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Non-Road Mobile Machinery Model – Updates 2015

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Preface

This project was carried out by IVL Swedish Environmental Research Institute on behalf of the Swedish Transport Administration. This is a somewhat condensed version of the original report, Jerksjö *et al* (2015), for the Swedish Transport Administration.

The overall objectives of this study were to 1. Improve the Swedish non-road mobile machinery model by adding data and functionalities; 2. Write a document describing the model (not presented in this version of the report); 3. Carry out a literature review over emission factors for real world driving of non-road machinery and 4. Arrange a workshop with the aim to discuss responsibility of the model and how to keep it updated.

Simultaneously with this project Statistics Sweden (SCB) carried out a project on behalf of the Swedish Energy Agency aiming at building a model (based on the Swedish non-road mobile machinery model) for calculations of energy use from non-road machinery. Within their project, SCB also planned to arrange a workshop to discuss the responsibility of the Swedish non-road mobile machinery model. This ended up in a co-arrangement of the workshop between IVL and SCB and hence co-financed by the Transport Administration and the Energy Agency.

Summary

The model used in Sweden for modelling fuel consumption and emissions from non-road machines has within this project been updated in following ways: several types of alternative fuels have been included, machines with an installed engine power above 560 kW have been added, load factors have been updated for some machine types, an algorithm that calculates the effect of the engine load factor on fuel consumption has been added, emission factors of machines that meets the Stage V emission standard have been added. In addition there were also a few more minor updates.

The effect on the national emissions from each update individually is in some cases relatively large. However, the total effects of all updates together did not lead to any major changes of the estimates of emissions and fuel consumption for the years 1990-2013.

In addition to mentioned model updates a literature review was carried out aiming to find emission factors based on on-board measurements (PEMS). Information was compiled from several sources and the emission factors were compared with emission factors from the model. The compliance for NOx, CO, and HC showed to be relatively good. The compliance for particles was not as good.

There was also a workshop arranged within the project with the aim to discuss the future national (agency) responsibility of the model and how data to the model can be collected. The workshop led to a good discussion about the possibilities to collect data to the model. Also discussions about the future responsibility of the model were started.

Sammanfattning

Modellen som används i Sverige för att modellera bränsleförbrukning och emissioner från arbetsmaskiner har inom detta projekt uppdaterats på följande områden: flera typer av alternativa bränslen har inkluderats, maskiner med en installerad motoreffekt över 560 kW har lagts till, lastfaktorer för vissa maskinkategorier har uppdaterats, en funktion som tar hänsyn till lastfaktorns inverkan på bränsleförbrukningen har lagts till, emissionsfaktorer för Steg V-maskiner har lagts till. Dessutom har några övriga mindre korrigeringar av modellen gjorts.

Tittar man på effekten på de nationella emissionerna av enskilda uppdateringar är den i vissa fall relativt stor. Däremot leder den sammanslagna effekten av alla uppdateringar i modellen inte till några större förändringar av uppskattade emissioner eller bränsleförbrukning för åren 1990-2013.

Utöver nämnda modelluppdateringar utfördes en litteraturstudie för att undersöka förekomst av emissionsfaktorer som baseras på ombordmätningar (PEMS). Information sammanställdes från ett flertal källor. Emissionsfaktorerna jämfördes därefter med de som finns i modellen. Det visade sig att överensstämmelsen är relativt god när det gäller utsläpp av NO_X, CO och HC. När det gäller partiklar var överensstämmelsen sämre.

Dessutom anordnades en workshop med syfte att diskutera var det nationella (myndighets-) ansvaret för modellen ska ligga i framtiden samt hur data till modellen kan samlas in. Workshopen ledde till en bra diskussion om möjligheterna att ta fram data till modellen. Även diskussioner om framtida ansvar för modellen inleddes.

1 About the model

This report describes updates of the model used for modelling air emissions and energy use of non-road mobile machinery in Sweden. The modelled results are used, e.g. for Sweden's air emissions reporting obligations to the UNFCCC, CLRTAP and EU. These calculations are carried out yearly by SMED [1] on behalf of the Swedish Environmental Protection Agency. The model is also regularly used by the Swedish Transport Administration and the Swedish Energy Agency.

The basic assumptions and methods of the model (hereafter also called NRMMM, Non-Road Mobile Machinery Model) are described in detail in Lindgren (2007), therefore no further detailed descriptions are given the present report.

2 Literature Review – Real World Emission Data

It is well known that real-world driving emissions from road vehicles can be very different from the type approval values obtained during type testing. Real-world emissions from non-road mobile machinery are yet not as well studied as for road vehicles, but in recent years there has been an increasing interest in such studies.

The most established method used for on-road emission measurements is called PEMS (Portable Emission Measurement System). There are two main purposes of doing PEMS measurements on non-road machinery and other vehicles. One is to get information that helps doing adequate emission estimates, e.g. for emission inventories on a national scale. The other purpose is to use PEMS to verify that the engine would fulfil the emission requirements if the type approval test was repeated.. This testing is required for heavy-duty truck engines complying with the Euro V or VI standards. The same method that is used for trucks can be used for non-road machinery as well, but since there are differences in how trucks and non-road machinery operate the method has to be modified. The NRMM PEMS Pilot Programme was launched to facilitate the introduction into the European NRMM emission legislation of the use of PEMS as a tool for in-service conformity testing (JRC, 2013).

In the US, Tier 4 non-road engines must meet not-to-exceed standards (NTE), which are measured without reference to any specific test schedule. NTE requirements are instead connected to a specific control area in the engine torque-speed map. The NTE standards became effective in 2011 for engines above 130 kW; in 2012 for 56-130 kW; and in 2013 for engines below 56 kW. In most engines, the NTE limits are set at 1.25 times the regular standard for each pollutant. In engines certified to NO_X standards below 2.5 g/kWh or PM standards below 0.07 g/kWh, the NTE multiplier is 1.5.

Within this study a literature review was carried out with the aim of finding emission factors for real-world operation of non-road machinery and to analyse how these emission factors compare to emission factors according to the NRMMM.

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[1] Svenska Miljöemissionsdata (SMED) is a consortium established in 2001 with the purpose of long-term gathering and developing of competence in Sweden in the field of emission statistics. www.smed.se

2.1 Emission factors from literature review

In this section emission factors found in the literature are compiled in two tables; Table 1 includes fuel-based emission factors and Table 2 includes work-based emission factors. In Table 3 correction factors calculated as the ratio between the emission factors from the literature (Table 2) and emissions factors according to the model are presented. A correction factor <1 means that the emission factor in the model is greater than the measured emission factor to which it is compared.

There is also a table in Appendix 1 containing additional work-based emission factors. A short summary of the reviewed sources can be found in Sections 2.2 – 2.4.

Table 1 Real-world driving emission factors on a fuel basis.

Machine	Power (kW)	Emission Standard	CO2	CO	HC	NO	NOx	PM[1]	Reference
			g/kg fuel						
Excavator	69	Tier 1		4.0	1.4	34		0.4	Abolhasani *et al* (2008)
Excavator	103	Tier 1		9.7	2.8	24		0.2	Abolhasani *et al* (2008)
Excavator	189	Tier 1		4.4	3.2	34		0.2	Abolhasani *et al* (2008)
Motor Grader	122	Tier 0		32	16	41		0.3	Frey *et al* (2008)
Motor Grader	145	Tier 1		15	17	33		0.3	Frey *et al* (2008)
Motor Grader	145	Tier 2		12	12	30		0.2	Frey *et al* (2008)
Motor Grader	148	Tier 3		8.8	6.2	20		0.2	Frey *et al* (2008)
Excavator and Wheel loaders[2]	37-162	Stage I		15	6		57	1.7	Fu *et al* (2012)
Excavator and Wheel loaders[2]	39-147	Stage II		10	2		36	1.0	Fu *et al* (2012)
Excavator[3]		Stage I-II		12	3.3		31	1.4	Fu *et al* (2012)
Wheel loader[4]		Stage I-II		17	7.6		83	1.5	Fu *et al* (2012)

1 opacity based measurements
2 average of 12 excavators and 8 wheel loaders - working cycle
3 average of 12 excavators, stage I and stage II - idling, moving and working cycles
4 average of 8 wheel loaders, stage I and stage II - idling, moving and working cycles

Table 2 Real-world driving emission factors on a work basis.

Machine	Power/size	Emission Standard	CO2	CO	HC	NO	NOx	NOx+HC	PM	Reference
			g/kWh							
Wheel loader[1]	-[2]	Stage II		5.1	0.3		6.2		1.0	Blassnegger (2014)
Wheel loader[1]	-[2]	Stage IIIA		2.3	0.2		5.1		0.5	Blassnegger (2014)
Wheel loader[1]	-[2]	Stage IIIB		0.3	0.01		1.4		0[3]	Blassnegger (2014)
Wheel loader[1]	-[2]	Stage IIIB		0.1	0.05		3.0		0[3]	Blassnegger (2014)
Excavator[5]	75-130 kW	Stage I		0.89	0.62		6.52		0.6	Blassnegger (2014)
Excavator	75-130 kW	Stage II		0.64	0.50		4.48		0.5	Blassnegger (2014)
Excavator	75-130 kW	Stage II		1.78	0.90		4.38		0.4	Blassnegger (2014)
Excavator	75-130 kW	Stage IIIA		0.38	0.09		5.45		0.05	Blassnegger (2014)
Excavator	75-130 kW	Stage IIIB[4]		2.75	0.06		3.97		0.8	Blassnegger (2014)
Excavator	75-130 kW	Stage IIIB		0.31	0.01		1.32		0***	Blassnegger (2014)
Excavator	197kW	Tier II		2.81	0.9		8.79		0.63	Lijewski (2013a)
Forest Harvester	129kW	Stage IIIA		1.56				8.28	0.62	Lijewski (2013b)
Chainsaw	2.5kW	Stage II		218.15	26.57		8.23			Lijewski (2013b)
Farm Tractor	122kW	Stage IIIB	715	2.22	0.24		3.82		1.02	Lijewski (2013c)

1 all emission factors read from bar graphs, may not be exact modelled values
2 information not included in the paper
3 not readable from bar graph, close to zero
4 hybrid
5 The excavators are designated as 20 t in the reference.

Table 3 Correction factors calculated as the ratio between emission factors in Table 2 and emission factors according to the NRMMM model.

Machine	Power/size	Emission Standard	CO2	CO	HC	NOx	PM
Excavator	75-130 kW	Stage I		0.3	1.1	1.0	2.4
Wheel loader	130-560 kW	Stage II		3.2	1.1	1.5	8.3
Excavator	75-130 kW	Stage II		0.3	1.3	1.1	2.7
Excavator	75-130 kW	Stage II		0.8	2.3	1.0	2.3
Excavator	130-560 kW	Tier II		1.8	3.3	2.1	5.3
Chainsaw	2.5kW	Stage II		0.6	0.4	6.9	
Wheel loader	130-560 kW	Stage IIIA		1.4	0.7	1.6	2.5
Excavator	75-130 kW	Stage IIIA		0.2	0.2	1.7	0.2
Forest Harvester	75-130 kW	Stage IIIA		0.7	-	2.3[2]	2.1
Wheel loader	130-560 kW	Stage IIIB		0.3	0.1	0.7	
Wheel loader	130-560 kW	Stage IIIB		0.1	0.3	1.5	
Excavator	75-130 kW	Stage IIIB[1]		1.8	0.3	1.2	31
Excavator	75-130 kW	Stage IIIB		0.2	0.1	0.4	
Farm Tractor	75-130 kW	Stage IIIB	0.8	1.5	1.3	1.2	41
Average[3]			**0.8**	**0.96**	**0.92**	**1.2**	**10**
Median[3]			**0.8**	**0.68**	**0.7**	**1.2**	**2.6**

1 hybrid
2 HC+NO_X
3 average of all diesel machinery (i.e. the chainsaw is excluded)

2.2 PEMS measurements on non-road machinery in the United States

The ERG (Eastern Research Group) has carried out a pilot study including PEMS measurements on 29 non-road mobile machines (USEPA, 2012). Gaseous and particulate matter emissions as well as activity data were collected over a typical working day. Emissions are in the report presented on work basis, fuel basis and time basis. The data collected throughout the study is anticipated to finally be used to develop relationships and emission rates in the MOVES model (the NONROAD model is included in the MOVES model from model version MOVES2014, see USEPA 2015). One conclusion from the study is that engine size and regulatory tier may not be meaningful variables for estimating emissions from non-road diesel engines as parameters such as engine speed range and engine load appear to influence the emission rates more. Data from the ERG study is presented on a fuel basis in Appendix 1 in this report.

