulate Pollutants from Non-road Mobile Machinery) Regulations 1999 (Revoked). This S.I., in compliance with the requirements of Directive 97/68/EC, defines the preconditions for type approval of certain types of NRMM. More specifically, it relates to measures against the emission of gaseous and particulate pollutants from internal combustion engines that are to be installed in NRMM. The directive also states that machines that are not compliant with the directive should not be placed on the market.

S.I. No. 270/2002 – European Communities (Control of Emissions of Gaseous and Particulate Pollutants from Non-road Mobile Machinery) (Amendment) Regulations 2002 (Revoked). This S.I. is an amendment of S.I. No. 396/1999 on the type approval and placing on the market of internal combustion engines to be installed in NRMM. The amendment of Annexes III and IV of Directive 97/68/EC, adapted to account for technical progress by Commission Directive 2001/63/EC, is hereby transposed into Irish law.

S.I. No. 147/2007 – European Communities (Control of Emissions of Gaseous and Particulate Pollutants from Non-road Mobile Machinery) Regulations 2007. S.I. No. 396/1999 and S.I. No. 270/2002 are both revoked in this S.I. This transposing of Directive 97/68/EC and its amendments in 2001, 2002 and 2004 related to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in various types of NRMM and to secondary engines fitted into vehicles intended for passenger or goods transport on the road. Type approval of certain types of NRMM powered by compression ignition engines became required to be able to control emissions of gaseous and particulate pollutants. The amendment in 2002 included emission limits for spark ignition engines used in NRMM for the first time, whereas the 2004 amendment introduced stricter emission limits on the engines already covered; it also introduced emission limits for some new classes of engine, for example those installed in inland waterway vessels, railcars and locomotives.

S.I. No. 155/2011 – European Communities Act 1972 (Environmental Specifications for Petrol, Diesel Fuels and Gas Oils for Use by Non-road Mobile Machinery, Including Inland Waterway Vessels, Agricultural and Forestry Tractors and Recreational Craft) Regulations 2011. This S.I. transposes Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 as regards the specification of petrol, diesel and gas oil and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC into Irish law. It also includes technical and environmental specifications for petrol and diesel fuels for road vehicles, but specifies the following for NRMM, including inland waterway vessels and recreational craft when not at sea, and agricultural and forestry tractors:

- They must have a maximum sulfur content of 10 mg/kg for gas oil generally.
- They must have a maximum sulfur content of 20 mg/kg at the final point of distribution to end users to accommodate minor contamination in the supply chain.
- Suppliers must provide appropriate information to consumers concerning any biofuel content of gas oils for use by NRMM as this cannot be used as marine fuel and may oxidise if stored for longer than 6 months.

S.I. No. 176/2012 – European Communities Act, 1972 (Environmental Specifications for Petrol, Diesel Fuels and Gas Oils for Use by Non-road Mobile Machinery, Including Inland Waterway Vessels, Agricultural and Forestry Tractors, and Recreational Craft) (Amendment) Regulations 2012. This regulation relates to the quality and testing of diesel fuels and transposes Commission Directive 2011/63/EU of 1 June 2011 amending, for the purpose of its adaptation to account for technical progress, Directive 98/70/EC of the European Parliament and of the Council into Irish law.

S.I. No. 407/2012 – European Communities (Control of Emissions of Gaseous and Particulate Pollutants from Non-road Mobile Machinery) (Amendment) Regulations 2012. This S.I. states that the number of engines (except those in railcars, locomotives and inland waterway vessels) that can be placed on the market under the flexibility scheme can be increased by 20–37.5% during the transition from stage IIIA to stage IIIB; the option to place a fixed number of engines on the market is also provided. An adapted, more limited, version is now also in place for locomotive engines. A limited exemption for replacement engines in railcars and locomotives is also included.

S.I. No. 417/2013 – European Communities (Control of Emissions of Gaseous and Particulate Pollutants from Non-Road Mobile Machinery) (Amendment) Regulations 2013. This S.I. concerns measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in NRMM. Annexes I, II, III, IV and VI are being amended, and Annexes XI and XII are being replaced, in accordance with the opinion of the Technical Committee of Motor Vehicles, competent under Article 15 of Directive 97/68/EC (EU, 1997). This is a transposition of Directive 2012/46/EU into Irish law.

S.I. No. 273/2014 – European Union (Sulphur Content of Heavy Fuel Oil and Gas Oil) Regulations 2014. These Regulations transpose certain provisions of Directive 1999/32/EC, as amended by Regulation (EC) No. 1882/2003, Directive 2005/33/EC, Regulation (EC) No. 219/2009, Directive 2009/30/EC and Directive 2012/33/EU, relating to the use of Heavy Fuel Oil and Gas Oil. The intention of this S.I. is to reduce the harmful effects to human health and the environment caused by SO_2 emissions produced by the combustion of certain types of liquid fuels. The regulation states that maximum sulfur content in gas oil may not exceed 0.10% by mass. However, this does not apply to gas oils intended for use by NRMM including inland waterway vessels, recreational craft and agricultural and forestry tractors.

S.I. No. 236/2015 – European Communities Act, 1972 (Environmental Specifications for Petrol, Diesel Fuels and Gas Oils for Use by Non-road Mobile Machinery, Including Inland Waterway Vessels, Agricultural and Forestry Tractors, and Recreational Craft) (Amendment) Regulations 2015. This S.I. is a further revision of the 2011 amendment of the above act transposed into Irish law and include updating standards EN 228 and EN 590 with regard to the testing of petrol and diesel.

S.I No. 160/2017 – European Union (Greenhouse Gas Emission Reductions, Calculation Methods and Reporting Requirements) Regulations 2017. This S.I. sets a target for the reduction of life cycle greenhouse gas emissions per unit of energy supplied and also defines rules on calculation methods and reporting requirements. The regulations apply to fuels used to move road vehicles, NRMM, agricultural and forestry tractors, recreational craft when not at sea, and electricity for use in road vehicles. The suppliers are required to report to the National Oil Reserves Agency (NORA) the total volume of each type of fuel or energy supplied, where purchased and its origin, as well as the life cycle greenhouse gas emissions per unit of energy.

S.I. 735/2021 – European Union (Internal Combustion Engines For Nonroad Mobile Machinery) (Gaseous and Particulate Pollutant Emission Limits and Type-Approval) Regulations 2021. This S.I. is the implementation of Regulation EU 2016/1628 into Irish law. Previous S.I.s are now revoked by this S.I.

1.5.3 Other international regulations

The US Environmental Protection Agency (US EPA, 2020) applies separate emission standards for different categories to account for the use of non-road engines in a wide range of applications with divergent characteristics. Regulations concerning aircraft are separated by emission type, whereas the regulations concerning heavy equipment and those for the marine sector are separated by engine type used in the machines and vessels. Further regulations exist for recreational vehicles, small equipment and tools (Dieselnet.com, 2017). In Japan the current standards are as strict as the US tier 4 and the EU stage IIIB regulations. Voluntary emissions standards for portable and transportable equipment not regulated under the special/non-road vehicle standards also exist. These standards provide recognition of low-emission engines for designation of low-emission construction machinery (Dieselnet.com, 2012). The emission requirements for diesel-fuelled NRMM in China have been progressively tightened from stage I to stage IV standards (Dieselnet.com, 2020). South Korean emission standards are also based on US regulations. Standards for construction equipment were introduced in 2004, while those for agricultural equipment were introduced in 2013 (Dieselnet.com, 2013).

The UK, on the other hand, has adapted the EU regulations by introducing legislation governing emissions produced by engines fitted in NRMM in the form of the Non-road Mobile Machinery (Emission of Gaseous and Particulate Pollutants) Regulations 1999, as amended. This sets emission standards for CO, HC and NO_x; for diesel engines it also sets emission standards for PM. The regulation also covers small spark ignition engines, e.g. those used in chainsaws and hedge trimmers, and constant-speed diesel engines. Imported engines and secondary engines mounted on road vehicles (e.g. motorised winches fitted to breakdown recovery vehicles) are also included in this amendment. In 2006 the regulations were further amended to include engines used in railcars, locomotives and inland water vessels. However, some exemptions apply depending on the size and the intended use of the equipment. Emissions from individual types of mobile machinery in the UK are calculated using a tier 3 methodology (see section 2.3, p. 21), and default machinery or engine-specific fuel consumption and emission factors (g/kWh) are taken from the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (EEA, 2019; Brown *et al*., 2020).

Engine and equipment manufacturers have put pressure on the regulatory authorities in the EU, USA and Japan to coordinate worldwide emission standards so that engine development and emission type approval and certification would be made more efficient for different markets. European stages I/II and III/IV were harmonised with US regulations to various extents, but this harmonisation was largely lost at stage V. For example, the stage V PM limits in European regulations require diesel particulate filters on all affected engines, whereas no filters are needed to meet the US tier 4 standards (Dieselnet.com, 2016).

1.5.4 Emission trends for the main air pollutants 1990–2019

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 last 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 1990–2019 (EEA, 2020b, 2021), 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 sulfur content in energy-related sectors towards low-sulfur fuels such as natural gas;
- using flue gas desulfurisation techniques in industrial facilities;
- implementing EU directives relating to the sulfur 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 (EEA, 2020b, 2021).

2 Methodology

2.1 Literature Review

An extensive literature review was carried out as a foundation for the localised research and to examine the general state of knowledge about NRMM. The areas investigated include pollutants emitted by NRMM; current national and international regulations surrounding the production, sale and use of NRMM: state of knowledge of research on NRMM; methods on how to measure its emissions; and different ways of compiling NRMM-specific emission inventories. The findings of this research were compiled into a literature review and are summarised in Chapter 1.

2.2 Data Collection

The process of collecting data and information was initiated in tandem with the literature search. Data collection was conducted using two main methodologies. The primary approach consisted of directly contacting potential data holders and data sources. Potential NRMM data holders were identified and classified into sectors. Each potential data holder was then contacted by email; the email provided details of the project along with the types of data that were being requested. The types of data requested were presented in the form of a sample data template. This included the following specific data on the NRMM held by the respondent: manufacturer, type of NRMM, age of NRMM, number of machines of this type in their possession, EU approval number, size of engine, power output (kW), type of fuel used and where it is bought, annual fuel use and annual operating hours. Where relevant, the email request was followed up with a telephone call. The option to provide the data requested in a different format if preferred by the respondent was given, but providing the survey to recipients in an easily editable electronic format proved suitable and became the preferred method of data collection. Data received were stored by sector in preparation for the data analysis. The secondary approach consisted of searching online for available databases and data sets, such as that of the Central Statistics Office (CSO).

2.3 Data Analysis

The data received from data holders in each sector were examined in detail. Where data were lacking, further attempts to contact the data holder were made. The initial analysis involved calculating the CO_2 emissions by a tier 1 calculation method using values received from the EPA (see Table 2.1 and equations 2.1–2.4).

