A methodology for estimating annual fuel consumption and emissions from non-road mobile machinery

-Annual emissions from the non-road mobile machinery sector in Sweden for year 2006

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SAMMANFATTNING

Denna rapport omfattar studier av bränsleförbrukning och emissioner från arbetsmaskiner utrustade med dieselmotorer med en effekt mellan 37 och 560 kW. Arbetsmaskiner omfattar bland annat traktorer, hjullastare, grävmaskiner, dumper och truckar. Arbetsmaskiner är i princip uteslutande utrustade med dieselmotorer vilka kraftigt bidrar till det totala utsläppen av en mängd olika föroreningar i samhället. I Europa bidrar arbetsmaskiner med ca 15-20 % av de totala utsläppen av kväveoxider (EEA, 2005).

Förutom att beräkna årlig bränsleförbrukning och emissioner omfattar denna studie även en inventering av antalet maskiner och dess årliga drifttid som funktion av både typ, storlek och ålder av maskinen. Totalt 14 olika kategorier av arbetsmaskiner identifierades samt en grupp med resterande maskiner. Varje typ av maskin delades upp i tre effektklasser, 37-75 kW, 75-130 kW samt 130-560 kW. Antalet maskiner, årlig drifttid, genomsnittlig motoreffekt, belastningsfaktor samt bränsleförbruknings- och emissionsfaktorer sammanställdes för varje typ av maskin, effektklass och årsmodell för de senaste 25 årsmodellerna. Årlig bränsleförbrukning och årliga emissionsnivåer beräknades individuellt för varje typ av maskin, effektklass och årsmodell.

Den i studien applicerade metoden skiljer sig på flera punkter från vad som använts i andra nyligen utförda studier inom liknande område, d.v.s. emissioner från arbetsmaskiner. I denna studie togs bland annat hänsyn till åldersfördelning, t.ex. sammanställdes både antalet arbetsmaskiner och deras drifttid individuellt för olika åldrar och årsmodeller för de olika maskinerna vilket har stor betydelse då framförallt den årliga drifttiden sjunker kraftigt med stigande ålder på maskinen. Dessutom anpassades bränsleförbruknings- och emissionsfaktorerna individuellt för varje typ av maskin, motoreffekt, ålder och aktivitet för att bättre anpassa resulterande bränsleförbrukning och emissionsmängder till verkliga förhållanden. Bränsleförbruknings- och emissionsfaktorerna var baserade på både CORINAIR Emission Inventory Guidebook och den Europeiska emissionslagstiftningen för arbetsmaskiner. Dessa data anpassades dock på grund av:

- skillnader i bränslekvalitet mellan det bränsle som används vid typgodkännande och svensk MK1 diesel,
- skillnader mellan det legala gränsvärdet och uppmätta nivåer vid typgodkännande,
- skillnader i motorbelastning mellan den testcykel som används vid typgodkännande och motorbelastning vid verkligt arbete med maskinen, och
- åldersbetingade förändringar i bränsleförbrukning och emissionsbildning.

Enligt resultaten från denna studie arbetade ca 290 000 arbetsmaskiner med en motoreffekt mellan 37 och 560 kW i Sverige under 2006 vilket är 25 % fler än vad som har antagits i tidigare studier (Flodström et al., 2004). Beräknad årliga bränsleförbrukningen och årliga emissionsmängder från sektorn arbetsmaskiner 2006 redovisas i tabell S1.

Tabell S1. Antal arbetsmaskine samt årlig bränsleförbrukning och emissionsmängder

	Enhet	Årliga mängder
Antal arbetsmaskiner	Antal	290 000
Bränsleförbrukning	Ton år^{-1}	880 000
CO_2	Ton år^{-1}	2 800 000
CO	Ton år^{-1}	6 000
HC	Ton år^{-1}	2 200
NO_x	Ton år^{-1}	23 000
PM	Ton år^{-1}	1 000
SO_x	Ton år^{-1}	1.8

Den beräknade årliga bränsleförbrukningen från arbetsmaskiner år 2006 var drygt 5 % lägre än tidigare uppskattade nivåer för 2002 trots det högre antalet maskiner. För de övriga emissionerna var skillnaderna ännu påtagligare. Emissioner av både kolmonoxid och kolväte motsvarade endast ca 1/3 av de tidigare uppskattade nivåerna, en reduktion motsvarande 13 000 respektive 5 100 ton. Motsvarande data för emissioner av kväveoxider var en halvering eller minskning med 20 000 ton. Partiklar var den emission som uppvisade de största skillnaderna, de i denna studie beräknade nivåerna motsvarade endast 25 % av tidigare redovisade utsläpp, en minskning med 3 100 ton.