In Abolhasani *et al* (2008), PEMS measurements on three excavators (Tier 1) are presented. All excavators performed similar tasks, including excavation of dirt and lifting heavy objects. Results from the study include (1) benchmark comparison of measured emission rates to estimates from the NONROAD model; (2) exploratory analysis of variation in emission rates with respect to engine variables; (3) characterization of the effect of microscale events (e.g. short term-events such as use of the bucket) during real-world operation on real-world emission rates; and (4) quantification of the variability in fuel consumption and emission rates with respect to variability in duty cycles.

It is concluded that the opacity-based PM data is likely not useful for estimation of the total PM emissions, but might be useful to determine relative differences among vehicles (or among modes for a given vehicle).

In Frey *et al* (2008) emissions from six motor graders were measured. Each machine was tested using both conventional petroleum diesel and B20 biodiesel. The machines were operated under normal duty cycles for road maintenance and repair. Besides comparing differences in emissions due to the different fuels the authors also compared measured fuel specific emission factors with emission factors from the US NONROAD model.

The emission rates for use of B20 versus petroleum diesel showed to be approximately the same for NO (NO_2 not measured) but significantly lower for PM, HC and CO. In general the average emission rates measured with PEMS are of similar magnitude to those found in the NONROAD model for NO, HC and CO. However, the measured PM emissions were found to be much lower than in the NONROAD model. As in Abolhasani *et al* (2008) the authors conclude that opacity-based PM emissions might only be useful to determine relative differences among vehicles and not absolute emissions.

2.3 PEMS measurements on non-road machinery in Europe

In a project founded by the Austrian Ministry of Environment 17 machines were measured with a PEMS system (Blassneger, 2014). The tested machines were excavators, wheel loaders, mini diggers and a road roller. For most of the machine types, machines complying with different emission standards were tested. The measurements were performed during 20 minutes for each machine when the machine was used in typical operational conditions.

One aim of the study was to find a method for developing emission factors for non-road machinery that could be used in a model similar to the HBEFA model (HBEFA, 2015), which is used for modelling real-world emissions from road vehicles. However, there are today no driving cycles that can be used to establish emission factors for construction machinery. Therefore, typical load/engine speed cycles were defined. Average emission maps were generated and these were then used to calculate emission factors for the defined cycles. To do this the PHEM model (Hausberger 2003) was used which is the same model that is used for developing emission factors for HBEFA.

In Blassneger (2014), modelled time-based emission factors are presented for stage IIIB wheel loaders in typical operating conditions. The modelled emission factors were in the study also calculated as g pollutant/kWh, but these data are not presented in the paper. Also measured work-based emission factors for wheel loaders from Stage II to stage IIIB in real world operation and for excavators from Stage I to Stage IIIB are presented.

In Lijewski *et al* (2013a) results from PEMS measurements on an excavator (Stage II, 197 kW) are presented. The measurements were performed under its actual operating conditions in a gravel pit. The results were related to the Stage II emission limits and it was found that the limits were exceeded for both NO_X and PM.

Lijewski *et al* (2013b) presents test results from emission measurements from a wheeled harvester (Stage IIIA, 129 kW) and a chainsaw (Stage II, 2.5 kW, gasoline) under actual operation conditions. The obtained results from the harvester measurements were compared to the Stage IIIA limits.

Lijewski *et al* (2013c) presents results from emission tests of a farm tractor operating in field with a cultivator. The main purpose of the study was to evaluate the method used for testing non-road vehicles in the US. It was determined that only during 61 % of the total operating time of the used test cycle the engine worked in the defined NTE test zone. This implies that the US NTE test may not be a suitable method for determining real-world emissions.

2.4 PEMS measurements on non-road machinery in China

In Fu *et al* (2012) gaseous and PM emissions were measured by means of PEMS on 12 excavators (37-147 kW, Stage I – Stage II) and 8 wheel loaders (45-162 kW, Stage I – Stage II). In the study average emission factors are estimated based on time and fuel consumption for the operation modes; idling, moving mode and working mode were estimated. It was also studied how the accumulated engine hours of a machine affects the emission rates.

2.5 Conclusions from published PEMS studies

The NO_X correction factors for diesel machines presented in Table 3 ranges from 0.4 to 2.1 with an average and median of 1.2. This indicates a good compliance between the model and the measured emission factors included in this comparison even though there is a large spread in the results between the different tests. Even for the other pollutants the medians and averages indicates a fairly good compliance. The greatest deviance is seen for particles. One explanation for this may be the different measurement methods used for measuring particles.

3 Workshop

As mentioned earlier the model and model results are used by the Swedish Environmental Protection Agency (SEPA), the Swedish Transport Administration (STA) and the Swedish Energy Agency (SEA). However, no agency has yet the official responsibility to manage and update the model. Due to this fact there is no plan of e.g. how often the model should be updated or what kind of functionalities the model should have. So far all efforts of keeping the model up to date have been done by STA and SEPA. However, the updates are not always well harmonised and there is a need for a plan of how to keep the model up to date in the future.

To address this issue there was a workshop arranged in cooperation between IVL and Statistics Sweden (SCB) on April 15th 2015. The workshop was divided into two sessions.

The first session was used to discuss how to develop a national system for recurring collection of data that can be used in the model. This session was aimed at organisations that may have data that can be used in the model and organisations that have an interest of using the model.

The second session was used to discuss the administration of the model in coming years. This session was aimed at SEPA, STA, SEA, SCB and IVL. Below follows a brief summary of the discussions from the first session.

The Swedish Trade Association for Suppliers of Mobile Machines has detailed information about machines sold (diesel machines > 37 kW) by their members on a monthly basis. They also have some information about the age distributions of the vehicle stock and estimates of average vehicle life times. Some of this data is confidential but may be used in the model if disclosure control is applied.

The Swedish Machinery Testing Institute (SMP) has at some occasions in the past provided data about, e.g. machine population and average lifetimes that has been implemented in the model. SMP are positive to provide data to the model in the future, provided that the work will be done on a regular basis making it possible to build up a system for how to extract and report data from their inspection register.

For later model years all machines are equipped with a data acquisition system that monitors and stores operational parameters. This kind of data may be very useful input to the model. During the workshop there were no concrete proposals for how to collect data and use these for keeping the model updated. A desirable scenario is that all responsibility of the model is given to a single agency and that a system for how to keep the model updated is developed. An example of a similar system can be seen for the Swedish road traffic sector. The road vehicle emission model used by Sweden is HBEFA (2015). Implementation of Swedish fleet data in this model is managed by the Swedish Transport Administration and is updated on a yearly basis. However, the preconditions are different from the non-road sector since data on all road vehicles are stored in the vehicle register.

There was also a discussion about the completeness of the model regarding included machine types. The conclusion was that some machine types may be missing but that the most important machine types are included.

It was also identified a need for preparing the model to include electrical and hybrid vehicles since the numbers are supposed to increase in the future.

Some participants asked for a model that more than on a national level can be used on a regional and/or sectoral level. For example it would be useful to be able to do detailed studies of energy use of a certain machine type in a specific sector.

4 Model updates

4.1 Machines with an installed engine power above 560 kW

The NRMMM has until now not included machines with an engine power above 560 kW. The main reason for this has been a lack of information about number of units, annual working hours etc. Today the knowledge about the population and yearly working hours for these machines is improved and implemented in the model.

Data that have been implemented in the model are based on Appelberg *et al* (2014), which was a study including an inventory of the machine population as of 2014. Table 4 shows information about machine types, where they are used, population, power range and annual work hours. Most of the annual work is done by machines used in the mining and quarrying industry. In addition to this a few machines are used in agriculture and there are also a few mobile generators with an installed power above 560 kW.

Table 4 Population, power range, annual work hours and sectors in which the machines are mainly used, Appelberg *et al* (2014).

Category	Sector	Population (2014)	Power (kW)	Annual work hours per machine
Wheel Loader	Mining/quarrying	10	597-1176	6500-7000
Truck	Mining/quarrying	72	700-2536	6500-7000
Mower-Conditioner	Agriculture	2	565-793	150
Forage harvester	Agriculture	2	650	<150
Generator	Power grids	22	616-1516	50-209
Generator	Other	75	576-950	50

Since the model requires population data, annual work etc. from 1990 and onwards some assumptions had to be done when implementing data from Appelberg *et al* (2014) in the model. The estimation of number of units from 1990-2014 are based on not published information from Appelberg *et al* (2014) regarding model year of the machines and information from the owners of the mining machines stating that none of the machines has yet been scrapped. The approximated number of machines 1990-2014 is shown in Figure 1.

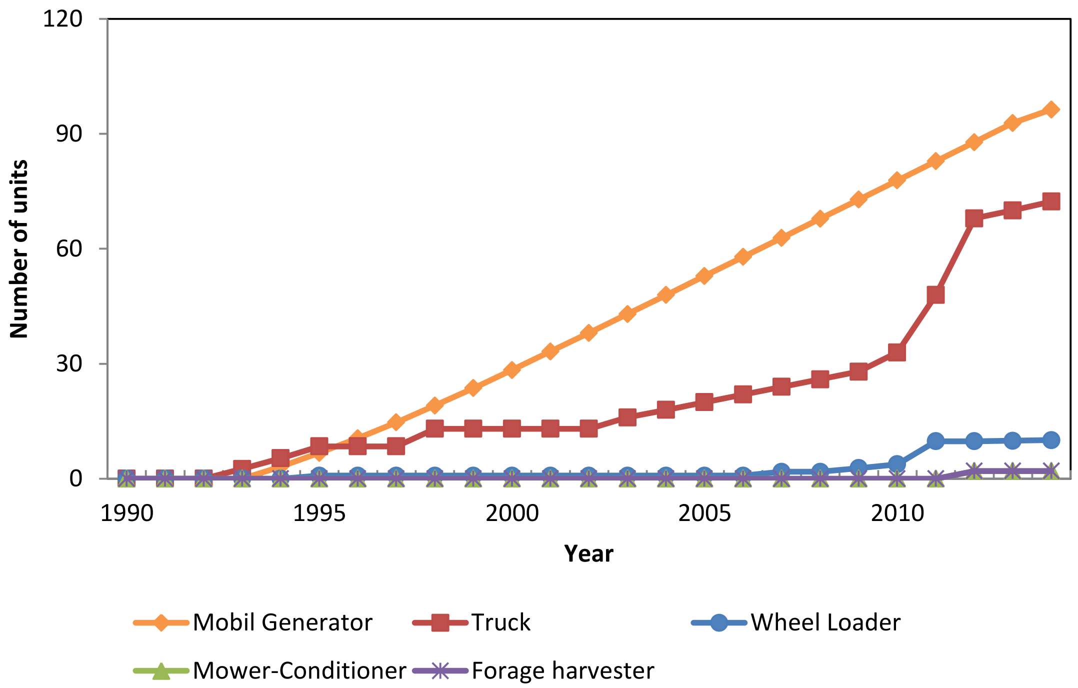

Figure 1 Accumulated number of units 1990-2014.

The model also requires average work hours, average installed power and average load factor for each machine type for all years. For these parameters the same value were set for all years since no other information was available. The values used are shown in Table 5. Annual work hours and average engine power are from Appelberg *et al* (2014). Load factors are estimated within this study using values from similar machine types with a lower engine power.

Table 5 Annual work hours, average engine power and average load factor implemented in the NRMMM.

Category	Annual work hours per machine	Power (kW)	Effective Load Factor (%)
Wheel loader	6750	1 100	28
Truck	6750	1 700	40
Mower-Conditioner	150	750	35
Forage harvester	150	600	35
Generator	50	800	34

The emission standard for all machine categories was set to be Stage 0 for machines with model year before 2019. From 2019 and onwards all new machines are assumed to fulfil the Stage V emission limits. The used base emission factors (uncorrected for deterioration etc.) are shown in Table 6.

Table 6 Fuel consumption and emission factors implemented in the NRMMM.

Category	Model year	FC	CO	VOC	NOx	PM g/kWh	N2O	CH4	NH3

All machines	1990-2018	254	5.0	1.35	14.4	1.1	0.035	0.05	0.002
All machines	2019-2030	254	3.5	0.19	3.5	0.045	0.035	0.05	0.002

4.2 Effective load factors

In a recent IVL study (Fridell and Bäckström ,2014) commissioned by the Swedish Transport Administration new load factor to be used e.g. in the NRMMM were proposed. The load factors were calculated using data collected from the on-board computer systems on a number of different NRMMs from two different manufacturers during normal operation in Sweden in 2013. In the collected data set fuel consumption and working hours were split into idle and operation. To get the load factors, the annual fuel consumption (in litres) was multiplied with the fuel density and divided by the specific fuel consumption, the installed engine power, and the annual operating hours. Data were only available for certain machine types. In order to calculate the load factors, specific fuel consumption for the engines of 220 – 230 g/kWh was used - the value was obtained from the engine manufacturers; and the diesel fuel density was set to 830 kg/m^3. The maximum rated power (expressed as the ISO net value) for the engines was taken from brochures from the manufacturers.