Step 1 – tonnes of diesel. The first step was to calculate tonnes of diesel. This was done by dividing the total reported litres of diesel by the value 1183 from Table 2.1.

$$\text{Diesel}_{\text{tonnes}} = \frac{\text{Diesel}_{\text{litres}}}{1183} \quad (2.1)$$

Step 2 – TJ of diesel. The second step was to calculate terajoules of diesel. This was done by multiplying the tonnes of diesel calculated in step 1 by the value for MJ/tonne of diesel, i.e. 43,308 from Table 2.1, and dividing the result by 1,000,000 (10^6).

$$\text{TJ of diesel} = \frac{\text{Diesel}_{\text{tonnes}} \times \text{MJ}_{\text{tonnes}}}{(10^6)} \quad (2.2)$$

Table 2.1. Values used for tier 1 CO_2 calculations

	Unit					
Fuel	**kg CO_2/litre**	**kg CO_2/kg**	**g CO_2/MJ**	**g CO_2/kWh**	**MJ/tonne**	**litres/tonne**
Petrol	2.36	3.121	70.00	251.9	44,589	1325
Diesel	2.68	3.174	73.30	263.9	43,308	1183
Kerosene	2.52	3.156	71.40	257.0	44,196	1250

Step 3 – CO_2/kt. The third and final step was to calculate CO_2 per kilotonne. This was done by multiplying the TJ of diesel by 73.30 and dividing the result by 1000 (10^3):

$$CO_2/kt = \frac{\text{TJ of diesel} \times 73.30}{(10^3)} \qquad (2.3)$$

When the calculations of the CO_2 emissions were completed, the same procedure was then used to calculate the emissions of BC, CH_4, CO, N_2O, NH_3, NMVOCs, NO_X, $PM_{2.5}$, PM_{10} and TSPs. These calculations were made using the guidance from the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019*. Methodologies for the estimation of combustion and evaporative emissions for selected NRMM sources listed in section 1.A.4, "Non-road mobile machinery", of the guidebook were followed (EEA, 2019, p. 3). The methodology for calculating emissions in the EMEP/EEA guidebook is separated into three tiers depending on the level of information available. Tier 1 requires the fewest data and emissions are estimated using a single average emission factor per pollutant, making this the least accurate tier. The calculations are based on fuel use alone.

For tier 2, fuel type and layers of engine technology are required, and the emission factors are separated into more detailed classification for the purposes of estimating emissions.

For tier 3, a substantial amount of information is required, and consequently much more accurate determinations of pollutant emissions are produced using this tier (EEA, 2019, p. 20). However, the number of data made available by data holders in this survey allowed for tier 1 calculations only. When calculating emissions using the tier 1 approach, emissions are estimated using the total fuel consumed in each of the source categories.

The following equation was used to calculate emissions for each NRMM category:

$$E_{pollutant} = \Sigma_{\text{fuel type}} FC_{\text{fuel type}} \times EF_{\text{pollutant fuel type}} \qquad (2.4)$$

where $E_{pollutant}$ is the emissions of the specific pollutant, $FC_{\text{fuel type}}$ is the fuel consumption for each fuel and $EF_{pollutant}$ is the emission factor for this pollutant for each fuel type (EEA, 2019, p. 21).

Table 2.2 shows the emission factors used for pollutant emission calculations for the data received using the bottom-up approach for collecting data (EEA, 2019, pp. 22 and 23).

The emissions for the pollutants listed in Table 2.2 were calculated according to the following formula, using the fuel consumption reported by the data holders and the emission factors in Table 2.2:

$$\text{g/tonne of fuel} = \frac{\text{Tonnes of diesel} \times EF}{(10^6)} \qquad (2.5)$$

Calculations for each pollutant were made for each reported NRMM and then summed to obtain a total for each sector.

The emergence of the COVID-19 pandemic during the data collection phase of the research project affected both the data collection process and the number and quality of the data received.

The implementation of remote working across various sectors limited access to data sets. Often the respondent was working remotely and was physically separated from either the correct data holder or the actual data files. This resulted in more communication attempts than would have been necessary under normal circumstances. There is also the possibility that all relevant information about the request did not reach the data holder or that the data holder was not able to physically access the data because travel restrictions were in place. It is recommended that, in the future, when planning data collection, arrangements be made to talk to data holders in person, to provide the opportunity to explain to the NRMM holder in more detail what data are requested.

Table 2.2. Emission factors for tier 1 calculations

NFR sector	Pollutant	Unit	Emission factor
1.A.4.c.ii-Agriculture	BC	g/tonnes of fuel	1111
	CH_4	g/tonnes of fuel	87
	CO	g/tonnes of fuel	11469
	CO_2	kg/tonnes of fuel	3160
	N_2O	g/tonnes of fuel	136
	NH_3	g/tonnes of fuel	8
	NMVOC	g/tonnes of fuel	3542
	NO_x	g/tonnes of fuel	34457
	PM_{10}	g/tonnes of fuel	1913
	$PM_{2.5}$	g/tonnes of fuel	1913
	TSP	g/tonnes of fuel	1913
1.A.4.c.ii-Forestry	BC	g/tonnes of fuel	626
	CH_4	g/tonnes of fuel	49
	CO	g/tonnes of fuel	7673
	CO_2	kg/tonnes of fuel	3160
	N_2O	g/tonnes of fuel	138
	NH_3	g/tonnes of fuel	8
	NMVOC	g/tonnes of fuel	1997
	NO_x	g/tonnes of fuel	28471
	PM_{10}	g/tonnes of fuel	943
	$PM_{2.5}$	g/tonnes of fuel	943
	TSP	g/tonnes of fuel	943
1.A.2.g.vii-Manufacturing and Construction and 1.A.4.a.ii-Commercial and Institutional	BC	g/tonnes of fuel	1306
	CH_4	g/tonnes of fuel	83
	CO	g/tonnes of fuel	10774
	CO_2	kg/tonnes of fuel	3160
	N_2O	g/tonnes of fuel	135
	NH_3	g/tonnes of fuel	8
	NMVOC	g/tonnes of fuel	3377
	NO_x	g/tonnes of fuel	32629
	PM_{10}	g/tonnes of fuel	2104
	$PM_{2.5}$	g/tonnes of fuel	2104
	TSP	g/tonnes of fuel	2104

3 Results and Discussion

Data were collected from numerous sources, including directly from NRMM users themselves. National-level data on fuels, along with surrogate data from other sources, were also acquired where data collection proved difficult. The Sustainable Energy Authority of Ireland (SEAI) compiles an official record of how energy is used in Ireland each year in the National Energy Balance (SEAI, 2020). It shows how different fuels are used in different sectors of society. However, NRMM is not included as a separate category in the sectors listed. The addition of this category would be of benefit to the accuracy of emissions calculated for this sector.

The collection of data for this report also included data from the CSO on economic activity, e.g. on gross value added (GVA). Initial information presented here looked at information on the national picture in terms of fuel use from NORA, and individual industrial sectors were subsequently examined in detail where possible.

3.1 National Oil Reserves Agency

In 1995, NORA, a stand-alone non-commercial state body under the aegis of the Minister for Communications, Energy and Natural Resources, was set up under the European Communities (Minimum Stocks of Petroleum Oils) Regulations 1995. The role of the company is the maintenance of Ireland's strategic oil reserves. In 2007 the National Oil Reserves Agency Act 2007 and the National Oil Reserves Agency Act 2007 (Returns and Levy) Regulations 2007 were introduced by the Minister for Communications, Energy and Natural Resources. These regulations dictate the information to be provided to the Minister by NORA, oil companies and oil consumers in monthly statistical returns. They also lay out the variation in the NORA levy to be paid and procedures for the invoicing and payment of this levy. In the "Statistics" section of NORA's website (www.nora.ie), the volume of oil consumption subject to NORA levy month by month from 2008 onwards can be found.

Byrne Ó Cléirigh Consulting is a company that was contracted by NORA to assist the agency with gathering and collating data on gas oil consumption in NRMM for administering compliance with S.I. 160 of 2017. This S.I. concerns the EU (Greenhouse Gas Emission Reductions, Calculation Methods and Reporting Requirements) Regulations 2017 (see section 1.5.2). It requires suppliers of transport fuels, including gas oil consumed in NRMM, to reduce the life cycle carbon intensity of the fuels they supply by 6% by 2020. S.I. 160 was recently amended by S.I. 670/2020 – EU (Greenhouse Gas Emission Reduction Methods and Reporting Requirements) (Amendment) Regulations 2020 – to ensure that the 6% requirement continues beyond 2020.

NORA, through the Department of the Environment, Climate and Communications, gathers monthly data on gas oil supplied to the transport and non-transport markets. Designated fuel suppliers are required to report the gas oil that they supply to the market to NORA. These suppliers are further required to report an 80:20 split in the gas oil they supply to the market, meaning that 80% of it is designated for NRMM activities and 20% for non-NRMM activities, e.g. boilers and generators (Byrne Ó Cléirigh Consulting, 2 December 2020, personal communication).

In 2020 the total amount of 10 ppm gas oil reported to NORA by suppliers was approximately 884 million litres. Based on the 80:20 split mentioned above, the 10 ppm gas oil used by NRMM was approximately 711 million litres (S. Malone, 3 February 2021, personal communication). Following this methodology of division, calculations of 80% of the total reported 10 ppm gas oil use, i.e. the part pertaining to NRMM, were made on the data available for the years 2012–2020, and the resulting quantities can be found in Table 3.1.

Emissions for the most relevant pollutants emitted by NRMM (CO_2, BC, CH_4, CO, N_2O, NH_3, NMVOC, NO_x, PM_{10}, $PM_{2.5}$ and TSP) were calculated by the tier 1 methodology outlined in section 2.3, based on the fuel use for each year (from Table 3.1). Following this, emissions of the same pollutants were calculated for the total fuel use data received for this project from data holders using the bottom-up approach, using 2019 as the base year. The emissions were calculated

Table 3.1. Reported 10 ppm gas oil use attributed to NRMM for the years 2012–2020

Year	Total litres of 10 ppm gas oil use	80% of total litres of 10 ppm gas oil (NRMM use)
2012	385,518,519	308,414,815
2013	447,508,286	358,006,629
2014	451,151,336	360,921,069
2015	509,312,262	407,449,810
2016	694,855,683	555,884,546
2017	741,805,511	593,444,409
2018	842,825,812	674,260,650
2019	847,308,723	677,846,978
2020	888,454,006	710,763,205

using the same method and the same emission factors as for the calculations based on the NORA data and were then added together for each pollutant. The resulting figures were then compared with the results of the calculations on NORA data for that same year, i.e. 2019. The results indicate that the data available from NORA are not sufficient to generate accurate calculations of emissions for NRMM. A large difference was expected between emissions calculated using the NORA data and emissions calculated using the data from the survey responses collated during this study because of the known large deficit in the information received from the data holders. However, the gap between the emissions from the two sets of calculations is not large enough to account for the large deficit in the information on NRMM fuel use received for this project (Table 3.2). This deficit in received information relating to fuel use by NRMM is mainly from the large construction, mining and quarrying industries, which either did not respond to attempted communications or did not share data. Our recommendation would be to either introduce national regulations making it mandatory to respond to surveys such as this or to establish strong relationships with these industries to ensure more detailed data collection in the future, which in turn would improve the completeness of the inventory.