Skillnaderna i beräknat antal arbetsmaskiner och beräknad bränsleförbrukning och emissionsmängd kan tillskrivas flera faktorer t.ex. mer detaljerat och tillförlitligt dataunderlag speciellt avseende maskinernas åldersfördelning och årliga drifttider som funktion av ålder på maskinen. Ytterligare en orsak till skillnaderna var anpassningen av bränsleförbruknings- och emissionsfaktorer till de förhållanden som råder under verkligt arbete med maskinerna i Sverige. Slutligen, den modell som användes för beräkning av årlig bränsleförbrukning och emissionsmängder hanterade varje typ av arbetsmaskin, effektkategori och årsmodell individuellt och inte endast som ett medelvärde.

ABSTRACT

This report comprises fuel consumption and emissions from non-road mobile machinery equipped with diesel engine with a rated power of 37 to 560 kW. Non-road mobile machinery comprises of tractors, wheel loaders, excavators, articulated haulers and trucks etc. Non-road mobile machinery is almost exclusively equipped with diesel engine and thus significantly contributes to the overall emissions of pollutants in the society. In Europe non-road mobile machinery contributes with about 15 to 20% of the total emissions of nitrogen oxides (EEA, 2005).

Besides estimates of annual fuel consumption and emission amounts this report also include inventories of the number of machines and the annual work hours. In total 15 different types of non-road mobile machinery was identified, of which one was other machinery. Each type of machinery was further divided into three net power regions. Information concerning number of machines, annual work hour, rated engine power, load factor and fuel consumption and emission factors were obtained for each type of machine, power region and model year for the last 25 years. Annual fuel consumption and emissions amounts were individually calculated for each type of machine, net power region and model year.

The methodology employed within this study differs to some extend to that of other recently conducted studies within the same area, emissions from non-road mobile machinery. Firstly, concern was taken to the age distribution, for example both the number of machinery and the annual work hour varies significantly with age or model year of the machinery. Secondly, both fuel consumption and emissions factors were individually adapted the each type of machinery and activity in order to better represent the actual use of the machinery and thus resulting fuel consumption and emissions. The fuel consumption and emission factors were based on the CORINAIR Emission Inventory Guidebook and European emissions regulations for non-road mobile machinery and adjusted for:

- differences in quality and specification between the fuel stipulated for use during type approval and Swedish diesel of environmental class 1,
- differences between the maximum value stipulated in the emission regulations and the recorded emission amounts during type approval,
- differences in engine load between the test cycle employed during type approval and during real use of the machinery, and
- deterioration in fuel consumption and emission formation with increasing age.

In total, 290 000 non-road mobile machinery with a rated engine power of 37 to 560 kW were estimated to operate in Sweden year 2006, which was about 25% more machinery compared with the last published study concerning number of non-road mobile machinery in Sweden (Flodström et al., 2004). The annual estimated fuel consumption and emission mounts from the non-road mobile machinery sector in Sweden for year 2006 is shown in table S1.

Table S1. Number of machinery and annual fuel consumption and emission amounts

	Unit	Annual amounts
Number of machinery	Units	290 000
Fuel consumption	Ton year^{-1}	880 000
CO_2	Ton year^{-1}	2 800 000
CO	Ton year^{-1}	6 000
HC	Ton year^{-1}	2 200
NO_x	Ton year^{-1}	23 000
PM	Ton year^{-1}	1 000
SO_x	Ton year^{-1}	1.8

The estimated annual fuel consumption was about 5% lower compared with previous studies despite the higher number of machinery included. For emissions the differences were even larger compared with the above-mentioned study. Emissions of both carbon monoxide and hydrocarbons were reduced with approximately 70% each or 13 000 and 5 100 ton respectively. Corresponding data for emissions of nitrogen oxides was 20 000 ton or 50%. However, the largest difference was obtained for emissions of particulate matter, the estimated amounts within the present study was reduced with 75% or 3 100 ton compared with the amounts estimated in previous studies.