The new load factors according to Fridell and Bäckström (2014) and the previously used factors are shown in Table 7.

Table 7 New (IVL, 2014b) and old load factors.

Machine type	**Engine size class (kW)**	**LF,** new (%)	**LF,** old (%)
Wheel loader	75-130	22	48
Wheel loader	130-560	28	48
Excavator (crawler)	37-75	39	40
Excavator (crawler)	75-130	37	40
Excavator (crawler)	130-560	38	40
Excavator (wheel)	75-130	30	40
Articulated hauler	130-560	23	21

4.3 Load dependent fuel consumption

The specific fuel consumption factors (g/kWh) used for diesel machinery in the model are based on the ISO C1 non-road measurement cycle in which the machines on average operates at 48 % of full engine load. The model, however, uses load factors that are more representative for real-world driving compared to the standard cycle. Since the specific fuel consumption varies with the engine load it is important to adjust the fuel consumption for the difference in load between the standard cycle and the model. Such adjustment is added in the updated model using Equation 1 (Arcadis, 2010):

$$LCF = 2.0095 - 2.1981 * \Delta LF + .11886 * \Delta LF^2 \qquad \text{Eq. 1}$$

where LCF (Load Correction Factor) is the correction factor and ΔLF is the ratio of the effective load factor and the load factor used in the ISO C1 non-road measurement cycle.

4.4 Stage V emission factors

Within the European Union there is currently a discussion to introduce a new emission stage, Stage V. For the first categories new type approvals become mandatory in 2018, remaining categories follows the coming years. Final decision regarding Stage V is expected late 2015 or early 2016. Proposed limits values are presented in Appendix 3.

Emission factors for Stage V engines have in this study been updated in the model and the used base emission factors are shown in Table 8. The base factors are in the model corrected with the different correction factors described in Lindgren (2007). The values of these correction factors are not presented in this report, but for most pollutants the corrected emission factors do not deviate much from the base factors. The fuel consumption factors will deviate 5-30 %, depending on machine type, from the base factor due to the load dependent fuel consumption correction described in section 4.3.

The specific fuel consumption was assumed to be unchanged from Stage IV to Stage V machines.

Table 8 Stage V base fuel consumption and base emission factors used in the model.

Fuel	**Power range**	**FC**	**CO**	**NMVOC**	**NOx**	**TSP**	**N2O**	**CH4**	**NH3**
	kW				g/kWh				
Diesel	<20	270	6.6	1.36	6.11	0.4	0.035	0.027	0.002
Diesel	20-37	262	5.0	0.40	4.29	0.015	0.035	0.012	0.002
Diesel	37-75	265	5.0	1.4	2.94	0.015	0.035	0.05	0.002
Diesel	75-130	260	5.0	0.19	0.4	0.015	0.035	0.05	0.002
Diesel	130-560	254	3.5	0.19	0.4	0.015	0.035	0.05	0.002
Diesel	>560	254	3.5	0.19	3.5	0.045	0.035	0.05	0.002
Diesel	>560*	254	3.5	0.19	0.67	0.035	0.035	0.05	0.002

*Generator sets

4.5 Sectoral allocation of emissions and energy use

The model is designed to be used in Sweden's yearly national greenhouse gas (and air pollutant) inventories. Following the IPCC 2006 Guidelines (IPCC, 2006) the national total emissions should be allocated to different sectors following the CRF (Common Reporting Format).

The sectoral allocation of emissions and energy use in the model is based mostly on SMED (2004). This source is today somewhat outdated and the allocation method used in the model is therefore in need of update. However, a detailed overview of how to allocate emissions from non-road machinery was not within the scope of this study, instead there was a more general overview of the allocation for assuring that emissions are allocated in line with the IPCC 2006 Guidelines. In addition to this some adjustments of sectoral allocations in the old model that seemed unreasonable have been changed.

One result of this overview was that two new CRF codes to which emissions and energy use from non-road machinery should be allocated were added to the model, 1A4a ii and 1A5b. In 1A4a ii, e.g. garden machinery for professional use should be allocated. Most of the machines in this code were earlier allocated to 1A3e Other. 1A5b should contain machines used for military activities. However, at this time no emissions or fuel are allocated to 1A5b in the model since more information about the use of working machinery in this sector is needed.

The changes in sectoral allocation resulted in that more emissions now are allocated to the forestry sector and less missions are allocated to the other sectors. The CRF codes used for emissions from non-road machinery after the updates are presented in Table 9. The complete allocation scheme used in the model is presented in Appendix 4.

Table 9 CRF codes in wich emissions and energy use from non-road machinery are reported

CRF- code	Category description
1.A.2.g.vii	Industry (including construction)
1.A.4.a.ii	Commercial/institutional
1.A.4.b.ii	Residential
1.A.4.c.ii	Agriculture/forestry (land-based)
1.A.3.e.ii	Other transportation, other (airports, harbour etc.)
1.A.5.b	Other, mobile (military)

Table 10 shows how the distribution of estimated national CO_2 emissions (2013) has changed after the updates made in this study.

Table 10 CO_2 emission fraction per CRF-sector according to the model; before updates described in this report (left), after updated allocation scheme (middle), updated allocation scheme and other updates described in this report (right).

		CO2		
		Old	New allocation	New allocation and other updates
1A2g vii	Industry	44 %	39 %	40 %
1A3e ii	Other transport	13 %	10 %	9 %
1A4a ii	Commercial/institutional	-	9 %	8 %
1A4b ii	Residential	12 %	11 %	11 %
1A4c ii	Agriculture	22 %	14 %	14 %
1A4c ii	Forestry	9 %	17 %	18 %
1A5b	Military	-	0%	0 %

4.6 Alternative fuels

The model was updated to include more fuels than just diesel and gasoline. The added fuels are biodiesel (not blended), methane, dual fuel (diesel and methane), ED95 and E85. There is also an option to specify components in all fuels, e.g. the share of biodiesel in conventional diesel or share of biogas/natural gas of used methane.

Emission factors and fuel consumption factors for the added fuels are based on the corresponding factors for diesel or petrol but are adjusted with correction factors according to Table 11. The correction factors are mass-based. The factors are basically taken from data for trucks (Euro V) from the COPERT 4 model (Emisia, 2015). For the dual fuel engine it is assumed that 50% of the energy comes from methane and 50% from diesel (Olofsson 2014). The thermal efficiency for the methane engine is set to 0.72 relative to a normal diesel engine (Olofsson 2014). For E85 the efficiency is set as the same as for a gasoline engine while it is set to the same value as for a diesel engine for the other fuels.

Table 11 Mass based correction factors for estimating fuel consumption and emissions of different fuels.

Fuel	Related to:	Fuel	NOX	N2O	NH3	NMVOC	CH4	CO	PM
Methane	Diesel	1.3	0.62	1	1	0.11	5.9	1.9	0.55
Dual Fuel	Diesel	0.97	0.62	1	1	0.11	5.9	1.9	0.55
ED95	Diesel	1.64	0.56	1	1	0.85	1.38	1.81	0.08
Biodiesel	Diesel	1.16	1.07	1	1	0.71	0.71	0.80	0.88
E85	Petrol	1.51	0.90	1	1	0.85	1.38	0.95	0.54

4.6.1 Projections

In this section results from made up scenarios are presented. The aim is to show how the model makes a projection and how it handles alternative fuels.

The energy projection used in the model is based on data from the Swedish Energy Agency (Swedish EPA, 2015) and is shown in Table 12 as a relative percentage change in energy use 2011-2030.

Table 12 Relative percentage change in energy use in non-road mobile machinery from 2011 to 2030.

CRF	Fuel	2011-2015	2011-2020	2011-2025	2011-2030
1A2g vii	Petrol	0.00	0.00	0.00	0.00
1A2g vii	Diesel	0.82	1.86	2.92	3.99
1A3e ii	Petrol	0.00	0.00	0.00	0.00
1A3e ii	Diesel	0.00	0.00	0.00	0.00
1A4a ii	Petrol	0.00	0.00	0.00	0.00
1A4a ii	Diesel	0.00	0.00	0.00	0.00
1A4b ii	Petrol	0.00	0.00	0.00	0.00
1A4b ii	Diesel	0.00	0.00	0.00	0.00
1A4c-agriculture	Petrol	0.00	0.00	0.00	0.00
1A4c-agriculture	Diesel	-15.00	-21.20	-27.41	-29.17
1A4c-Forestry	Petrol	0.00	0.00	0.00	0.00
1A4c-Forestry	Diesel	-4.73	-8.41	-8.41	-6.23
1A5b	Petrol	0.00	0.00	0.00	0.00
1A5b	Diesel	0.00	0.00	0.00	0.00

Emissions were calculated based on three scenarios:

Base Scenario: No transition from diesel or petrol to alternative fuels.

Scenario 1: The share of diesel fuelled machines of the total sold machines (37-560 kW) decreases with 2 % per year from 2015-2020 and with 4 % per year from 2020-2030. These machines will be replaced by equal shares of machines fuelled with methane, methane and diesel (dual fuel), ED95 and biodiesel. It was assumed that there will be no transition from petrol to E85.

Scenario 2: The share of diesel fuelled machines of the total sold machines (37-560 kW) decreases with 2 % per year from 2015-2020 and with 4 % per year from 2020-2030. These machines will be replaced by machines fuelled with ED95. It was assumed that there will be no transition from petrol to E85.

Scenario 3: The share of diesel fuelled machines of the total sold machines (37-560 kW) decreases with 2 % per year from 2015-2020 and with 4 % per year from 2020-2030. These machines will be replaced by machines fuelled with biodiesel. It was assumed that there will be no transition from petrol to E85.

The calculated emissions of CO_2 and NOx using the described scenarios are shown in Figure 2 and Figure 3. As can be seen the NOx emissions will not be significantly affected by the fuel changes in the scenarios. In Scenario 1 and Scenario 2 the NOx emissions decrease by 5 % in 2030 compared to the Base Scenario. Scenario 3 will lead to an increase of approximately 1 % in 2030 compared to the Base Scenario. The decrease in fossil CO_2 will be 17 %, 22 % and 23 % for Scenario 1, Scenario 2 and Scenario 3 respectively.

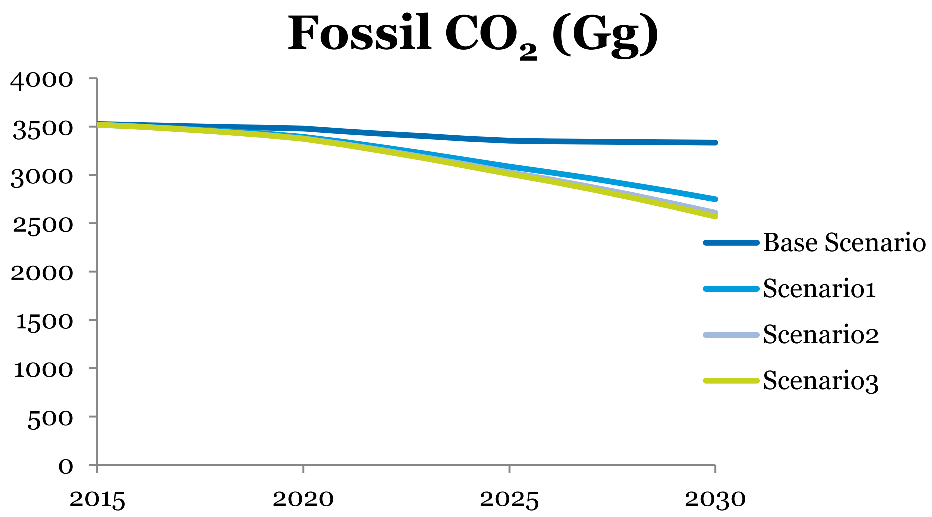

Figure 2 Calculated fossil CO_2 emissions 2015-2013 for the used scenarios.