3.2 Aviation Industry

DAA (previously the Dublin Airport Authority) and regional airports were contacted and data on airport ground operation vehicles and machinery were requested. Statistics on landing and take-off (LTO) in 2019 for each regional airport in Ireland were received from the EPA, and, based on this information, the percentage of LTOs per airport was calculated. Data pertaining to fuel use by ground operation vehicles in airports were received from data holders in airports, representing over 90% of the total LTOs in 2019, and the percentage of fuel use for the remaining airports was extrapolated based on this figure.

Emissions of the most common pollutants were calculated per airport based on the fuel use information received from data holders (Table 3.3). As nearly 80% of all LTOs in 2019 took place at Dublin Airport, the calculations showed that this airport was the largest emitter of pollutants.

The emissions calculated are currently not representative of all NRMM activity at airports, as only information from ground operations related to airport activities involving NRMM owned by the airport was reported. Despite several communication attempts, no data were forthcoming from airline companies regarding their ground operation NRMM activities. Hence, the calculations are based only on airport ground movements associated with the airports' machines, not on those associated with airlines. These emissions can therefore be taken only as an

Table 3.2. Comparison of total NRMM pollutant emissions based on survey reported data with those based on NORA data (2019)

Data set	Pollutant and unit										
	BC (t)	CH_4 (t)	CO (t)	N_2O (t)	NH_3 (t)	NMVOC (t)	NO_x (t)	PM_{10} (t)	$PM_{2.5}$ (t)	TSPs (t)	CO_2 (t)
NORA data	748.32	47.56	6173.39	77.35	4.58	1934.99	18696.09	1205.57	1205.57	1205.57	1810647.89
Reported data	572.72	44.02	5795.73	69.04	4.06	1792.04	17423.64	979.92	979.92	979.92	1605108.69
Difference	175.61	3.54	377.67	8.32	0.52	142.94	1272.45	225.65	225.65	225.65	205539.19
Difference (%)	23.47	7.44	6.12	10.75	11.35	7.39	6.81	18.72	18.72	18.72	11.35

Table 3.3. Total pollutants emissions for ground equipment in airports (excluding those owned by airlines)

Pollutant	Emissions (t)
BC	0.14
CH_4	0.01
CO	1.14
N_2O	0.01
NH_3	0.00
NMVOC	0.36
NO_x	3.46
PM_{10}	0.22
$PM_{2.5}$	0.22
TSP	0.22
CO_2	335.45

indication of the trend and not as a complete overview of the total pollutants emitted by airport ground equipment in 2019. In order to collect the complete information required, it should be mandatory for all NRMM proprietors, be they airport authorities, airlines or other ground machinery handlers, to commit to annual reporting of the details of their NRMM, as suggested in Chapter 2, so that an up-to-date inventory of their NRMM fleet is available at all times.

3.3 Shipping Industry (Ports)

Information on the total tonnage of goods handled by all ports and classified by region of trade for 2019 was received from the CSO. According to this, there are 21 commercially active ports in Ireland, with the largest in terms of volume handled being Dublin, Shannon Foynes and Cork. A calculation to obtain the percentage of tonnage handled by each port was made based on the total figure handled in Ireland compared with the figures handled by each port. In the data collection phase of the project, information on the fuel use by NRMM in ports, representing 49.46% of import and export tonnages, was received from data holders (Dublin). Based on an extrapolation from that figure, emissions of the main pollutants were calculated for each port in operation in Ireland, using the emission factors from Table 3.1 in the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (EEA, 2019). The total emissions calculated for NRMM in ports for 2019 are listed in Table 3.4 and shown as a graph in Figure 3.1.

Table 3.4. Pollutant emissions for NRMM in ports in 2019

Pollutant	Emissions (t)
BC	3.93
CH_4	0.25
CO	32.43
N_2O	0.41
NH_3	0.02
NMVOC	10.17
NO_x	98.22
PM_{10}	6.33
$PM_{2.5}$	6.33
TSP	6.33
CO_2	9555.82

3.4 Local Authorities

All 31 local authorities in Ireland were contacted to request information about their NRMM fleet, but only four of the authorities provided usable fuel data. To acquire more information about NRMM use and fuel consumption by local authorities, information about the fuels used was requested and received from the SEAI. The data included the fuel type or category reported by the local authorities themselves, which enabled the identification of which part of the total fuel used was related to NRMM. As local authorities are already required to report details of fuel use to the SEAI using the public sector energy monitoring and reporting system, an additional requirement to report the type and amount of fuel used by NRMM owned by them should be added to the existing reporting requirements.

When the figures from the SEAI report were compared with the figures gathered from the local authorities themselves using the bottom-up approach, significant differences emerged in the fuel use reported. The differences can be partially explained by the facts that data were not received from all local authorities during the bottom-up approach data collection phase and that the SEAI does not have a separate section for NRMM in its report.

In order to collect more extensive data, further information was obtained from the CSO. Information extracted from the 2016 population census contained both the population and the geographical area of each local authority. Of the four local authorities that provided information on fuel use, two were based in

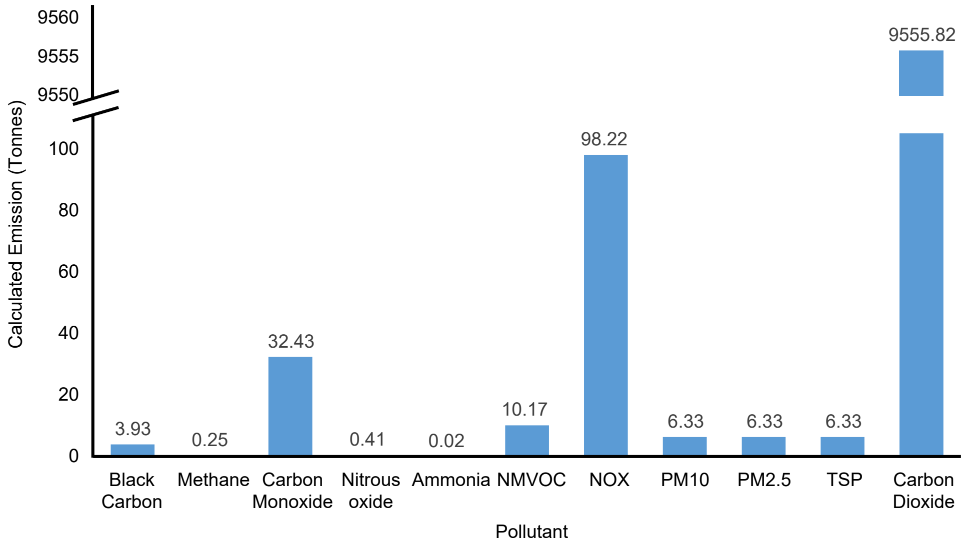

Figure 3.1. Total calculated pollutant emissions for NRMM in all ports in 2019.

a primarily rural setting and two in a primarily urban setting. These fuel data were used in an extrapolation calculation to cover all local authorities. As both the population size and the geographical area vary significantly between local authorities, two versions of these calculations were deemed appropriate: one based on the population of each local authority and one based on the total area covered by each local authority.

When using the population as the basis for the calculations, the fuel use reported by the four local authorities was added together and the resulting value was divided by the total population of the same four local authorities, giving an average fuel use per person. This average fuel use was then multiplied by the population of each local authority, resulting in an average fuel use for each local authority. Emissions of each pollutant based on this fuel use were subsequently calculated for each local authority using the methodology from the EMEP/EEA guidebook (Figure 3.2).

Similar calculations were made using the geographical area of each local authority as the basis. The reported sizes of local authorities were added together to

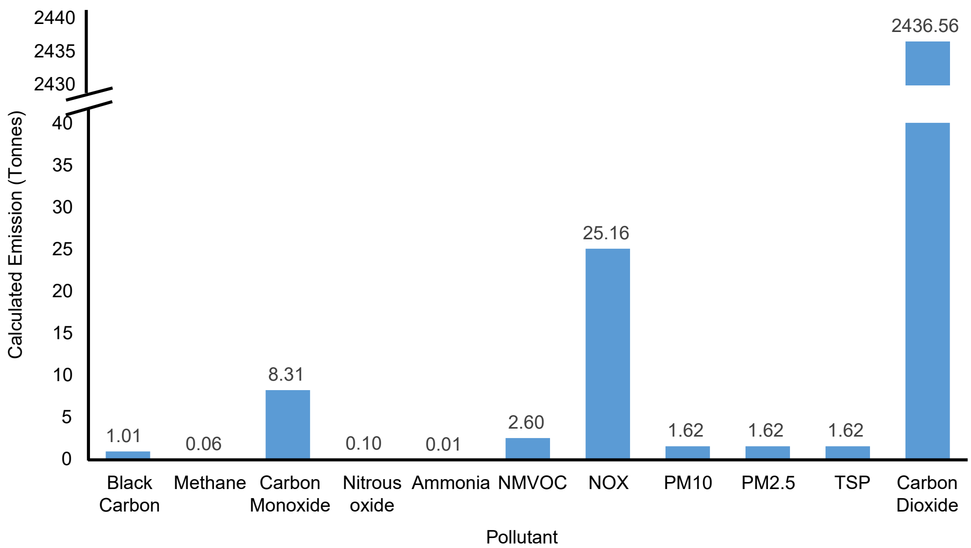

Figure 3.2. Pollutant emission calculations for all local authorities based on size of population. Emissions are from local authorities' NRMM fleets.

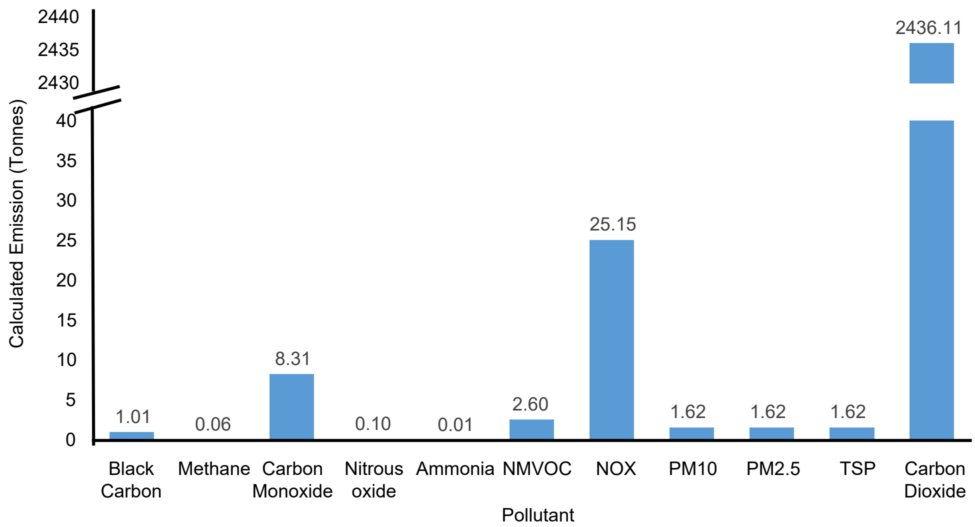

Figure 3.3. Pollutant emission calculations for all local authorities based on geographical area. Emissions are from local authorities' NRMM fleets.

calculate the total geographical area of Ireland (in km^2). The percentage of the geographical area of Ireland accounted for by each local authority was also calculated. The percentage of total fuel use was then calculated for each local authority by multiplying the percentage area by total estimated fuel use (as before) and dividing by 100 (Figure 3.3). The results obtained using both these methodologies were graphically analysed and some significant differences became evident (Figure 3.4). For example, as Dublin is a densely populated but relatively small geographical area, using the population as the basis for calculations produced significantly higher estimates than if the geographical area was used; the reverse applied to Mayo, as this local authority covers a relatively large geographical area with a sparse population. A hybrid of these two calculation methods would be most likely to give a more accurate estimate in future estimations, but a requirement for each local authority to keep up-to-date records on its NRMM fleet would give the most accurate basis for calculating the pollutant emissions of these machines.