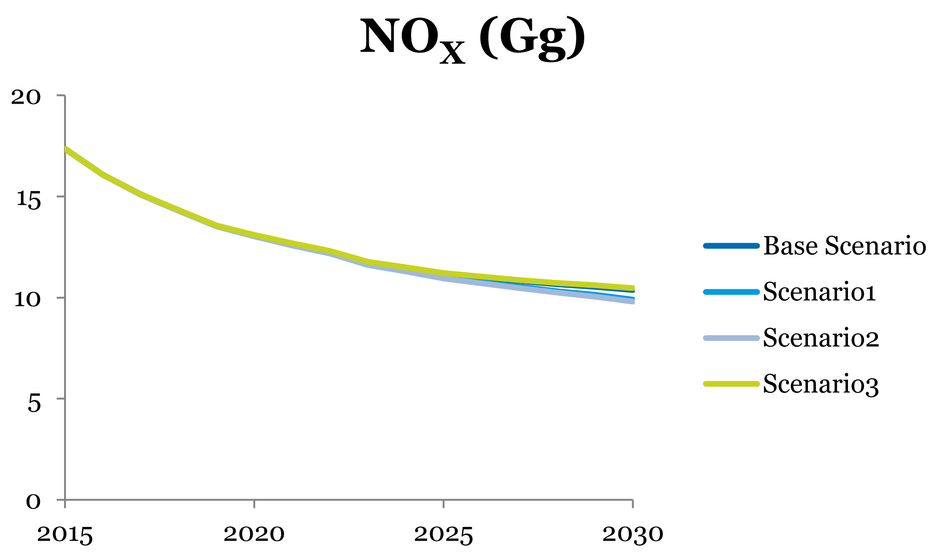

Figure 3 Calculated NOx emissions 2015-2013 for the used scenarios.

4.7 Other updates

Some corrections of the model that originally not were within the scope of this study were made since the need emerged. The corrections are listed below.

1. The 37-75 kW tractor population from 1991 to 2000 was updated since SCB, who has provided all tractor stock data to the model, identified that the population of industry tractors had been mixed up with residential tractors. Since the model use different annual work hours, load factors etc. for industry tractors and residential tractors this affects the calculated emissions and fuel use not only on sectoral level but also on a national level.
2. The load factor for mobile cranes (37-56 kW) was set to 40 %. In the previous model version a load factor was missing, resulting in no emissions from this machine category even if the population was estimated to 81 vehicles in 2013.
3. Some minor corrections of base emission factors that was found incorrect.

The update of tractor population is the only one of these updates that lead to significant changes in the estimated emissions and fuel consumption, which can be seen in the following chapter.

5 Effects of model updates on CO_2, NO_X and TSP

This section describes changes in estimated national total emissions due to the model updates described in Chapter 4.

Figure 4 to Figure 6 show contributions from each update to the total difference between the old and the updated model version. The updated emission factors and the load factor for mobile cranes described in Section 4.7, are reported together in the staple named “Other”. The figures represent emission year 2013.

Similar figures representing other years would show similar trends with the exceptions of the contribution from machines > 560 kW, which would increase between 1990 and 2013, and the changed tractor population which affects 1991-2000. Figure 7 shows how the different updates influence the CO2 trend from 1990 to 2013.

The figures show contributions from each update individually but not the combined effect of two updates. For example, adding machines > 560 kW and at the same time adding load dependent fuel consumption factors will not give the same contribution as if doing these two updates separately and adding the results. This means that the sum of all individual updates is not equal to the same total as if calculating the combined effect of all updates, though the differences are relatively small.

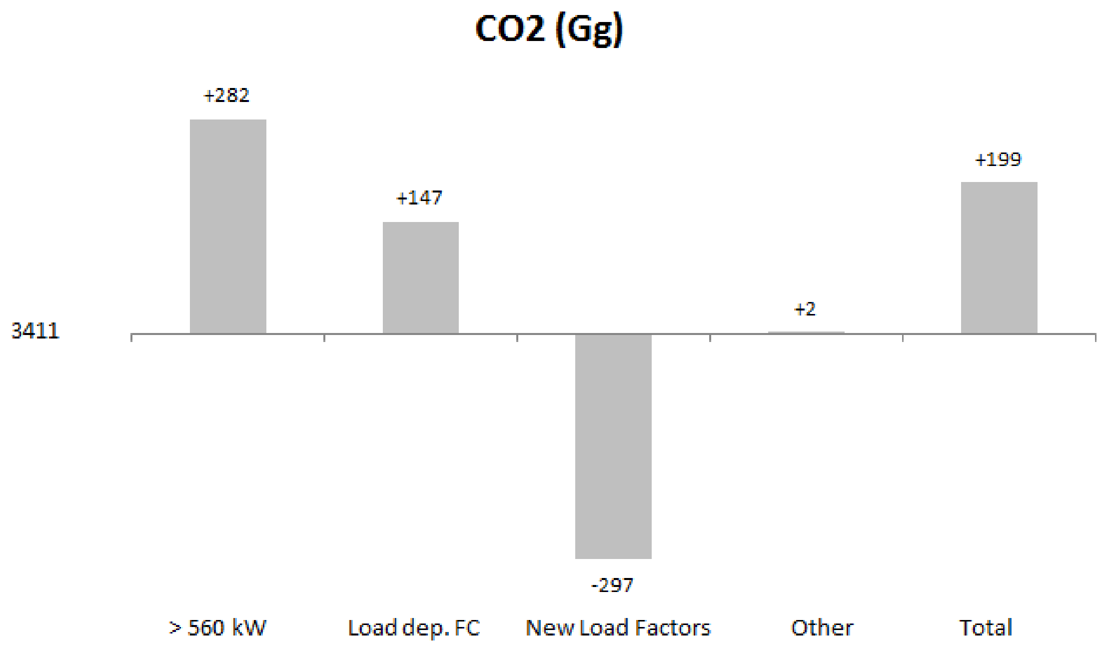

Figure 4 CO_2 emissions 2013 calculated with the old model version (3411 Gg) and contributions from the different updates to the new total.

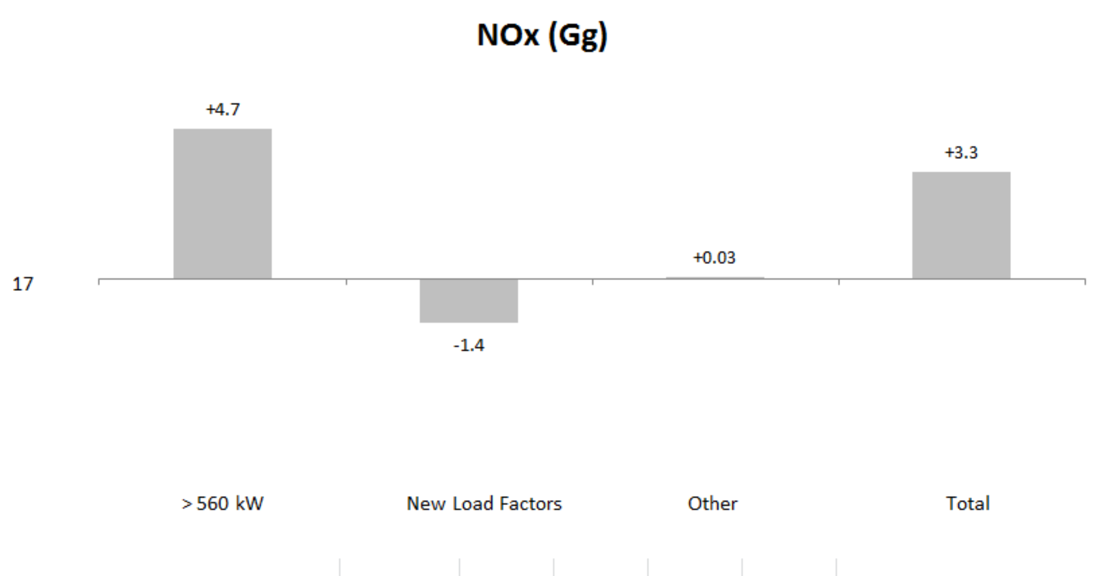

Figure 5 NOx emissions 2013 calculated with the old model version (17 Gg) and contributions from the different updates to the new total.

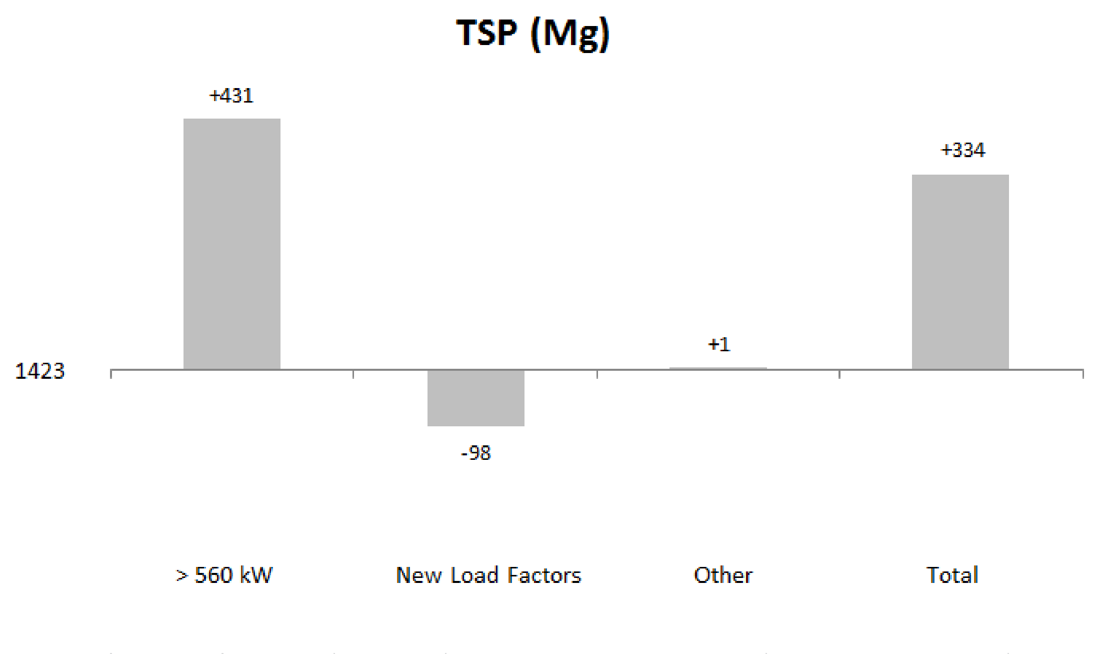

Figure 6 TSP emissions 2013 calculated with the old model version (1423 Mg) and contributions from the different updates to the new total.

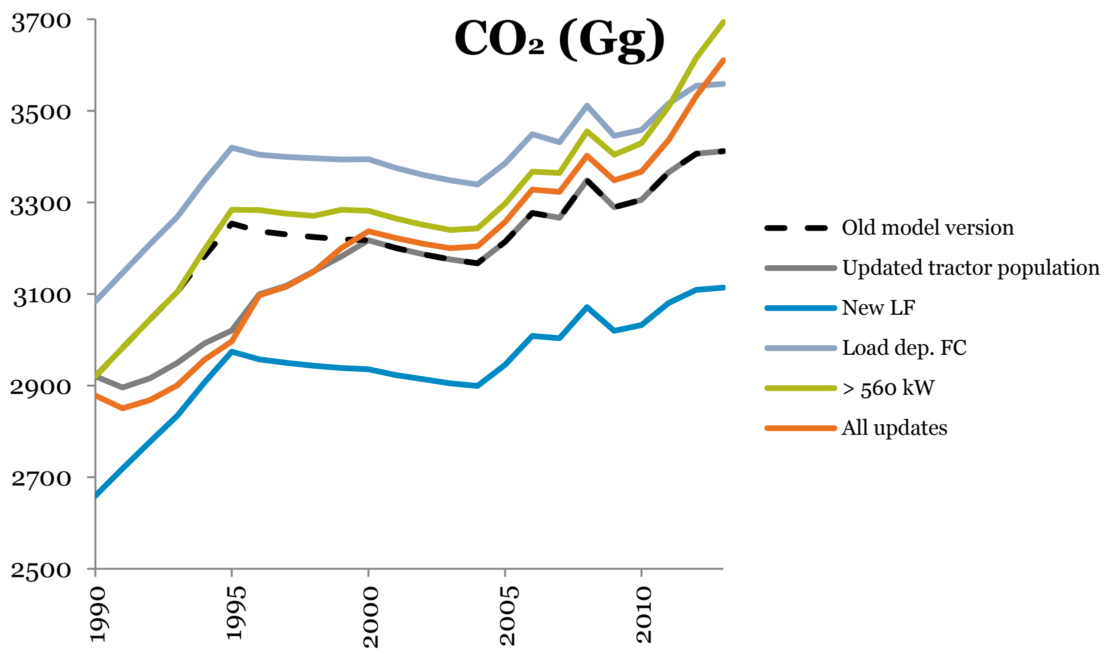

Figure 7 CO_2 emissions 1990-2010 (note scale of the y-axis).

6 Emission trends, 1990-2014

This section shows emission trends of CO2, NO_X, TSP and NMVOC calculated with the updated model compared to the old model version (Figure 8 to Figure 10) and contributions from the five main machine categories used in the model as calculated with the updated model (Figure 12 to Figure 15).

The largest discrepancy in emission estimates when comparing the model versions is seen for the years 1991-2000. This difference is due to the updated load factors (see section 4.2) and the updated tractor population (se section 4.7).

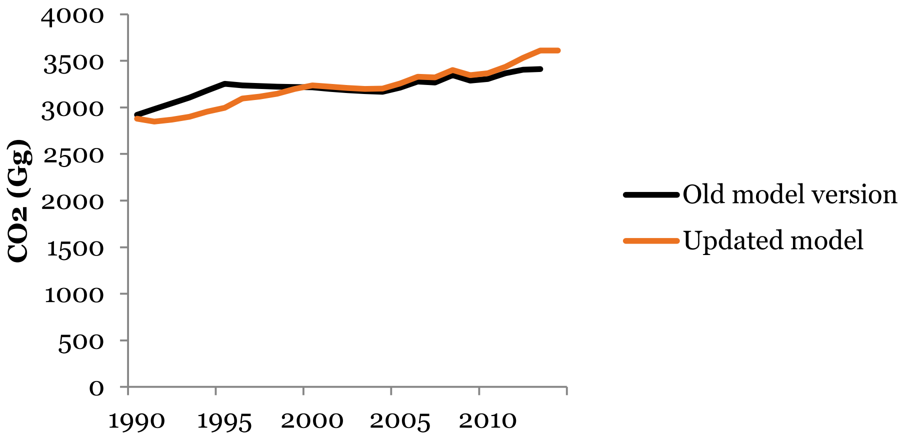

Figure 8 CO_2 emissions 1990-2014.

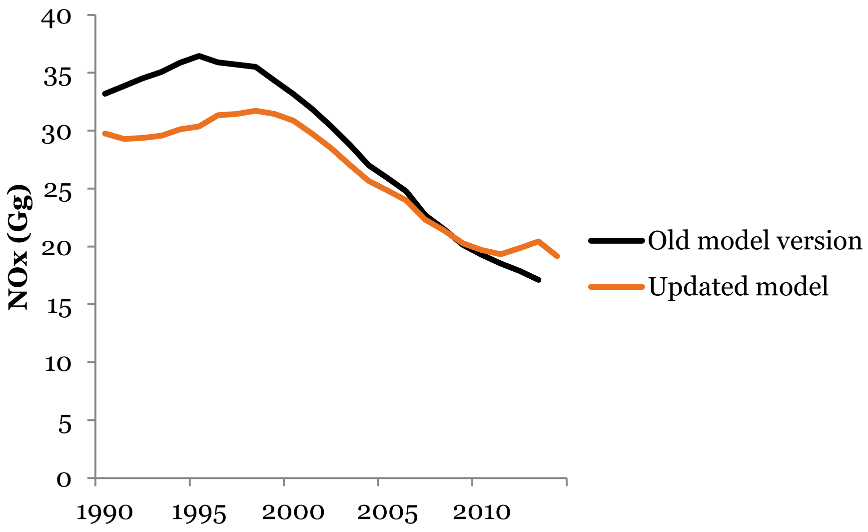

Figure 9 NO_X emissions 1990-2014.

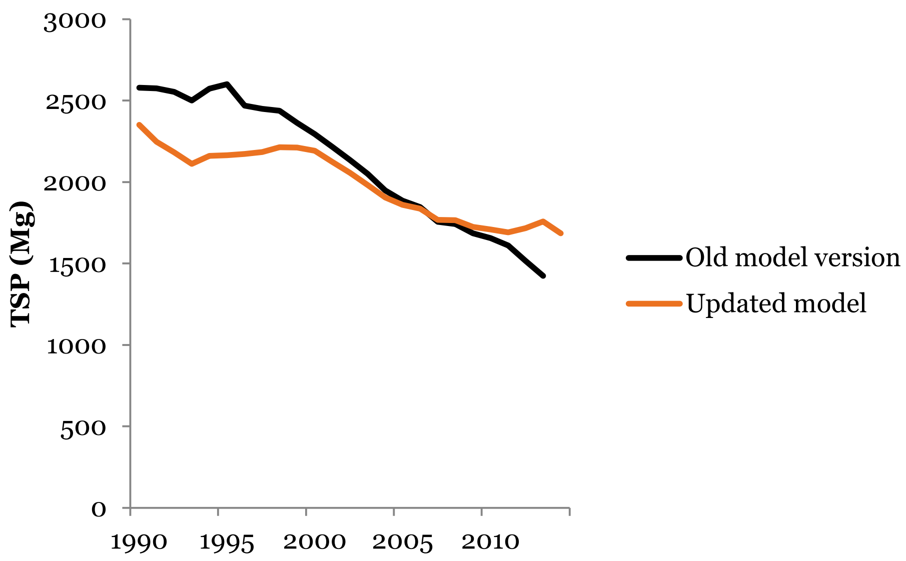

Figure 10 TSP emissions 1990-2014.

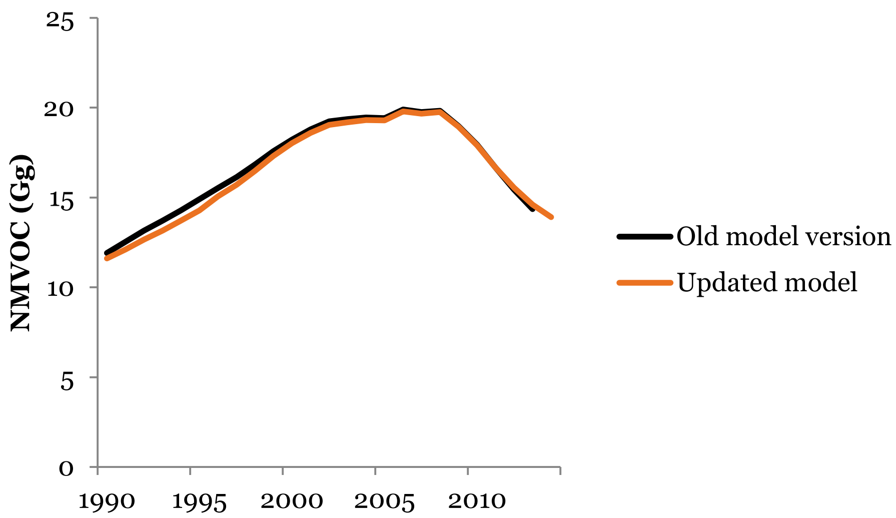

Figure 11 NMVOC emissions 1990-2014.

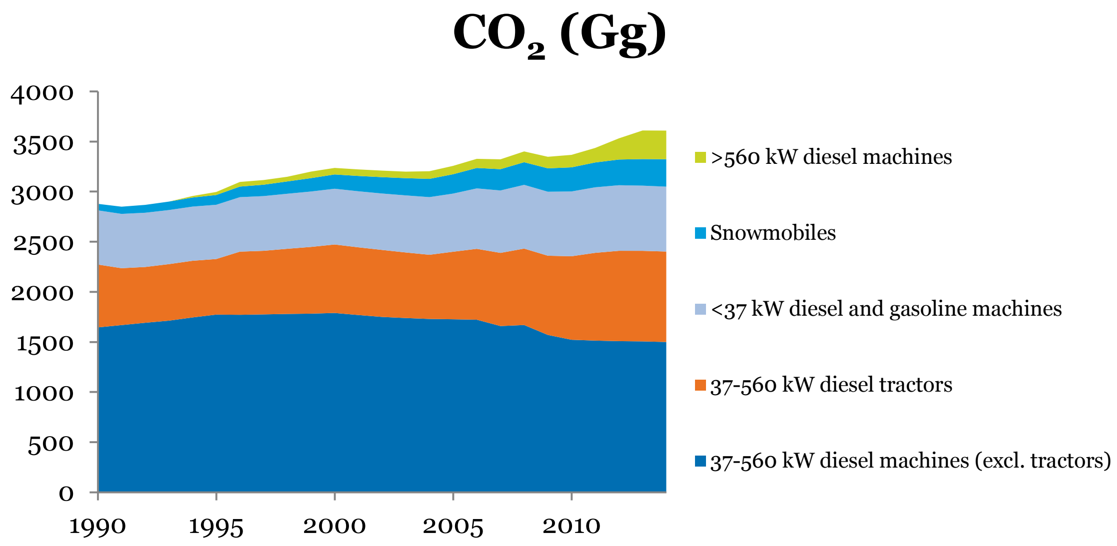

Figure 12 CO_2 emissions 1990-2014.

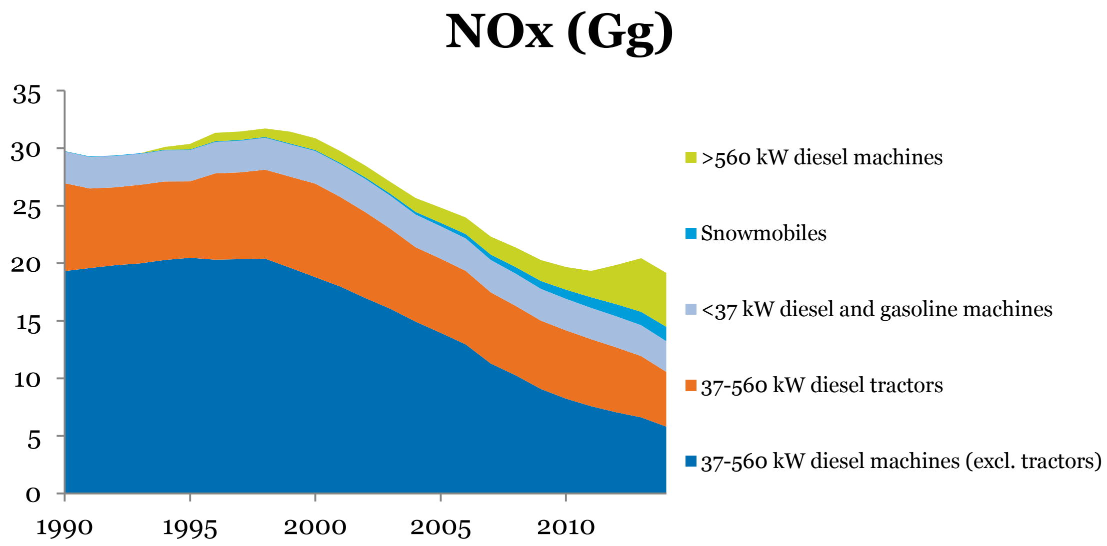

Figure 13 NO_X emissions 1990-2014.

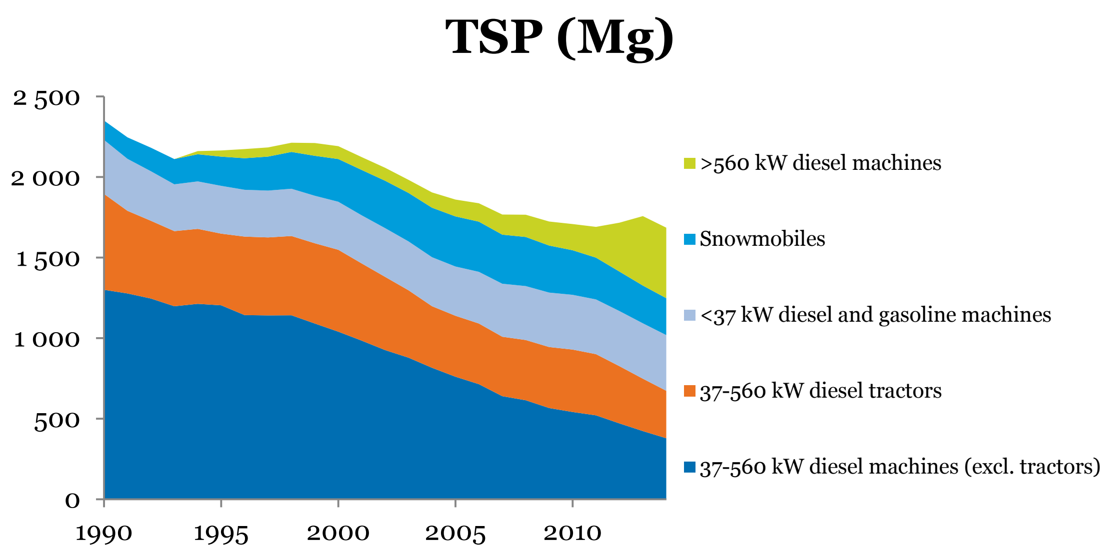

Figure 14 TSP emissions 1990-2014.