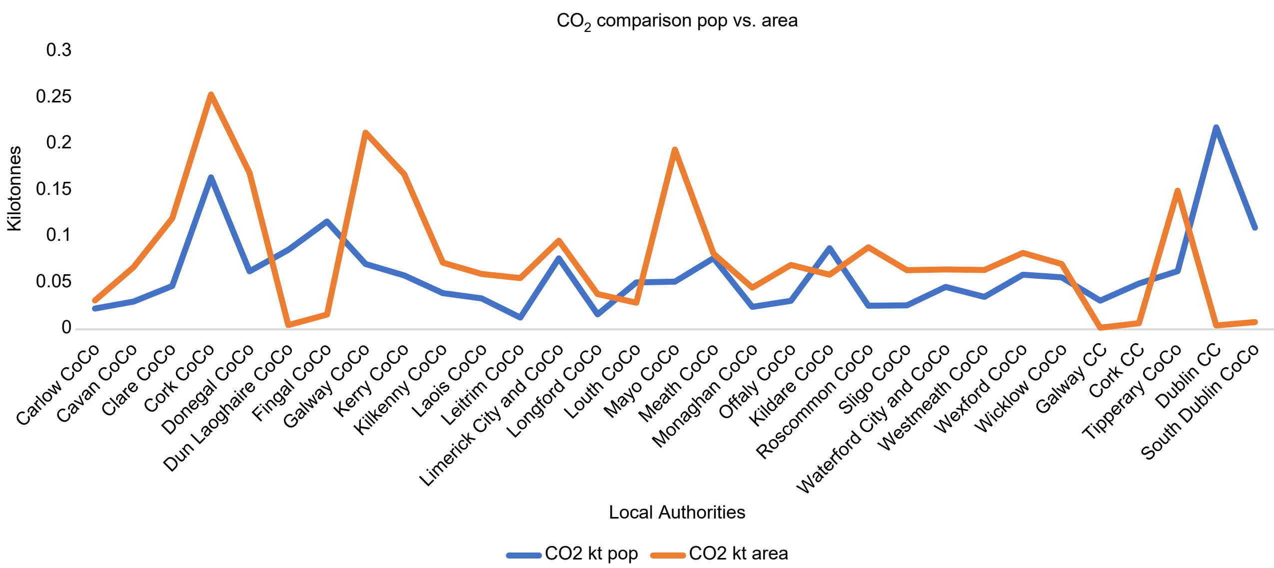

Figure 3.4. Comparison between CO_2 emission calculations based on population and area. Emissions are from local authorities' NRMM fleets. CC, City Council; CoCo, County Council.

3.5 Agriculture and Forestry

Limited data were received from Teagasc and Coillte, but the main source of information was an agricultural and forestry organisation that represents *c*.70% of total agricultural consumption in Ireland. The data received from the organisation are based on actual machine use by farm and forestry contractors in Ireland. The figures are derived from a combination of the number of machine types in contractor fleets, the average hours worked per season, and machine fuel tank capacities together with the fuel used. These data were based on extensive surveys conducted by the organisation itself. There are between 350 and 400 forestry harvesting machines with a tank capacity of *c*.300 litres, sufficient for 1 day of work, working in Ireland. If calculations are based on the higher number of machines working 150 days each year, that equates to 15.75 million litres of diesel annually. There are also between 450 and 500 forwarder machines with a fuel capacity of 200 litres, enough for 1 day of work, working in Ireland. These machines will work in tandem with the harvesters, and basing calculations on the higher number of machines working for 150 days each year equates to an additional 13.5 million litres of gas oil used annually. This gives a total consumption for the forestry contractor sector of over 29.25 million litres for harvesting activities. The other significant NRMM activities in forestry are related to planting and road construction. These duties are normally carried out by approximately 400 hydraulic excavators, each with an average fuel tank capacity of 250 litres. Basing calculations on 150 days of work in forestry annually, this will equate to a further 15 million litres of gas oil being used.

In total, the gas oil consumption in the forestry machinery contractor sector has been estimated to be in the region of 45 million litres annually (Michael Moroney, Chair of The Association of Farm & Forestry Contractors in Ireland, FCI Ireland, 12 August 2020, personal communication). The figures mentioned above represent about 50% of the contractors that operate on a professional level in Ireland. Estimating fuel use per machine comes with its own challenges, however, as almost 100% of the fuel is bought in bulk delivery form; it is mostly delivered directly to the farm contractor's yard for storage, with tractors being filled daily or as the need arises. The total fuel use for pit silage systems, baled silage systems, slurry spreading systems and other agricultural activities, such as hedge cutting, fertiliser and lime spreading, sowing and combine harvesting, was received from the association, as was the fuel consumption for forestry activities.

The total fuel consumption for the Irish agricultural contracting sector in 2019 was 340 million litres, and for the forest machinery contractor sector it was 44.25 million litres. Added together, these two sectors accounted for just under 70% (69.86%) of the total agriculture and forestry sector gas oil consumption in 2019, i.e. 550 million litres (Government of Ireland, 2019). Using these figures, pollutant emissions were calculated for each category. The results are shown in Table 3.5. The first row shows the emissions for the contractors in the forestry sector; the second row shows the emissions for the contractors in the agriculture sector; the third row shows these two combined, i.e. the total for the contractors in forestry and agriculture, amounting to 70% of total emissions; and the fourth row shows the emissions for the total agriculture and forestry sector, i.e. 100%, in Ireland. Emissions of total agricultural and forestry NRMM are based on fuel usage data received from the industry representative.

Table 3.5. Pollutant emissions from forestry and agriculture contractors' NRMM fleets compared with total agricultural and forestry NRMM emissions, in tonnes

	Pollutant										
NRMM users	BC	CH_4	CO	N_2O	NH_3	NMVOC	NO_x	PM_{10}	$PM_{2.5}$	TSP	CO_2
Forestry contractors	23.42	1.83	287.01	5.16	0.30	74.70	1064.95	35.27	35.27	35.27	118,199.49
Agricultural contractors	319.31	25.00	3296.25	39.09	2.30	1017.99	9903.11	549.81	549.81	549.81	908,199.49
Combined contractors	342.72	26.84	3583.25	44.25	2.60	1092.69	10,968.07	585.08	585.08	585.08	1,026,398.99
Total agriculture and forestry sector	516.53	40.45	5332.16	63.23	3.72	1646.75	16,019.74	889.39	889.39	889.39	1,469,146.24

3.6 Irish Rail

Trains are also defined as NRMM. In 2020 rail consumed *c*.36 million litres of diesel (Peter Smyth, Chief Mechanical Engineer, Irish Rail, 3 February 2021, personal communication). Irish Rail provided detailed information about its train fleet. This included type of rail fleet; type of fuel consumed by that fleet; type of NRMM, vehicle quantity and vehicle age in years within that fleet; quantity, power (kW) and NRMM type within the traction engine category; and quantity, power (kW) and NRMM type within the generator engine category. These data were, however, not complete, so some data necessary for calculating emissions of a higher tier are still missing. Some fuel consumption data were missing and there were some gaps in the information reported on quality, power and NRMM type within both the traction engine and the generator engine categories. Information on annual working hours and equipment technology, i.e. what stage the engine belongs to, was also missing.

Based on this information, pollutant emissions for each pollutant were calculated using the tier 1 methodology (Table 3.6 and Figure 3.5).

Table 3.6. Yearly emissions by the Irish Rail fleet

Pollutant	Emissions (t)
BC	45.67
CH_4	2.90
CO	376.76
N_2O	4.72
NH_3	0.28
NMVOC	118.09
NO_x	1141.03
PM_{10}	73.58
$PM_{2.5}$	73.58
TSP	73.58
CO_2	110,504.37

3.7 Construction Industry

Attempts were made to contact the top 40 construction companies directly, both by phone and by email, but few replies were received. One large construction company, however, was very interested in this research project and provided very detailed information about its own NRMM and some information pertaining to one of its subcontractors. Furthermore, the company was very interested in incorporating methods on how to monitor NRMM pollutant emissions into one of its recently started projects. However, the information currently provided by this company is not sufficient to allow an extrapolation calculation for the whole industry. A large association in the construction industry was also approached to see if it could assist with information either on NRMM directly or on how to best collect the information. However, no information was forthcoming, as it shares information only with its own members.

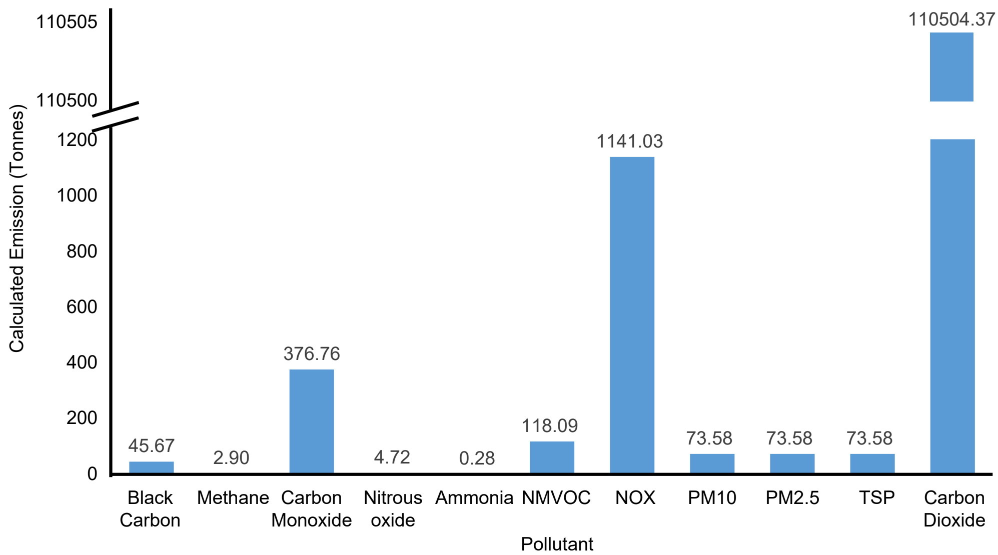

Figure 3.5. Pollutants emissions by the Irish Rail diesel fleet in 2019.