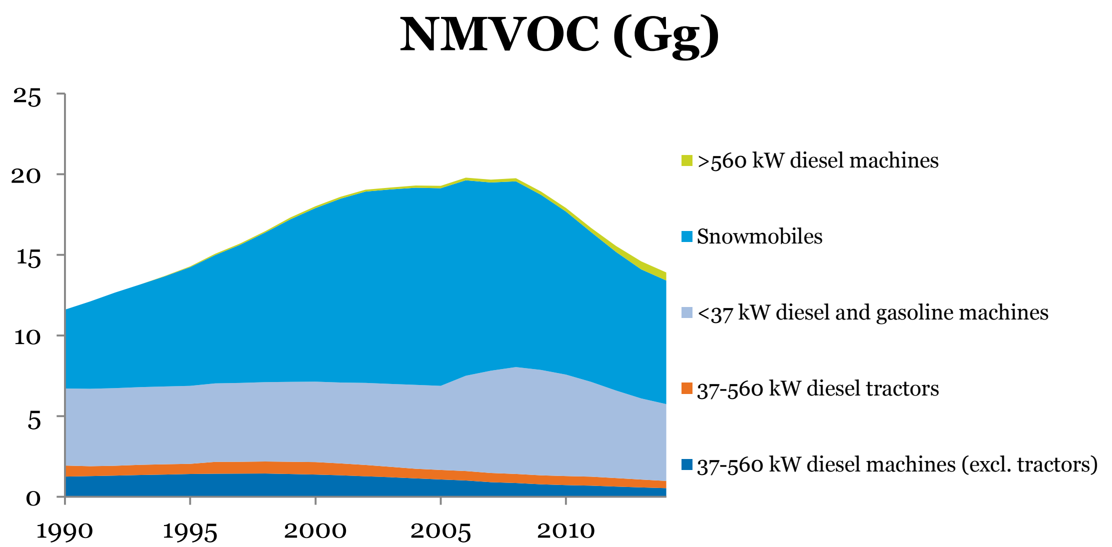

Figure 15 NMVOC emissions 1990-2014.

7 Uncertainty analysis

Within this study an analysis is done on what the uncertainties are in the resulting emission calculations. This has been done using a certain machine type as an example. It has been chosen to study wheel loaders in the power range 130-560 kW. The reason is that in-use data from on-board data systems were available for this machine type – regarding usage - from two major machine manufacturers.

The uncertainty analysis is done using the Monte Carlo method and the software package @Risk (Pallisade, 2015). Within the Monte Carlo model uncertainty distributions are assigned to all input parameters and then calculations are done using random numbers within these distributions. This essentially means that the calculations are done many times (thousands) and the value for each parameter is determined by a random value within the distribution. The resulting distribution is then analysed by statistical methods.

For the case of the wheel loaders the yearly fuel consumption and the NO_X emissions were analysed.

For the fuel consumption the basic equation is

$$FC = Hr * P * LF * SFC \qquad \text{Eq. 2}$$

where FC is the fuel consumption in gram [g], Hr is the number of operating hours [h], P is the engine power rating [kW], LF is the engine load factor (dimensionless, a value between 0 and 1) and SFC is the specific fuel consumption [g/kWh], i.e., mass of fuel consumed per engine output work. Correspondingly, the equation for estimating the emissions of CO_2, NO_X, etc. is formulated as:

$$E_i = Hr * P * LF * EF_i \qquad \text{Eq. 3}$$

where E_i is the emission in g of substance *i*, and EF_i is the emission factor stated in the unit g/kWh.

In the model these equations are used for a specific model-year. The contributions from the model years are then summed in order to get the emission for a reporting year.

Here follows a description of the in-data used in the analysis of uncertainties. All results are shown in Table 13.

Hr – the yearly hours the machine is used – is in NRMMM taken from data from readings of the usage time done at the yearly inspection of the machines. For the uncertainty we use data from machine deliverers showing the actual annual use of individual machines. The data is fitted to a distribution giving the spread. The average value for Hr is different in this data than what is used in the model, since only machines of more recent model years are covered - these machines are used more than older machines. Therefore the relative uncertainty is applied in the model.

For P the uncertainty is obtained in the same way and from the same data source as for Hr. Again the relative uncertainty from the data is applied in the model.

The LF is also obtained from these data (see Fridell and Bäckström, 2014) and the uncertainty is obtained from a fit as for Hr and P.

The SFC in the model is given as a basic value corrected with three correction factors for machine age, fuel quality and transient operation, respectively. The SFC values are taken from the model. The uncertainty for SFC is taken from data for large trucks presented by Kouridis et al. (2010) and used as a relative uncertainty. These data are used in view of lack of available data for the SFC for non-road machinery.

EF_{NOX} in the model is given by the legal limit and adjusted for machine age, fuel quality and transient operation. Again, uncertainty data are not available for NRMM and therefore taken from data for trucks from Kouridis et al. (2010).

Table 13 Parameters used in the uncertainty analysis.

Quantity	Value	Source	Uncertainty distribution	Moment	Source
Hr	Varies with machine age. Average is 1066 h.	NRMMM with origin in readings from yearly machine inspections.	Weibull	mean 1938 h; stdev 1242 h; relative stdev 0.64	Fitted distribution to data from actual machine operation
P	195-201 kW	Lindgren (2007)	Lognormal	Mean 236 kW, stdev 50 kW: relative stdev 0.21	Fitted distribution to data from actual machine operation
LF	28%	Fridell and Bäckström (2014)	Normal	0.066	Fitted distribution to data from actual machine operation
SFC	254 g/kWh	NRMMM	Lognormal	Relative stdev 0.04	Copert data for trucks
EF_{NOX}	Varies with model year	NRMMM	Lognormal	Varies with model year (from 27% for Euro 0 to 5% for Euro IIIb)	Copert data for trucks

For an emission inventory the average emission for a machine is of interest. Thus, the variability from machine to machine is not the primary interest but rather how well the average is described and the uncertainty in the average. The variability in the average and for individual machines is connected through the standard deviation of the average being equal to the standard deviation of the variability divided by the square root of the number of observations (number of machines with data). In the model the uncertainty is obtained by using the uncertainty of the average for each model year and then analysing the total uncertainty from this. The results are presented in Table 14.

Table 14 Calculated fuel consumption and NOx emission.

Parameter	Value (tonne/year)	Uncertainty (SD)
Fuel consumption Sweden	58000	507
NO_X emissions	891	9.0
Fuel consumption one machine	42	23

Using the uncertainty in the variability rather than the uncertainty of the average the standard deviation becomes much larger (9300 tonne/year for fuel and 131 tonne/year for NO_X).

The model may also be used to calculate the emissions and fuel consumption for a specific machine. In this case the variability between individual machines must be considered and the uncertainty becomes large mainly through the variability in the yearly operation time.

8 Completeness of the model regarding machine types

The relevance and completeness of the machine categorisation in the model was reviewed. Questions asked were: Is the model's categorisation in line with, e.g. the 2006 IPCC Guidelines and do the current categories cover all non-road mobile machinery used in Sweden? The review is based on information given in the literature, mainly IPCC (2006), EEA (2013), Winther and Nielsen (2006), Off-highway research (2012) and Arcadis (2010).

In the analysis of guidelines and other literature, all kinds of mobile machinery that occurred were identified, categorised and in a few cases somewhat simplified. The analysis covers all land-based non-road machineries (except rail engines), their characteristics, sector they are used in and relevance (some do not exist in Sweden).

The outcome is a list (Appendix 5) of machinery categories organised by sectors, where some categories may be similar but are used in different sectors and therefore consequently have different characteristics and/or may be used in a different way. The list is intended to be matching the categorisation in current model, to evaluate its relevance and completeness.

Although a difficulty in the review was that the categories in the current model are given in Swedish and the categories in the literature are given in English, still an attempt to match the categories was done. The review resulted in a grouping of categories from the literature, namely;

1. Machine types that easily could be matched with the NRMMM.
2. Machine types that have no obvious correspondence in the NRMMM, but could be allocated to an existing category after consideration.
3. Machine types that most likely not have a separate engine, but is an attachment to another machine (mainly within agriculture).
4. Machine types that could not be found in the NRMMM and consequently are considered as "missing".
5. Machine types that are considered as missing in the NRMMM but are judged as not relevant for various reasons.

From the review it can be seen that the vast majority of the machine types found in the literature could be sorted and categorized into the existing Swedish model. Why the Swedish model contains far fewer categories than found in the literature, is explained by that earlier inventories in Sweden show that many machine types appear in very small numbers and account for a very small share of the total emissions, accordingly, they are aggregated into fewer “other”- or “Truck/Tractor”-like categories. This is especially clear when it comes to the category “Övrigt” in the model, which sum up “Other” machines with no respect to sector, and contains a number of machine types that are clearly known but not reasonable to separate because of their small influence on fuel consumption and emissions.

Machine types found in the literature and guidelines but not found in the NRMMM that probably do not have a separate engine, but are just attached to other machines, are presented in Table 15:

Table 15 Auxiliary machines without own separate power supply.

English name in literature	*Swedish translation, proposed*
Land roller (agriculture)	Åkervält
Agriculture Mowers	Slåttermaskin
Swatcher (agriculture)	Slåttermaskin
Baler	Balpress
Manure distributors	Gödselspridare
Sprayer (agriculture)	Spridare/Sprayare agri
Tiller (agriculture)	Plog

Some machine type categories that appear in the literature and in the guidelines are not found at all in the NRMMM even after considering re-categorization. However, some of these machine types have uncertain relevance for various reasons (see Comment, explanation-field). These are presented in Table 16.

Table 16 Missing machine types in the current Swedish model.

English name in literature	*Swedish translation, proposed*	*Comment, explanation*
Ice rink machine	Ismaskin	
Piste grooming machine	Pistmaskin	
Drill rig	Borrigg	
Scraper, motor scraper	Markskrapa	No market in Sweden (Off highway-research, 2012)
Pipe layer	Rörläggare	
Piling machine	Pålningsmaskin	
Aerial lift	Skylift	
Suction machine	Sugmaskin	Unsettled translation/definition
Refuse compressor	Kompressor lastbil	Road vehicle
Air compressor	Kompressor	
Leaf blower/vacuum	Lövblåsare	
Peat breaking machine	Torvbrytningsmaskin	
Blower	Industriblåsmaskin	Unsettled translation/definition
Broomer	Sop-/borstmaskin	Unsettled translation/definition
Vacuums	Industridammsugare	Unsettled translation/definition
Sweeper, scrubber	Sopmaskin våt	Unsettled translation/definition
Welder	Svetsmaskin	Electrified
Garden shredder	Kompostkvarn	
Cement mixer	Cementblandare	Electrified
Rod cutter	Vinkelslip	Electrified
Wood splitter, wood cutters	Vedklyvare	Electrified

8.1 Conclusions from completeness review

From the completeness review it can be said that the NRMMM most likely includes all machines that may have a significant impact on the total fuel consumption and emissions from non-road machines in Sweden. One exception may be piste grooming machines which may have significant yearly fuel consumption. This is also a conclusion that was drawn from the workshop described in Section 3.

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Appendix 1 Emission factors from PEMS measurements

The table in this appendix is from USEPA (2012).