As this is an industry that uses a large amount of NRMM of various types, both directly when used by construction companies and indirectly when used by contractors, some regulation of the registration of data for NRMM owned by companies and contractors is recommended. The emissions from NRMM in this sector are likely to form a significant part of the total NRMM pollutant emissions in Ireland. As almost no information was forthcoming from this large sector in the bottom-up data collection approach for this project, there remains a large deficit in the total emissions calculated.

3.8 Mining and Quarrying

Data received from the mining and quarrying sector were insufficient to base any calculations on. One quarry provided detailed information on its fuel use in 2019 and emissions were calculated based on that. One of the largest mines also provided partial information, but it was not enough to allow an extrapolation calculation for the whole industry. As this too is a large sector, and because of the lack of data forthcoming, there remains a large deficit in the total emissions calculated.

3.9 Gross Value Added

Because of the lack of data forthcoming in a number of sectors, GVA data were used as a surrogate. GVA is a measure of the value of goods and services produced in an area, industry or sector of an economy. GVA information was provided by the CSO for the agriculture, manufacturing and construction sectors. These data sets can be used as indicators of fuel consumption by NRMM for these sectors. Using methodologies from the EMEP/EEA guidebook, the following calculations were carried out.

For manufacturing and construction, the following formula was determined based on a linear relationship:

$$F_{\text{liquid}} = 0.49 \times \text{GVA} \qquad (3.1)$$

where F_{liquid} represents the amount of liquid fuel used by NRMM in manufacturing and construction. The resulting value is given in terajoules.

For agriculture the formula changes to:

$$F_{\text{liquid}} = 3.4 \times \text{GVA} \qquad (3.2)$$

where F_{liquid} represents the amount of liquid fuel used by NRMM in agriculture. The resulting value is given in terajoules.

GVA data pertaining to the years 1995–2020 for the construction, agriculture, and mining and quarrying industries were provided by the CSO. When calculated pollutant emissions for agriculture and forestry based on the GVA data were compared with the emissions calculated from the reported data, it emerged that the emissions calculated from the reported data were almost double those calculated from the GVA data for each pollutant, as shown in Table 3.7. This shows that using proxy data rather than actual use data can lead to discrepancies in estimating the emissions associated with that sector.

3.10 Total Reported Fuel Use by Sector

During the data collection part of the project it emerged that there was some confusion surrounding the type of fuel used by NRMM. Some data holders used “diesel” and “gas oil” interchangeably and could not tell the difference or did not know which type was used. This highlights the importance of making sure that the type and amount of each fuel is correctly reported. Knowing the correct type of fuel is imperative for using the

Table 3.7. Comparison of pollutant emissions calculated from reported data and GVA data, in tonnes

	Pollutant										
Data sets	BC	CH_4	CO	N_2O	NH_3	NMVOC	NO_x	PM_{10}	$PM_{2.5}$	TSP	CO_2 (kt)
Reported data	516.53	40.45	5332.16	63.23	3.72	1646.75	16,019.74	889.39	889.39	889.39	1469.15
GVA	274.27	21.48	2831.30	33.57	1.97	874.40	8506.25	472.25	472.25	472.25	783.67
Difference	242.26	18.97	2500.86	29.66	1.74	772.35	7513.49	417.14	417.14	417.14	685.48

correct pollutant emission calculation and the correct emission factors. Listing the type of fuel the NRMM uses on the paperwork accompanying its sale would make it easier for the purchaser to add the correct fuel to its records and hence make it easier to fulfil future reporting requirements.

The total fuel use reported per sector is shown in Table 3.8. However, a large number of data holders that provided this project with other information about their NRMM fleet omitted to include any information on fuel use.

Table 3.8. Fuel use per sector, in litres

Sector	Diesel	Gas oil	Petrol
Airports	124,614	29,154	469
Ports		1,761,306	
Construction		36,334	
Local authorities	81,427	173,055	4380
Mining and quarrying		3,803,124	
Agriculture and forestry		550,000,000	
Railways	41,369,198		
Miscellaneous		6580	

4 Conclusion and Recommendations

Table 4.1 outlines the emissions attributable to NRMM for the year 2019 as calculated during our research. However, it must be stated that there are large gaps in the data made available for the project, mainly from the large construction and mining and quarrying sectors. This means that the emission calculations are indicative rather than fully accurate.

TSP and PM_{10} are assumed to be equal to the $PM_{2.5}$ value because the PM produced during the combustion process is almost entirely composed of the smaller fraction (i.e. $PM_{2.5}$).

The total calculated emissions broken down per sector, based on information made available for this project, are shown in Table 4.2.

These calculations were completed using the data received through the bottom-up collection survey, using a methodology based on the *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019* (EEA, 2019). While every effort was made by the researchers to collect data across the aviation, ports, construction, local authorities, mining and quarrying, agriculture and forestry, and railroads sectors, the figures calculated in Table 4.2 are underestimations of the total emissions associated with NRMM because of the lack of data made available to the project. It was found that using proxy data, such as GVA from the CSO and NORA fuel use statistics, as the basis for calculations underestimated emissions when compared with calculations using actual use data. This shows that accurate determination of emissions depends on the availability of sufficient and detailed data. With more detailed data available, a higher tier methodology can be used for calculating the emissions and the overall quality of the emission inventory can be improved.

Table 4.1. Emissions calculated for 2019 based on the fuel information made available for this project through the bottom-up approach

Pollutant	Emissions
CO_2	1605.1 kt
BC	572.7 t
CH_4	44.0 t
CO	5795.7 t
N_2O	69.0 t
NH_3	4.1 t
NMVOC	1792.0 t
NO_x	17,423.6 t
PM_{10}	979.9 t
$PM_{2.5}$	979.9 t
TSP	979.9 t

While it is encouraging that more attention is being given to the wide-ranging category of NRMM in terms of acknowledging its large contribution to total pollutant emissions, it is clear that it is a difficult category to collect activity data for. Because the machinery is so varied, ranging from large construction machinery to small handheld gardening equipment, it is very difficult to devise a universal solution. What has become very clear from this research is that there is a need to devise a methodology for registering and recording the number, machine age, fuel use and other relevant data for all the different machines in this category. During the data collection phase of the project it quite often emerged that it was not evident to the contact what these machines are, who is in charge of them and where relevant information, such as the manufacturer, type approval number, engine power, annual operating hours or even the age of the machine, can be found. In addition, a certain reluctance to disclose this information was detected in some respondents. This attitude was most noticeable within larger industrial sectors, such as the construction and mining and quarrying industries. It was often stated that this is commercially sensitive information and hence cannot be shared.

As NRMM continues to contribute to overall emissions in greater relative quantities, its accurate quantification becomes ever more important. This transparency in what data and what method are used when compiling the emission inventories is of utmost importance for the users of the inventory.

Numerous studies have highlighted the difficulties in calculating the emissions from these machines and their cumulative effects, due to the large variety of different machines and vehicles and the difficulty in measuring their in-use emissions. Of the three

Table 4.2. Total calculated NRMM pollutant emissions for 2019 broken down per sector (based on fuel information made available for this project), in tonnes

	Pollutant										
Sector	BC	CH_4	CO	N_2O	NH_3	NMVOC	NOx	PM_{10}	$PM_{2.5}$	TSP	CO_2
Airports	0.14	0.01	1.14	0.01	0.00	0.36	3.46	0.22	0.22	0.22	335.45
Ports	3.93	0.25	32.43	0.41	0.02	10.17	98.22	6.33	6.33	6.33	9512.25
Local authority/area	1.01	0.06	8.31	0.10	0.01	2.60	25.15	1.62	1.62	1.62	2436.11
Construction (response received from one company)	0.04	0.00	0.33	0.00	0.00	0.10	1.00	0.06	0.06	0.06	97.06
Mining and quarrying	5.40	0.34	44.53	0.56	0.03	13.96	134.85	8.70	8.70	8.70	13,059.65
Agriculture and forestry	516.53	40.45	5332.16	63.23	3.72	1646.75	16,019.74	889.39	889.39	889.39	1,469,146.24
Miscellaneous	0.01	0.00	0.06	0.00	0.00	0.02	0.18	0.01	0.01	0.01	17.58
Irish Rail	45.67	2.90	376.76	4.72	0.28	118.09	1141.03	73.58	73.58	73.58	110,504.37
Total	572.72	44.02	5795.73	69.04	4.06	1792.04	17,423.64	979.92	979.92	979.92	1,605,108.69

existing methods of compiling emission inventories (bottom-up emissions, top-down emissions and actual measurement of data), actual measurement of data is the most accurate, but this method is usually available only for large point sources. Therefore, a full and comprehensive understanding of the numbers and types of NRMM in existence and the impact these machines have on total emissions does not generally yet exist. Underestimation of some pollutants happens because the fuel use and emissions of these machines are sometimes reported under stationary machinery, as the emissions of air pollutants tend to be higher for mobile machinery than for stationary plant.

As the accuracy of air quality modelling studies is reliant on the accuracy of the emissions inventory used as input, clarity or indeed uniformity in how the NRMM inventory has been developed would allow the user to make an informed decision on whether or not the method, and consequently the emissions inventory, is suitable for their needs at the time. Such detail would also facilitate improved estimations of uncertainties in both emissions and resulting air quality, which are important when communicating information regarding public health.

The level of detail in the data available and, as a consequence, the country-specific emission inventories vary hugely between different countries. This gives rise to the need to unify the standards of inventory development and regulations in the long term, so that it makes for an easier comparison between emission inventories in different countries.

Various regulations regarding emissions are in force for different countries, and as of 1 January 2017 EU Regulation (EU) 2016/1628 applies in EU countries. This regulation governs emissions from NRMM and establishes emission limits for gaseous and particulate pollutants for engines. It also defines administrative and technical requirements for EU type approval. This type approval is a prerequisite for placing new engines on the EU market and safeguards approved machines from unfair competition from unapproved ones. In these regulations EU emission standards for engines used in new NRMM have been broken down into stages I–V and the stages have been implemented incrementally. Although there is some overlap between the EU and the USA, 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 in accordance with the EMEP/EEA guidebook, which was published in its original form in 1996 to give information about how to estimate emissions from both anthropogenic (including NRMM) and natural emission sources in accordance with EU regulatory requirements. This guidebook has been updated and made more relevant many times since then, with the latest update being undertaken in 2019.

According to the latest EU emission inventory report, for 1990–2018 (EEA, 2020b), there is a downward trend in emissions of the main air pollutants. While this is good news, further research on NRMM is still needed to fully comprehend the role that emissions from this complex group of machines and vehicles play in the total worldwide emissions, and to strive to make the emission inventories even more accurate. As some of the data holders were reluctant to share information for fear of sensitive information reaching competitors, the present research has highlighted the potential benefits that could be gained from the establishment of new regulations to assure data holders that the information received will be used only to establish details about the NRMM fleet in Ireland and to compile an accurate pollutant emissions inventory. From our research for this project it emerged that some countries have built up longstanding relationships between industry, research facilities and reporting agencies to establish a way of transferring information between the data holder and the reporting agency. This kind of relationship-building is recommended to facilitate Irish NRMM emission reporting too.