Equipment type	Manufacturer	Model	Model Year	Rated HP	Tier	Test Time (mins)	Fuel Used (gals)	CO2	CO	THC	NOx	Range
									(g/kW-hr)			
Backhoe loader	JC Bamford Exc	1085B	1985	64	Tier 0	61	0.79	-	-	-	-	50 ≤ hp < 100
Backhoe loader	John Deere	963	1985	75	Tier 0	8.7	1.1	-	-	-	-	50 ≤ hp < 100
Well Driller	Cummins/JW Bell	963	1985	76	Tier 0	-	-	0.709	3.7	2.3	12.46	50 ≤ hp < 100
Wheel loader	Case	953	1988	63	Tier 0	95	5.5	-	-	-	-	50 ≤ hp < 100
Backhoe loader	John Deere	963CB	1995	75	Tier 0	15	0.69	0.712	2.4	1.2	11.292	50 ≤ hp < 100
Crawler Dozer	Caterpillar	963CB	1995	87	Tier 0	111	10	0.752	3.9	-	13.68	50 ≤ hp < 100
Crawler Dozer	Caterpillar	12H	1996	87	Tier 0	483	-	0.736	3.9	-	13.26	50 ≤ hp < 100
Tractor Loader	Case	320B	1997	68	Tier 0	114	9.0	0.725	6.2	2.6	13.72	50 ≤ hp < 100
Roller Compactor	Hyster	D6RXL	1997	83	Tier 0	86	5.8	-	-	-	-	50 ≤ hp < 100
Crawler Dozer	John Deere	953C	1999	84	Tier 1	136	9.3	0.726	1.5	0.52	6.71	50 ≤ hp < 100
Boring Machine	Vermeer	TH83	2002	64	Tier 2	57	1.1	-	-	-	-	50 ≤ hp < 100
Backhoe loader	John Deere	TH84	2002	84	Tier 2	188	3.4	-	-	1.4	18.269	50 ≤ hp < 100
Backhoe loader	John Deere	963C	2002	84	Tier 2	161	12	0.735	3.5	0.71	8.963	50 ≤ hp < 100
Excavator	Case	544H	2003	120	Tier 0	263	9.0	0.682	5.8	4.1	17.443	100 ≤ hp < 175
Track dozer	Caterpillar	953C	2004	150	Tier 0	305	16	0.739	4.4	1.5	7.653	100 ≤ hp < 175
Track Dozer	Caterpillar	WA180	Unk	150	Tier 0	424	8.3	-	-	-	-	100 ≤ hp < 175
Track Dozer	Caterpillar	963B	1998	121	Tier 0	17	1.2	0.745	3.4	0.45	8.959	100 ≤ hp < 175
Track dozer	Caterpillar	963B	1998	160	Tier 0	186	15	0.722	3.2	0.70	7.345	100 ≤ hp < 175
Track dozer	Caterpillar	PC300LC-6LC	1998	160	Tier 0	265	21	0.705	2.9	0.78	6.826	100 ≤ hp < 175
Grader	Caterpillar	PC300LC	2003	140	Tier 0	483	33	-	-	-	-	100 ≤ hp < 175
Excavator	Caterpillar	GD655	2005	128	Tier 1	7.2	0.28	0.736	1.3	0.74	7.596	100 ≤ hp < 175

Equipment type	**Manufacturer**	**Model**	**Model Year**	**Rated HP**	**Tier**	**Test Time (mins)**	**Fuel Used (gals)**	**CO2**	**CO** (g/kW-hr)	**THC**	**NOx**	**Range**
Track dozer	Caterpillar	PC400LC	1993	175	Tier 1	269	31	0.73	3.6	0.98	4.57	100 ≤ hp < 175
Track Dozer	Caterpillar	PC400LC	2000	170	Tier 1	606	77	-	-	0.72	8.47	100 ≤ hp < 175
Telescopic Lift	Caterpillar	325D	2006	101	Tier 1	327	27	1.035	2.2	0.59	10.46	100 ≤ hp < 175
Telescopic Lift	Caterpillar	450D	2006	101	Tier 1	344	37	1.182	2.4	0.50	11.35	100 ≤ hp < 175
Truck loader	Caterpillar	450D	2006	160	Tier 1	82	0.64	0.679	1.3	0.59	7.97	100 ≤ hp < 175
Articulated Loader	John Deere	210S Series 2	1977	130	Tier 2	-	-	0.721	2.6	0.68	7.49	100 ≤ hp < 175
Track loader	Caterpillar	410B Turbo	1983	128	Tier 2	206	4.4	1.211	2.9	0.35	7.5	100 ≤ hp < 175
Articulated Loader	Komatsu	4B-3.9	1987	124	Unk	400	8.7	0.725	3.5	3.0	17.654	100 ≤ hp < 175
Track dozer	Caterpillar	480FLL	1992	220	Tier 1	275	2.8	0.717	2.3	0.47	6.838	175 ≤ hp < 300
Track dozer	Caterpillar	410D Turbo	1995	220	Tier 1	68	1.5	0.735	1.9	0.32	7.184	175 ≤ hp < 300
Excavator	Komatsu	D4CXL	1996	232	Tier 1	100	3.4	0.69	1.2	0.53	9.42	175 ≤ hp < 300
Excavator	komatsu	D4CXL	1996	255	Tier 2	470	13	0.805	2.2	0.65	5.061	175 ≤ hp < 300
Grader	Komatsu	570 LXT	1997	197	Tier 2	215	2.1	-	-	-	-	175 ≤ hp < 300
Excavator	Komatsu	C340C	1997	330	Tier 0	186	-	0.936	1.6	0.75	12.859	300 ≤ hp < 600
Excavator	Komatsu	550H	1999	321	Tier 1	244	8.7	0.685	1.3	0.35	5.394	300 ≤ hp < 600
Track Excavator	Caterpillar	Navigator D16x20A	2006	300	Tier 3	-	-	0.787	2.3	0.58	3.44	300 ≤ hp < 600
Excavator	John Deere	310G	2006	349	Tier 3	168	2.1	0.659	1.0	0.20	3.971	300 ≤ hp < 600
Excavator	John Deere	310J	2007	349	Tier 3	365	8.4	-	-	-	-	300 ≤ hp < 600

Appendix 2 – Stage V emission limits

This appendix contains Stage V emission limits for the engine sub categories NRE, NRG, NRS and NRSh. The categories are briefly described. A more detailed description can be found in European Commission (2014a).

Stage V emission limits for engine category NRE (European Commission, 2014b).

Emission stage	Engine sub-category	Power range	Engine ignition type	CO	HC	NOx	PM mass	PN
		kW		**g/kWh**	**g/kWh**	**g/kWh**	**g/kWh**	**#/kWh**
Stage V	NRE-v-1 NRE-c-1	0<P<8	CI	8.00	(HC+NOx≤7.50)		0.40[1)]	-
Stage V	NRE-v-2 NRE-c-2	8≤P<19	CI	6.60	(HC+NOx≤7.50)		0.40	-
Stage V	NRE-v-3 NRE-c-3	19≤P<37	CI	5.00	(HC+NOx≤4.70)		0.015	$1x10^{12}$
Stage V	NRE-v-4 NRE-c-4	37≤P<56	CI	5.00	(HC+NOx≤4.70)		0.015	$1x10^{12}$
Stage V	NRE-v-5 NRE-c-5	56≤P<130	all	5.00	0.19	0.40	0.015	$1x10^{12}$
Stage V	NRE-v-6 NRE-c-6	130≤P≤560	all	3.50	0.19	0.40	0.015	$1x10^{12}$
Stage V	NRE-v-7 NRE-c-7	P>560	all	3.50	0.19	3.50	0.045	-

1) 0.6 for hand-startable, air-cooled direct injection engines

Category NRE', comprising:

(a) engines for non-road mobile machinery intended and suited to move, or to be moved by road or otherwise that are not excluded under Article 2(2) (see European Commission, 2014a) and are not included in any other category set out in points (2) to (10) (see European Commission, 2014a).

Stage V emission limits for engine category NRG (European Commission, 2014b).

Emission stage	Engine sub-category	Power range	Engine ignition type	CO	HC	NOx	PM mass	PN
		kW		**g/kWh**	**g/kWh**	**g/kWh**	**g/kWh**	**#/kWh**
Stage V	NRG-v-1 NRG-c-1	P>560	alla	3.50	0.19	0.67	0.035	-

Category NRG, comprising engines having a reference power that is greater than 560 kW exclusively for use in generating sets.

Engines for generating sets other than those having the characteristics set out in the first sub-paragraph shall be included in the categories NRE or NRS, according to their characteristics;

Stage V emission limits for engine category NRSh (European Commission, 2014b).

Emission stage	Engine sub-category	Power range	Engine ignition type	CO	HC + NOx
		kW		**g/kWh**	**g/kWh**
Stage V	NRSh-v-1a	0<P<19	SI	805	50
Stage V	NRSh-v-1b			603	72

Category NRSh, comprising hand-held SI engines having a reference power that is less than 19 kW exclusively for use in hand-held machinery.

Stage V emission limits for engine category NRS (European Commission, 2014b).

Emission stage	Engine sub-category	Power range	Engine ignition type	CO	HC + NOx
		kW		**g/kWh**	**g/kWh**
Stage V	NRS-vr-1a NRS-vi-1a	0<P<19	SI	610	10
Stage V	NRS-vr-1b NRS-vi-1b			610	8
Stage V	NRS-v-2a	19≤P≤30		610	8
Stage V	NRS-v-2b NRS-v-3	19≤P<56		4.40*	2.70*

* Optionally, as alternative, any combination of values satisfying the equation (HC+NOX) × CO 0.784 ≤ 8.57 as well as the following conditions: CO ≤ 20,6 g/kWh and (HC+NOX) ≤ 2,7 g/kWh.

Category NRS, comprising SI engines, having a reference power that is less than 56 kW and not included in category NRSh.

Appendix 3 – Allocation scheme

Machine type	Sector	Engine power	Fuel	Technology	1A2g vii	1A3e	1A4a	1A4b	1A4c	1A4c	1A5b
Traktor	Jord-/skogsbruk	37-75	Diesel		0%	0%	0%	0%	50%	50%	0%
Traktor	Jord-/skogsbruk	75-130	Diesel		0%	0%	0%	0%	50%	50%	0%
Traktor	Jord-/skogsbruk	130-560	Diesel		0%	0%	0%	0%	50%	50%	0%
Traktor	Samhälle	37-75	Diesel		0%	0%	100%	0%	0%	0%	0%
Traktor	Samhälle	75-130	Diesel		0%	0%	100%	0%	0%	0%	0%
Traktor	Samhälle	130-560	Diesel		0%	0%	100%	0%	0%	0%	0%
Traktor	Industri	37-75	Diesel		99%	1%	0%	0%	0%	0%	0%
Traktor	Industri	75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Traktor	Industri	130-560	Diesel		0%	100%	0%	0%	0%	0%	0%
Hjullastare		>560	Diesel		100%	0%	0%	0%	0%	0%	0%
Truck		>560	Diesel		100%	0%	0%	0%	0%	0%	0%
Slaghack		>560	Diesel		0%	0%	0%	0%	100%	0%	0%
Exakthack		>560	Diesel		0%	0%	0%	0%	100%	0%	0%
Generatoraggregat		>560	Diesel		87%	2%	11%	0%	0%	0%	0%
Skördetröska		37-75	Diesel		0%	0%	0%	0%	100%	0%	0%
Skördetröska		75-130	Diesel		0%	0%	0%	0%	100%	0%	0%
Skördetröska		130-560	Diesel		0%	0%	0%	0%	100%	0%	0%
Skotare		37-75	Diesel		0%	0%	0%	0%	0%	100%	0%
Skotare		75-130	Diesel		0%	0%	0%	0%	0%	100%	0%
Skotare		130-560	Diesel		0%	0%	0%	0%	0%	100%	0%
Skördare		37-75	Diesel		0%	0%	0%	0%	0%	100%	0%
Skördare		75-130	Diesel		0%	0%	0%	0%	0%	100%	0%
Skördare		130-560	Diesel		0%	0%	0%	0%	0%	100%	0%
Hjullastare		37-75	Diesel		70%	30%	0%	0%	0%	0%	0%

Machine type	Sector	Engine power	Fuel	Technology	1A2g vii	1A3e	1A4a	1A4b	1A4c	1A4c	1A5b
Hjullastare		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Hjullastare		130-560	Diesel		75%	25%	0%	0%	0%	0%	0%
Grävlastare		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Grävlastare		75-130	Diesel		0%	0%	0%	0%	100%	0%	0%
Grävlastare		130-560	Diesel		0%	0%	0%	0%	100%	0%	0%
Bandgrävmaskin		<37	Diesel		100%	0%	0%	0%	0%	0%	0%
Bandgrävmaskin		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Bandgrävmaskin		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Bandgrävmaskin		130-560	Diesel		100%	0%	0%	0%	0%	0%	0%
Hjulgrävmaskin		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Hjulgrävmaskin		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Hjulgrävmaskin		130-560	Diesel		100%	0%	0%	0%	0%	0%	0%
Kompaktlastare		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Kompaktlastare		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Kompaktlastare		130-560	Diesel		100%	0%	0%	0%	0%	0%	0%
Dumper		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Dumper		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Dumper		130-560	Diesel		100%	0%	0%	0%	0%	0%	0%
Mobilkran		37-75	Diesel		100%	0%	0%	0%	0%	0%	0%
Mobilkran		75-130	Diesel		100%	0%	0%	0%	0%	0%	0%
Mobilkran		130-560	Diesel		91%	9%	0%	0%	0%	0%	0%
Truck		37-75	Diesel		10%	90%	0%	0%	0%	0%	0%
Truck		75-130	Diesel		98%	2%	0%	0%	0%	0%	0%
Truck		130-560	Diesel		69%	31%	0%	0%	0%	0%	0%
Övrigt		37-75	Diesel		0%	100%	0%	0%	0%	0%	0%
Övrigt		75-130	Diesel		3%	97%	0%	0%	0%	0%	0%
Övrigt		130-560	Diesel		11%	89%	0%	0%	0%	0%	0%