A further recommendation to resolve some of the other issues would be a mandatory registration form to be filled in at the time of purchase of each machine and for each company to have a file that includes all these relevant data for each NRMM in its fleet, which would be updated every time a new NRMM was acquired. This would, of course, be easier for some sectors in the NRMM category than for others. For large industrial machinery providers and resellers, for example, it would be relatively easy to keep a file for each machine. This file would include the following information about each machine in stock: manufacturer, EU approval number, type of machine, age of machine, type of fuel used, engine size and power output (kW). This file would be updated with each new machine arriving in stock. When a machine was sold, this recorded information would be added to the other documentation involved in completing the sale. When the transaction was completed, the new owner of the machine would then be required to add information on the amount of fuel bought (yearly/monthly/etc., depending on type and use), where the fuel is bought from and the operating hours of the machine (annual/monthly/etc., depending on frequency of use) to the existing file. Alternatively, data-sharing agreements could be set up between the EPA and the main data holders. Looking at other options, another recommendation would be to make it mandatory to report the type and amount of fuel used in NRMM in the already mandatory public service reporting to the SEAI. Another option would be for the authority carrying out the business energy use survey to add a question asking what portion of the fuel is used for NRMM.

Some difficulties with this type of documentation may arise when it comes to small and infrequently used machines, in particular those used in private households and gardening. These machines are often filled from bulk tanks, which makes it difficult to specify the amount of fuel used and hours of usage for each machine. However, registration forms for such NRMM could be adapted to better suit the intended use. Keeping a record of each machine as it enters the market, whether by way of import or local manufacture, and ensuring that this record travels with the machine as it changes owner is the first step recommended in starting to compile an accurate inventory of the NRMM fleet in Ireland.

With the increasing focus on air quality and pollutant emissions, it is imperative that we have a full understanding of all pollutant sources. As greater understanding of larger sources, e.g. home heating and transport, has been the focus to date, it is now time that other areas contributing to pollutant emissions are investigated in greater detail. The concern about greenhouse gas and air pollutant emissions from NRMM has risen considerably in recent decades. As mitigation efforts for on-road vehicle emissions improve, it is thought that non-road mobile machines will eventually surpass on-road vehicles as the leading source of mobile pollution.

References

Abolhasani, S., Frey, H.C., Kim, K., Rasdorf, W., Lewis, P. and Pang, S.H., 2008. Real-world in-use activity, fuel use, and emissions for nonroad construction vehicles: a case study for excavators. *Journal of the Air & Waste Management Association* 58(8): 1033–1046. https://doi.org/10.3155/1047-3289.58.8.1033

Achten, P.A.J., 1990. *The Forgotten Category – Energy Consumption and Air Pollution by Mobile Machinery.* Innas BV, Netherlands.

An, H., Yang, W.M., Maghbouli, A., Li, J., Chou, S.K. and Chua, K.J., 2013. Performance, combustion and emission characteristics of biodiesel derived from waste cooking oils. *Applied Energy* 112: 493–499. https://doi.org/10.1016/j.apenergy.2012.12.044

Athanassiadis, D., 2000. Energy consumption and exhaust emissions in mechanized timber harvesting operations in Sweden. *Science of the Total Environment* 255: 135–143. https://doi.org/10.1016/S0048-9697(00)00463-0

Bak, F., Grouleff, M. and Friis, K., 2003. *Forurening fra traktorer og ikke- vejgående maskiner i Danmark.* Miljøprojekt nr. 779. Miljøstyrelsen, Copenhagen.

Berg, S. and Karjalainen, T., 2003. Comparison of greenhouse gas emissions from forest operations in Finland and Sweden. *Forestry* 76(3): 271–284. https://doi.org/10.1093/forestry/76.3.271

Berg, S. and Lindholm, E.L., 2005. Energy use and environmental impacts of forest operations in Sweden. *Journal of Cleaner Production* 13(1): 33–42. https://doi.org/10.1016/j.jclepro.2003.09.015

Brown P., Cardenas, L., Choudrie, S., Jones, L., Karagianni, E., MacCarthy, J., Passant, N., Richmond, B., Smith, H., Thistlethwaite, G., Thomson, A., Turtle, L. and Wakeling, D., 2020. *UK Greenhouse Gas Inventory, 1990 to 2018 Annual Report for Submission under the Framework Convention on Climate Change*. Available online: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2004231028_ukghgi-90-18_Main_v02-00.pdf (accessed 22 February 2022).

Cadle, S.H., Ayala, A., Black, K.N., Graze, R.R., Koupal, J., Minassian, F., Murray, H.B., Natarajan, M., Tennant, C.J. and Lawson, D.R., 2008. Real-world vehicle emissions: a summary of the Seventeenth Coordinating Research Council on Road Vehicle Emissions Workshop. *Journal of the Air & Waste Management Association* 58(1): 3–11. https://doi.org/10.3155/1047-3289.58.1.3

Cao, T., Durbin, T.D., Russell, R.L., Cocker, D.R., Scora, G., Maldonado, H. and Johnson, K.C., 2016. Evaluations of in-use emission factors from off-road construction equipment. *Atmospheric Environment* 147: 234–245. https://doi.org/10.1016/j.atmosenv.2016.09.042

Cao, T., Russell, R.L., Durbin, T.D., Cocker III, D.R., Burnette, A., Calavita, J., Maldonado, H. and Johnson, K.C., 2018. Characterization of the emissions impacts of hybrid excavators with a portable emissions measurement system (PEMS)-based methodology. *Science of the Total Environment* 635: 112–119. https://doi.org/10.1016/j.scitotenv.2018.04.011

Centre for Low Emissions Construction, 2019. What is non-road mobile machinery? Available online: http://www.clec.uk/advice/what-non-road-mobile-machinery (accessed 22 February 2022).

Christensen, A., Westerholm, R. and Almén, J., 2001. Measurement of regulated and unregulated exhaust emissions from a lawn mower with and without an oxidizing catalyst: a comparison of two different fuels. *Environmental Science & Technology* 35(11): 2166–2170. https://doi.org/10.1021/es0002565

Cui, M., Chen, Y., Feng, Y., Cheng, L., Zheng, J., Tian, C., Yan, C. and Zheng, M., 2017. Measurement of PM and its chemical composition in real-world emissions from non-road and on-road diesel vehicles. *Atmospheric Chemistry and Physics* 17(11): 6779. https://doi.org/10.5194/acp-17-6779-2017

Czechlowski, M., Adamski, M., Wojciechowski, T., Niedbała, G. and Wojdak, E., 2016. Changes in the emission of toxic compounds from farming machinery used in Poland between 2011 and 2013. *Journal of Research and Applications in Agricultural Engineering* 61(3): 57–61.

Dalgaard, T., Halberg, N. and Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture, Ecosystems & Environment* 87(1): 51–65. https://doi.org/10.1016/S0167-8809(00)00297-8

Davidson, E.A., David, M.B., Galloway, J.N., Goodale, C.L., Haeuber, R., Harrison, J.A., Howarth, R.W., Jaynes, D.B., Lowrance, R.R., Thomas, N.B. and Peel, J.L., 2011. *Excess Nitrogen in the US Environment: Trends, Risks, and Solutions*. Issues in Ecology Report Number 15. Ecological Society of America, Washington, DC.

DECC (Department of Communications, Climate Action and the Environment), 2020. *Fuel Standards.* Available online: https://www.dccae.gov.ie/en-ie/environment/topics/air-quality/fuel-standards/Pages/default.aspx (accessed 24 July 2020).

Denby, B., Georgieva, E. and Lükewille, A., 2011. *The Application of Models under the European Union's Air Quality Directive: A Technical Reference Guide*. Technical Report 10/2011. European Environmental Agency, Copenhagen.

Desouza, C.D., Marsh, D.J., Beevers, S.D., Molden, N. and Green, D.C., 2020. Real-world emissions from non-road mobile machinery in London. *Atmospheric Environment* 223: 117301.

Dieselnet.com, 2012. Emission standards. Japan: nonroad engines. Available online: https://dieselnet.com/standards/jp/nonroad.php (accessed 22 February 2022).

Dieselnet.com, 2013. Emission standards. Korea: nonroad diesel engines. Available online: https://dieselnet.com/standards/kr/nonroad.php (accessed 22 February 2022).

Dieselnet.com, 2016. Emission standards. EU: nonroad engines. Available online: https://dieselnet.com/standards/eu/nonroad.php (accessed 17 July 2020).

Dieselnet.com, 2017. Emission standards. United States: nonroad diesel engines. Available online: https://dieselnet.com/standards/us/nonroad.php (accessed 22 February 2022).

Dieselnet.com, 2020. Emission standards. China: nonroad diesel engines. Available online: https://dieselnet.com/standards/cn/nonroad.php#intro (accessed 22 February 2022).

EEA (European Environment Agency), 1996. *EMEP/CORINAIR Air Pollutant Emission Inventory Guidebook – First Edition 1996*. Available online: https://www.eea.europa.eu/publications/emep-corinair-atmospheric-emission-inventory (accessed 22 February 2022).

EEA (European Environment Agency), 2019. *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2019*. EEA Report No. 13/2019. Available online: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019 (accessed 28 March 2022).

EEA (European Environment Agency), 2020a. *Emission Database for Global Atmospheric Research (EDGAR).* Available online: https://www.eea.europa.eu/themes/air/links/data-sources/emission-database-for-global-atmospheric (accessed 22 February 2022).

EEA (European Environment Agency), 2020b. *European Union Emission Inventory Report 1990–2018 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP).* Available online: https://www.eea.europa.eu/publications/european-union-emission-inventory-report-1990-2018 (accessed 22 February 2022).

EEA (European Environment Agency), 2021. *Annual European Union Greenhouse Gas Inventory 1990–2019 and Inventory Report 2021*. Available online: https://www.eea.europa.eu/publications/annual-european-union-greenhouse-gas-inventory-2021 (accessed 22 February 2022).

EGCSA (Exhaust Gas Cleaning Systems Association), 2019. What are the effects of sulphur oxides on human health and ecosystems? Available online: https://www.egcsa.com/technical-reference/what-are-the-effects-of-sulphur-oxides-on-human-health-and-ecosystems/ (accessed 22 February 2022).

EMEP Centre on Emission Inventories and Projections, 2020. Data viewer – reported emissions data. Available online: https://www.ceip.at/data-viewer (accessed 22 February 2022).

Engel, A.M., Wegener, J. and Lange, M., 2012. Greenhouse gas emissions of two mechanised wood harvesting methods in comparison with the use of draft horses for logging. *European Journal of Forest Research* 131(4): 1139–1149. https://doi.org/10.1007/s10342-011-0585-2

Ettl, J., Bernhardt, H., Pickel, P., Remmele, E., Thuneke, K. and Emberger, P., 2018. Transfer of agricultural work operation profiles to a tractor test stand for exhaust emission evaluation. *Biosystems Engineering* 176: 185–197. https://doi.org/10.1016/j.biosystemseng.2018.10.016

EU (European Union), 1985. 85/338/EEC: Council Decision of 27 June 1985 on the adoption of the commission 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. OJ L 176, 6.7.1985, pp. 14–17.

EU (European Union), 1997. Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery. OJ L 059, 27.02.1998, pp. 1–86.

EU (European Union), 2013. Regulation (EU) No 167/2013 of the European Parliament and of the Council of 5 February 2013 on the approval and market surveillance of agricultural and forestry vehicles. OJ L 60, 2.3.2013, pp. 1–51.

EU (European Union), 2016. Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC. OJ L 252, 16.9.2016, pp. 1–65.

EU (European Union), 2020. Regulation (EU) 2020/1040 of the European Parliament and of the Council of 15 July 2020 amending Regulation (EU) 2016/1628 as regards its transitional provisions in order to address the impact of the COVID-19 crisis. OJ L 231, 17.7.2020, pp. 1–3.

European Commission, 2017. *NAIADES II Implementation Group 1st Commission Expert Group meeting on IWT Brussels, 26 June 2017*. Available online: https://ec.europa.eu/transparency/expert-groups-register/screen/meetings/consult?lang=en&meetingId=1555&fromExpertGroups=true (accessed 22 February 2022).

European Commission, 2020. Emissions from non-road mobile machinery. Available online: https://ec.europa.eu/growth/sectors/automotive/environment-protection/non-road-mobile-machinery_en (accessed 22 February 2022).

European Commission, no date. The EU and international air pollution policy. Available online: https://ec.europa.eu/environment/air/policy/index.htm (accessed 14 March 2022).

Eustat, 2020a. NFR nomenclature. Available online: https://en.eustat.eus/documentos/elem_13174/definicion.html#:~:text=Definitions%20NFR%20Nomenclature-,NFR%20Nomenclature,European%20Environment%20Agency%20(EEA) (accessed 22 February 2022).

Eustat, 2020b. SNAP nomenclature. Available online: https://en.eustat.eus/documentos/elem_13173/definicion.html#:~:text=English%20acronym%20of%20Selected%20Nomenclature,for%20activities%20resulting%20in%20emissions (accessed 22 February 2022).

Faber, P., Drewnick, F. and Borrmann, S., 2015. Aerosol particle and trace gas emissions from earthworks, road construction, and asphalt paving in Germany: emission factors and influence on local air quality. *Atmospheric Environment* 122: 662–671.

Frey, H.C., Kim, K., Pang, S.H., Rasdorf, W.J. and Lewis, P., 2008. Characterization of real-world activity, fuel use, and emissions for selected motor graders fueled with petroleum diesel and B20 biodiesel. *Journal of the Air & Waste Management Association* 58(10): 1274–1287. https://doi.org/10.3155/1047-3289.58.10.1274

Fu, M., Ge, Y., Tan, J., Zeng, T. and Liang, B., 2012. Characteristics of typical non-road machinery emissions in China by using portable emission measurement system. *Science of the Total Environment* 437: 255–261. https://doi.org/10.1016/j.scitotenv.2012.07.095

Fuc, P., Lijewski, P., Kurczewski, P., Ziolkowski, A. and Dobrzynski, M., 2017. The analysis of fuel consumption and exhaust emissions from forklifts fueled by diesel fuel and liquefied petroleum gas (LPG) obtained under real driving conditions. *ASME International Mechanical Engineering Congress and Exposition* 58417: V006T08A060. https://doi.org/10.1115/IMECE2017-70158

Gabele, P., 1997. Exhaust emissions from four-stroke lawn mower engines. *Journal of the Air & Waste Management Association* 47(9): 945–952. https://doi.org/10.1080/10473289.1997.10463951

Gas Networks Ireland, no date. Carbon monoxide. Available online: https://www.gasnetworks.ie/home/safety/carbon-monoxide/ (accessed 22 February 2022).

Giannelli, R.A., Fulper, C., Hart, C., Hawkins, D., Hu, J., Warila, J., Kishan, S., Sabisch, M.A., Clark, P.W., Darby, C.L. and Ensfield, C., 2010. In-use emissions from non-road equipment for EPA emissions inventory modeling (MOVES). *SAE International Journal of Commercial Vehicles* 3: 181–194. https://doi.org/10.4271/2010-01-1952

Gietzelt, C., Degrell, O. and Mathies, K., 2012. In-use emission measurements on combustion engines used in mobile machinery. *Landtechnik* 67: 366–369. https://doi.org/10.15150/lt.2012.338

Gis, W., Żółtowski, A. and Taubert, S., 2012. Preliminary evaluation of emissions from off road mobile machinery operating in real working conditions. *Journal of KONES* 19: 125–134.

Government of Ireland, 2019. *Minister Creed launches Annual Review and Outlook 2019*. Available online: https://www.gov.ie/en/press-release/9eb3e0-minister-creed-launches-annual-review-and-outlook-2019 (accessed 14 March 2022).

Guo, X., Wu, H., Chen, D., Ye, Z., Shen, Y., Liu, J. and Cheng, S., 2020. Estimation and prediction of pollutant emissions from agricultural and construction diesel machinery in the Beijing-Tianjin-Hebei (BTH) region, China. *Environmental Pollution* 260: 113973. https://doi.org/10.1016/j.envpol.2020.113973

Hou, X., Tian, J., Song, C., Wang, J., Zhao, J. and Zhang, X., 2019. Emission inventory research of typical agricultural machinery in Beijing, China. *Atmospheric Environment* 216: 116903. https://doi.org/10.1016/j.atmosenv.2019.116903

Janulevičius, A., Juostas, A. and Pupinis, G., 2013. Tractor's engine performance and emission characteristics in the process of ploughing. *Energy Conversion and Management* 75: 498–508. https://doi.org/10.1016/j.enconman.2013.06.052

Kagawa, J., 2002. Health effects of diesel exhaust emissions—a mixture of air pollutants of worldwide concern. *Toxicology* 181: 349–353. https://doi.org/10.1016/S0300-483X(02)00461-4

Karjalainen, T. and Asikainen, A., 1996. Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. *Forestry: An International Journal of Forest Research* 69(3): 215–228. https://doi.org/10.1093/forestry/69.3.215

Karjalainen, T., Zimmer, B., Berg, S., Welling, J., Schwaiger, H., Finér, L. and Cortijo, P., 2001. *Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products.* European Forest Institute Discussion Paper 10. European Forest Institute, Joensuu, Finland.

Klvac, R. and Skoupy, A., 2009. Characteristic fuel consumption and exhaust emissions in fully mechanized logging operations. *Journal of Forest Research* 14(6): 328. https://doi.org/10.1007/s10310-009-0143-7

Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M. and Denier Van Der Gon, H.A.C., 2014. TNO-MACC_II emission inventory; a multi-year (2003–2009) consistent high-resolution European emission inventory for air quality modelling. *Atmospheric Chemistry and Physics* 14(20): 10963–10976. https://doi.org/10.5194/acp-14-10963-2014

Kwon, S., Kim, S.W., Kim, K.H., Seo, Y., Chon, M.S., Kim, D., Park, S., Roh, H.G., Suh, H.K. and Park, S., 2018. Exhaust emission characteristics of excavator with 6.0 liter diesel engine in real work conditions. *Internal Combustion Engine Division Fall Technical Conference* 51999: V002T04A006.

Lang, J., Tian, J., Zhou, Y., Li, K., Chen, D., Huang, Q., Xing, X., Zhang, Y. and Cheng, S., 2018. A high temporal-spatial resolution air pollutant emission inventory for agricultural machinery in China. *Journal of Cleaner Production* 183: 1110–1121. https://doi.org/10.1016/j.jclepro.2018.02.120

Lijewski, P., Merkisz, J. and Fuć, P., 2013. Research of exhaust emissions from a harvester diesel engine with the use of portable emission measurement system. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering* 34(1): 113–122.

Lijewski, P., Merkisz, J., Fuc, P., Siedlecki, M. and Ziolkowski, A., 2015. *The Measurement of Particulate Matter from Construction Machinery under Actual Operating Conditions (No. 2015-01-2810).* SAE Technical Paper. SAE International, Warrendale, PA. https://doi.org/10.4271/2015-01-2810

Lijewski, P., Merkisz, J., Fuć, P., Ziółkowski, A., Rymaniak, Ł. and Kusiak, W., 2017a. Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport. *European Journal of Forest Research* 136(1): 153–160. https://doi.org/10.1007/s10342-016-1015-2

Lijewski, P., Fuc, P., Dobrzynski, M. and Markiewicz, F., 2017b. Exhaust emissions from small engines in handheld devices. *MATEC Web of Conferences* 118: 00016.

Lindgren, M. and Hansson, P.A., 2002. PM—power and machinery: effects of engine control strategies and transmission characteristics on the exhaust gas emissions from an agricultural tractor. *Biosystems Engineering* 83(1): 55–65. https://doi.org/10.1006/bioe.2002.0099

Lindgren, M., Arrhenius, K., Larsson, G., Bäfver, L., Arvidsson, H., Wetterberg, C., Hansson, P.A. and Rosell, L., 2011. Analysis of unregulated emissions from an off-road diesel engine during realistic work operations. *Atmospheric Environment* 45(30): 5394–5398. https://doi.org/10.1016/j.atmosenv.2011.06.046

López-Aparicio, S., Guevara, M., Thunis, P., Cuvelier, K. and Tarrasón, L., 2017. Assessment of discrepancies between bottom-up and regional emission inventories in Norwegian urban areas. *Atmospheric Environment* 154: 285–296. https://doi.org/10.1016/j.atmosenv.2017.02.004

Lovarelli, D. and Bacenetti, J., 2019. Exhaust gases emissions from agricultural tractors: state of the art and future perspectives for machinery operators. *Biosystems Engineering* 186: 204–213. https://doi.org/10.1016/j.biosystemseng.2019.07.011

Mamakos, A., Bonnel, P., Perujo, A. and Carriero, M., 2013. Assessment of portable emission measurement systems (PEMS) for heavy-duty diesel engines with respect to particulate matter. *Journal of Aerosol Science* 57: 54–70. https://doi.org/10.1016/j.jaerosci.2012.10.004

McReynolds, L., Alquist, H., and Wimmer, D., 1965. *Hydrocarbon Emissions and Reactivity as Functions of Fuel and Engine Variables 650525.* Technical Paper 650525. SAE International, Warrendale, PA. Available online: https://www.sae.org/publications/technical-papers/content/650525/ (accessed 22 February 2022).