Machine type	Sector	Engine power	Fuel	Technology	1A2g vii	1A3e	1A4a	1A4b	1A4c	1A4c	1A5b
Övrigt	Banverket	20-37	Diesel		0%	100%	0%	0%	0%	0%	0%
Traktor	Hushåll	20-37	Diesel		0%	0%	0%	100%	0%	0%	0%
Traktor	Jordbruk	<20	Diesel		0%	0%	0%	0%	100%	0%	0%
Traktor	Jordbruk	20-37	Diesel		0%	0%	0%	0%	100%	0%	0%
Generatoraggregat	Entreprenad	<20	Diesel		100%	0%	0%	0%	0%	0%	0%
Sorteringsverk	Entreprenad	20-37	Diesel		100%	0%	0%	0%	0%	0%	0%
Vibratorplattor	Entreprenad	<20	Diesel		100%	0%	0%	0%	0%	0%	0%
Asfaltsågar	Entreprenad	<20	Diesel		100%	0%	0%	0%	0%	0%	0%
Pumpaggregat	Entreprenad	<20	Diesel		100%	0%	0%	0%	0%	0%	0%
Kedjegrävare/kabelplogar	Entreprenad	<20	Diesel		100%	0%	0%	0%	0%	0%	0%
Kylaggregat distribution	Övrigt	<20	Diesel		50%	0%	50%	0%	0%	0%	0%
Kylaggregat fjärr	Övrigt	<20	Diesel		50%	0%	50%	0%	0%	0%	0%
Frysaggregat fjärr	Övrigt	<20	Diesel		50%	0%	50%	0%	0%	0%	0%
Truck, motviktstruck bensin	Diverse	20-37	Bensin 4t	4-takt	50%	0%	50%	0%	0%	0%	0%
Minitraktor och hobbytraktor	Hushåll	20-37	Bensin 4t	4-takt	0%	0%	0%	100%	0%	0%	0%
Generatoraggregat	Entreprenad	<20	Bensin 4t	4-takt	100%	0%	0%	0%	0%	0%	0%
Vibratorstampar	Entreprenad	<20	Bensin 2t	2-takt	100%	0%	0%	0%	0%	0%	0%
Vibratorplattor	Entreprenad	<20	Bensin 4t	4-takt	100%	0%	0%	0%	0%	0%	0%
Asfaltsågar	Entreprenad	<20	Bensin 4t	4-takt	100%	0%	0%	0%	0%	0%	0%
Pumpaggregat	Entreprenad	<20	Bensin 4t	4-takt	100%	0%	0%	0%	0%	0%	0%
Häcksax (privat)	Hushåll	<20	Bensin 2t	2-takt	0%	0%	0%	100%	0%	0%	0%
Häcksax (yrkes)	Offentlig verksamhet	<20	Bensin 2t	2-takt	0%	0%	100%	0%	0%	0%	0%
Trimmer inkl. röjsåg (privat)	Hushåll	<20	Bensin 2t	2-takt	0%	0%	0%	100%	0%	0%	0%
Trimmer inkl. röjsåg (yrkes)	Offentlig verksamhet	<20	Bensin 2t	2-takt	0%	0%	100%	0%	0%	0%	0%
Jordfräs	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	50%	50%	0%	0%	0%
Högtryckstvättaggregat	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	50%	50%	0%	0%	0%
Gräsklippare, handledd (privat)	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	0%	100%	0%	0%	0%

Machine type	Sector	Engine power	Fuel	Technology	1A2g vii	1A3e	1A4a	1A4b	1A4c	1A4c	1A5b
Gräsklippare, handledd (yrkes)	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	100%	0%	0%	0%	0%
Snöslunga	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	50%	50%	0%	0%	0%
Gräsklippare, åkbar (privat)	Hushåll	<20	Bensin 4t	4-takt	0%	0%	0%	100%	0%	0%	0%
Gräsklippare, åkbar (yrkes)	Offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	100%	0%	0%	0%	0%
Högtryckstvättaggregat	Hushåll och offentlig verksamhet	<20	Bensin 4t	4-takt	0%	0%	50%	50%	0%	0%	0%
Motorsåg, fritid	Hushåll	<20	Bensin 2t	2-takt	0%	0%	0%	100%	0%	0%	0%
Motorkapare	Skogsbruk	<20	Bensin 2t	2-takt	0%	0%	0%	0%	0%	100%	0%
Motorsåg, yrkes	Skogsbruk	<20	Bensin 2t	2-takt	0%	0%	0%	0%	0%	100%	0%
Röjsåg	Skogsbruk	<20	Bensin 2t	2-takt	0%	0%	0%	0%	0%	100%	0%
Skoter	Yrkesbruk		Bensin	Konv 2-takt	0%	0%	0%	0%	100%	0%	0%
Skoter	Yrkesbruk		Bensin	2-takt EFI	0%	0%	0%	0%	100%	0%	0%
Skoter	Yrkesbruk		Bensin	2-takt direktin insp.	0%	0%	0%	0%	100%	0%	0%
Skoter	Yrkesbruk		Bensin	4-takt	0%	0%	0%	0%	100%	0%	0%
Skoter	Hushåll		Bensin	Konv 2-takt	0%	0%	0%	100%	0%	0%	0%
Skoter	Hushåll		Bensin	2-takt EFI	0%	0%	0%	100%	0%	0%	0%
Skoter	Hushåll		Bensin	2-takt direktin insp.	0%	0%	0%	100%	0%	0%	0%
Skoter	Hushåll		Bensin	4-takt	0%	0%	0%	100%	0%	0%	0%

Appendix 4 – Machine types

The table in this appendix shows machine types found in the literature, which sector they are used in and proposed Swedish translation. The abbreviations used in the table are explained below:

Sector: ag= agriculture; ci= commercial/ institutional; con=construction; i= industry; f= forestry; hg= household and garden; o= other

English name, proposed	Sector used in literature	Swedish translation	Other occuring English names
Agricultural tractor	ag	Jordbrukstraktor	
Harvester/Combines	ag	Skördetröska	Harvester, Combines
Other gasoline agri	ag	Övriga bensin jordb	
Land roller agri	ag	Åkervält	Tamper, Tamper roller
Agriculture Mowers	ag	Slåttermaskin	
Baler	ag	Balpress	
Manure distributors	ag	Gödselspridare	
Sprayer agri	ag	Spridare agri	
Swatcher agri	ag		
Tiller agri	ag	Plog	
Two-wheel tractor agri	ag	Tvåhjulstraktor	
Cultivator agri prof	ag	Jordfräs jordb prof	
Lawn mower prof	ci	Gräsklippare prof	
Riding mower prof	ci	Gräsklippare åkbar prof	Front mower, Lawn tractor, Garden tractor, Lawn and garden tractor
Refrigerating units short dist	ci	Kylaggregat kortdist	Refrigerating units
Refrigerating units long dist	ci	Kylaggregat långdist	Refrigerating units
Hedge cutter prof	ci	Häcksax prof	
Shrub clearer prof	ci	Buskság prof	slope and brush cutter, slope cutter
Trimmer prof	ci	Röjsåg prof	Edgers, bush cutters, clearing saw
Tractors (transport)	ci	Lastbil transport	
Snow-clearing machine	ci	Snöplog	
Ice rink machine	ci	Ismaskin	
Piste groomer machine	ci	Pistmaskin	
Aerial lift	con	Skylift	Skylift, aerial platform
Articulated dumper	con	Dumper ledad	Dumper, Hauler, Articulated dump truck, Articulated hauler, Tender, articulated dumper etc.
Rigid dumper	con	Dumper	Dumper, Rigid dump truck, dump truck, rigid dump truck, rigid

English name, proposed	Sector used in literature	Swedish translation	Other occuring English names
			dumper etc.
Asphalt paver	con	Asfaltläggare	Concrete paver, surfacing equipment in construction
Backhoe	con	Traktorgrävare	Backhoe loaders, rigid backhoe, articulated backhoe,
Vibratory plate	con	Vibratorplattor	Rammer, Compactor, compaction equip., tamper
Compactor	con	Vält	Roller, Land roller, Rammer, compaction equip., tamper,
Bull dozer wheel	con	Hjulschaktare	Dozer, Dozer wheel typ
Bull dozer crawler	con	Bandschaktare	Dozer,Bull dozer, Crawler dozer, track type dozer
Crawler excavator	con	Bandgrävmaskin	Track type excavators
Wheeled excavator	con	Hjulgrävmaskin	Wheeled HE, Loader
Wheeled loader	con	Hjullastare	Loader
Crawler loader	con	Bandlastare	Track typ loaders, Loader
Cutter construction	con	Skärare bygg	
Drill rig	con	Borrigg	Bore, drill rigs,
Compact loader	con	Kompaktlastare	Skid-steer loaders, Mini loaders, Skid-steer tractors
Mini excavator	con	Minigrävare	
Trencher	con	Kedjegrävare	
Rough terrain crane	con	Mobilkran terräng	
Grader	con	Vägskrapa/väghyvel	Motor grader
Scraper	con	Markskrapa	Motor scraper
Rigid lift truck	con	Lyfttruck	Rough Terrain Lift Truck- Rigid
Telescopic handler	con	Teleskoplyfttruck	Rough Terrain Lift Truck-telescopic
Telescopic loader	con	Teleskoplastare	
Generator	con	Generatoraggregat	Generator sets
Crushing equipment	con	Stenkross	
Cement mixer	con	Cementblandare	Cement and mortar mixers
Pump	con	Pumpaggregat	
Presssure washer	con	Högtryckstvätt	High pressure cleaners
Slicer	con	Skärmaskin	
concrete breakers/saws	con	Betongsåg/betongspett	
Pipe layer	con	Rörläggare	
Rod cutter	con	Vinkelslip	
Piling machine	con	Pålningsmaskin	
Conveyors	con	Transportband	
Suction machine	con/ci	Sugmaskin	
Aerial lift	con/i	Skylift	Skylift, aerial platform

English name, proposed	Sector used in literature	Swedish translation	Other occuring English names
Refuse compressor	con/i/ci	Kompressor lastbil	
Air compressor	con/i	Kompressor	Air/gas compressors, mobile compressor
Mobile crane	con/i	Mobilkran	Truck-mounted Telescopic crane
Hauler forestry	f	Dumper skogsb	
Chain saw prof	f	Motorsåg	
Harvester forestry	f	Skördare	Harvester
Forwarder forestry	f	Skotare	
Skidder	f	Lunnare	
Log loader	f	Timmerlastare	
Shredder	f		
Tree processor	f	Flisare	
Feller/buncher	f	Fällare/läggare	
Cultivator forestry	f	Jordfräs skogsb	
Tractor forestry	f	Skogsbrukstraktor	
Chipper	f/hg	Flishuggare	
All Terrain	hg	Fyrhjuling	All terrain vehicles
Hobby chain saw	hg	Motorsåg priv	
wood splitter	hg	Vedklyvare	Wood cutters
Gardening tiller	hg	Jordfräs priv	Cultivator priv
Garden shredder	hg		
Lawn mower priv	hg	Gräsklippare priv	
Riding mower priv	hg	Gräsklippare åkbar priv	
Other gasoline (household)	hg	Övriga bensin priv	
Hedge cutter priv	hg	Häcksax priv	
Shrub clearer priv	hg	Busksåg priv	
Trimmer priv	hg	Röjsåg priv	
leaf blower/vacuum	hg	Lövblåsare	
Snow blower	hg	Snöslunga	
Golf cart	hg	Golfbil	
Minibike	hg	Minicross	
Off-road motorcycle	hg	Motorcross	
Snowmobiles/skidoo	hg	Snöskoter	
Peat breaking machine	i	Torvbrytningsmaskin	
Blower	i	Industriblåsmaskin	
Broomer	i	Sop-/borstmaskin	
Welder	i	Svetsmaskin	
Vacuums	i	Industridammsugare	

English name, proposed	Sector used in literature	Swedish translation	Other occuring English names
Tractor	i	Dragtruck	
Swapper	i		
Off-highway truck	i	Terrängfordon	
Fork lift	i/ci	Gaffeltruck	Forklift truck
Other gasoline (industry)	i/ci	Övriga bensin industri	
Sweeper	i/ci/o	Sopmaskin våt	Scrubber
Industrial tractors	i/ci/o	Industritraktor	
Pushing tractor	i/ci/o	Snöplog och andra plogar	
Airports GSE Light duty	o	Hamn- och flygplatsfordon lätta	
Airports GSE Medium duty	o	Hamn- och flygplatsfordon medium	
Airports GSE Heavy duty	o	Hamn- och flygplatsfordon tunga	
Locomotives shunting	o	Arbetståg mindre	Work train
Railcar	o	Spårfordon	
Locomotive main	o	Arbetståg större	

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