Merkisz, J., Lijewski, P., Fuc, P., Siedlecki, M. and Weymann, S., 2015. The use of the PEMS equipment for the assessment of farm fieldwork energy consumption. *Applied Engineering in Agriculture* 31(6): 875–879. https://doi.org/10.13031/aea.31.11225

Merkisz, J., Lijewski, P., Fuc, P., Siedlecki, M. and Ziolkowski, A., 2016. Development of the methodology of exhaust emissions measurement under RDE (Real Driving Emissions) conditions for non-road mobile machinery (NRMM) vehicles. *IOP Conference Series: Materials Science and Engineering* 148: 012077. https://doi.org/10.1088/1757-899X/148/1/012077

Miller, C.A., Hidy, G., Hales, J., Kolb, C.E., Werner, A.S., Haneke, B., Parrish, D., Frey, H.C., Rojas-Bracho, L., Deslauriers, M. and Pennell, B., 2006. Air emission inventories in North America: a critical assessment. *Journal of the Air & Waste Management Association* 56(8): 1115–1129. https://doi.org/10.1080/10473289.2006.10464540

Millo, F., Cornetti, G. and Miersch, W., 2002. *An Experimental Survey on the Emissions Characteristics of Small SI Engines for Non-road Mobile Machinery*. Technical Paper 2001-01-1834. SAE International, Warrendale, PA.

Minnesota Pollution Control Agency, 2020. Sulfur dioxide. Available online: https://www.pca.state.mn.us/air/sulfur-dioxide-so2 (accessed 22 February 2022).

Muresan, B., Capony, A., Goriaux, M., Pillot, D., Higelin, P., Proust, C. and Jullien, A., 2015. Key factors controlling the real exhaust emissions from earthwork machines. *Transportation Research Part D: Transport and Environment* 41: 271–287. https://doi.org/10.1016/j.trd.2015.10.002

NASA, 2020. Carbon dioxide. Available online: https://climate.nasa.gov/vital-signs/carbon-dioxide/ (accessed 22 February 2022).

Notter, B., Wüthrich, P. and Heldstab, J., 2016. An emissions inventory for non-road mobile machinery (NRMM) in Switzerland. *Journal of Earth Sciences and Geotechnical Engineering* 6: 273–292.

Pirjola, L., Rönkkö, T., Saukko, E., Parviainen, H., Malinen, A., Alanen, J. and Saveljeff, H., 2017. Exhaust emissions of non-road mobile machine: real-world and laboratory studies with diesel and HVO fuels. *Fuel* 202: 154–164. https://doi.org/10.1016/j.fuel.2017.04.029

Priest, M.W., Williams, D.J. and Bridgman, H.A., 2000. Emissions from in-use lawn-mowers in Australia. *Atmospheric Environment* 34(4): 657–664. https://doi.org/10.1016/S1352-2310(99)00192-2

Puranen, A. and Mattila, M., 1992. Exhaust emissions from work machinery in Finland. *Environment International* 18: 467–476. https://doi.org/10.1016/0160-4120(92)90265-6

Richmond, B., Misra, A., Broomfield, M., Brown, P., Karagianni, E., Murrells, T., Pang, Y., Passant, N., Pearson, B., Stewart, R., Thistlethwaite, G., Wakeling, D., Walker, J. and Wiltshire, C., 2019. *UK Informative Inventory Report (1990 to 2013).* National Atmospheric Emissions Inventory Programme, London.

Sawyer, R.F., Harley, R.A., Cadle, S.H., Norbeck, J.M., Slott, R. and Bravo, H.A., 2000. Mobile sources critical review: 1998 NARSTO assessment. *Atmospheric Environment* 34(12–14): 2161–2181. https://doi.org/10.1016/S1352-2310(99)00463-X

SEAI (Sustainable Energy Authority of Ireland), 2020. National Energy Balance. Available online: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/ (accessed 14 March 2022).

Sennoune, M., Muresan, B., Capony, A., Jullien, A. and Proust, C., 2014. In situ evaluation of earthwork machinery emissions. Paper presented at the Transport Research Arena (TRA) 5th Conference, Paris, France, 14–17 April.

Starcrest Consulting Group, 2015. *The Port of Long Beach Air Emission Inventory*. Long Beach, CA.

Swiss Federal Office for the Environment, 2015. *Non-road Energy Consumption and Pollutant Emissions*. Swiss Federal Office for the Environment, Bern, Switzerland.

Symeonidis, P., Ziomas, I. and Proyou, A., 2004. Development of an emission inventory system from transport in Greece. *Environmental Modelling & Software* 19(4): 413–421. https://doi.org/10.1016/S1364-8152(03)00140-3

Szymlet, N., Siedlecki, M., Lijewski, P. and Sokolnicka, B., 2018. Specific emission of harmful compounds analysis from an agricultural tractor in a modified NRSC test. *Journal of Research and Applications in Agricultural Engineering* 63(4): 220–224.

Thuneke, K., Huber, G., Ettl, J., Emberger, P. and Remmele, E., 2016. *Real Driving Emissions of Vegetable Oil Fuelled Tractors.* Conference paper. Available online: https://www.tfz.bayern.de/mam/cms08/en/dateien/realdrivingemissions_eubce_2016.pdf (accessed 30 March 2022).

Transportation Research Board and National Research Council, 2000. *Modeling Mobile-Source Emissions*. The National Academies Press, Washington, DC. https://doi.org/10.17226/9857

US EPA (United States Environmental Protection Agency), 1997. *Introduction to the Emission Inventory Improvement Program*. Available online: https://www.epa.gov/sites/production/files/2015-08/documents/i01.pdf (accessed 22 February 2022).

US EPA (United States Environmental Protection Agency), 2018. *MOVES and Other Mobile Source Emissions Models*. Nonroad technical reports. Available online: https://www.epa.gov/moves (accessed 14 March 2022).

US EPA (United States Environmental Protection Agency), 2020. *Regulations For Emissions from Nonroad Vehicles and Engines*. Available online: https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-nonroad-vehicles-and-engines (accessed 22 February 2022).

Wang, F., Li, Z., Zhang, K., Di, B. and Hu, B., 2016. An overview of non-road equipment emissions in China. *Atmospheric Environment* 132: 283–289. https://doi.org/10.1016/j.atmosenv.2016.02.046

Winther, M. and Nielsen, O.-K., 2006. *Fuel Use and Emissions from Non-road Machinery in Denmark from 1985–2004 – and Projections from 2005–2030*. Danish Ministry of the Environment, Copenhagen.

Winther, M., Nielsen, O.-K., Hansen, L.G., Nielsen, L.D., Nielsen, O.A. and Hels, T. (eds), 2007. Artikelsamling fra Trafikdage på Aalborg Universitet 2006. *ISP's Skriftserie* 316: 352–361. Available online: http://www.trafikdage.dk/program/Artikelsamling_2006.pdf (accessed 14 March 2022).

Wiśniewski, P. and Kistowski, M., 2020. Greenhouse gas emissions from cultivation of plants used for biofuel production in Poland. *Atmosphere* 11(4): 394. https://doi.org/10.3390/atmos11040394

Yu, F., Li, C., Liu, J., Liao, S., Zhu, M., Xie, Y., Sha, Q., Huang, Z. and Zheng, J., 2020. Characterization of particulate smoke and the potential chemical fingerprint of non-road construction equipment exhaust emission in China. *Science of the Total Environment* 723: 137967. https://doi.org/10.1016/j.scitotenv.2020.137967

Zhang, Y., Peng, Y.Q., Wang, W., Gu, J., Wu, X.J. and Feng, X.J., 2017. Air emission inventory of container ports' cargo handling equipment with activity-based "bottom-up" method. *Advances in Mechanical Engineering* 9(7): 1687814017711389. https://doi.org/10.1177/1687814017711389

Zhang, Q., Yang, L., Ma, C., Zhang, Y., Wu, L. and Mao, H., 2020. Emission characteristics and chemical composition of particulate matter emitted by typical non-road construction machinery. *Atmospheric Pollution Research* 11(4): 679-685. https://doi.org/10.1016/j.apr.2019.12.018

Zheng, J., Zhang, L., Che, W., Zheng, Z. and Yin, S., 2009. A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment. *Atmospheric Environment* 43(32): 5112–5122. https://doi.org/10.1016/j.atmosenv.2009.04.060

Abbreviations

CLRTAP	Convention on Long-range Transboundary Air Pollution
CORINE	Coordination of Information on the Environment
CSO	Central Statistics Office
EPA	Environmental Protection Agency
GVA	Gross value added
HC	Hydrocarbon
LTO	Landing and take-off
NECD	National Emissions Reduction Commitments Directive
NFR	Nomenclature for reporting
NMVOC	Non-methane volatile organic compound
NORA	National Oil Reserves Agency
NO_x	Nitrogen oxide
NRMM	Non-road mobile machinery
PAH	Polyaromatic hydrocarbon
PEMS	Portable emission measurement systems
PM	Particulate matter
RDE	Real driving emissions
SEAI	Sustainable Energy Authority of Ireland
S.I.	Statutory Instrument
SNAP	Selected Nomenclature for Air Pollutants
TSP	Total suspended particles
UF	Ultrafine
UNECE	United Nations Economic Commission for Europe

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Emissions from and Fuel Consumption Associated with Off-road Vehicles and Other Machinery

Authors: Rita Hagan, Emma Markey, Jerry Clancy, Mark Keating, Aoife Donnelly, David O'Connor, Liam Morrison and Eoin McGillicuddy

Identifying Pressures

Non-road mobile machinery (NRMM) is a large category that until recently had not been widely researched in terms of its contribution of exhaust emissions to overall air pollution. The emissions from NRMM contribute significantly to air pollution by emitting carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HCs), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter (PM). The lack of uniformity of NRMM and the fact that they are used in many and varied sectors, ranging from large-scale machines used in the construction sector to smaller handheld machines used in private gardens, render it difficult to form a full understanding of the number of these machines currently in operation in Ireland and their contribution to overall emissions. As there is no legal requirement to report NRMM emissions or fuel type and use at the national level, data collection currently relies on the data holder's goodwill. Calculations using national figures show that to gain better understanding of pollutants emitted by NRMM, receiving detailed usage information from data holders is required to improve inventory accuracy.

Informing Policy

To lower emissions from NRMM and improve air quality, it is recommended that more data are collected from sectors such as rail, construction, and aviation, and from Transport Infrastructure Ireland. A further recommendation is that new data fields should be added to the annual business energy use survey carried out by the Central Statistics Office (CSO) and to the Sustainable Energy Authority of Ireland (SEAI) public sector energy monitoring and reporting system, to enable the calculation of NRMM emissions data. This will enable the EPA to incorporate data into the national emissions inventory under a separate NRMM category and it will enable the Department of the Environment, Climate and Communications to inform the 5-year sectoral carbon budget and air quality measures. NRMM users can use the data generated to make informed machinery purchase choices, as they would have the knowledge of which low-emission options are available.

Developing Solutions

An estimation of emissions from NRMM in Ireland had not been conducted previously. This research used the bottom-up approach of contacting NRMM owners and data holders to request data about their NRMM fleet and its fuel use. From the data collected it was possible to attribute 1605.1 kt of CO_2 emissions in 2019 to NRMM, for example. It emerged that the requested information is not readily available. It is therefore recommended that documentation containing more detailed information about the machinery be added to the documentation required during purchase, especially when NRMM is purchased for commercial use. Documentation for each machine would be kept in an easily accessible file to facilitate reporting of these data. Establishing strong relationships between the agency responsible for collecting the data and the data holders would further aid the collecting of data and the compiling of NRMM emissions inventories.

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