The differences obtained could be attributed to several aspects, for example significantly improved inventory data and especially the age distribution and annual work hour as function of machinery age. Another important characteristics of the present study were the adaptation of fuel consumption and emission factors to the actual use and conditions in Sweden. Finally, the model employed calculated the annual fuel consumption and emission amounts for each type of machinery, net power region and model year individually and not only as averages.

CONTENT

NOTATIONS

E	Fuel consumption or emissions, g
N	Number of units
Hr	Annual use, h
P	Rated power, kW
Lf	Load factor
Be	Brake specific fuel consumption or emissions, g kWh-1
i	year
b	Base year
x	Average lifetime, year
d	Slope constant
α	Annual use of new machines, h
θ	Angel of inclination
B_0, B_1, B_2, B_3	Equation dependent constants
Y	Annual use for new machinery, h
$W_{real\text{-}use}$	Correction factor for emissions based on the real use of non-road mobile machinery
$E_{real\text{-}use}$	Absolute emissions based on the real use of non-road mobile machinery, g h^{-1}
E_{ISO}	Absolute emissions based on the ISO 8178 C1 regulation, g h^{-1}

INTRODUCTION

The most common source of propulsion in non-road mobile machinery today, and in the foreseeable future, is the diesel engine. Large non-road mobile machinery, with a rated engine power above 37 kW are almost exclusively equipped with diesel engines. Non-road mobile machinery consists of several different types of machinery, such as agricultural and forestry tractors and construction equipment *e.g.* wheel loaders, excavators, articulated haulers and road maintenance equipment, which are used for a range of different operations with varying engine load characteristics.

Today, emissions from combustion engine are considered to be a serious problem for the environment and human health. The exhaust gas is composed of three major components water vapour, carbon dioxide and nitrogen oxide. However, the exhaust gas also contains several combustion by-products such as particulate matter, carbon monoxide, nitrogen oxides and various hydrocarbons that can be hazardous to the environment and toxic to humans (Heywood, 1988; Bosch, 1996). Some of the most prominent pollutants from diesel engines are particulate matter and nitrogen oxide. In Europe, non-road mobile machinery accounts for approximately 15 to 20% of the total emissions of nitrogen oxides (EEA, 2005).

In order to reduce the air pollutions from vehicles and machines equipped with internal combustion engines the European union has adopted several emission regulations. Directives 97/68/EC, 2000/25/EC and 2004/26/EC regulates the emission limits for type approval of new engines intended for use in non-road mobile machinery and agricultural and forestry tractors. Since the first legislation came into force in 1999 emission limits for type approval has become increasingly tighter and tighter. In 2008 when stage III B is fully implemented for all non-road mobile machinery with a rated engine power between 37 and 560 kW emissions of nitrogen oxides and particulate matter will have been reduced by approximately 60% each compared with the conditions in 1999. In 2014 when new engines needs to be type approval according to stage IV emissions of PM will only be 3 to 4% of the amount in 1999. Moreover, in stage III B in the European legislation for non-road mobile machinery a transient test cycle, the non-road transient cycle, will be employed for measurements of particulate matter instead of the previously used static test cycle. The introduction of a transient test procedure is assumed to further reduce the emissions.

Due to the long life span of most non-road mobile machinery, emission regulations will only have a minor effect on the overall air quality in near time. In Sweden there are about 330 000 tractors according to the Swedish vehicle register (SIKA, 2006). At the same time the annual sales returns of tractors are about 3 500 to 4 000 units. However, according to a recent study by Wetterberg et al. (2007) the annual operation time for various types of non-road mobile machinery decreases considerably with increasing age.

High quality data on fuel consumption and engine exhaust gas emissions amounts from non-road mobile machinery are needed in order to estimate the overall emissions from the non-road mobile machinery sector in Sweden. Members of the European Union are obligated to report annual national anthropogenic air emission inventories to the European Union and other international conventions such as the United Nations Framework on Climate Changes (UNFCCC) and the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (CLRTAP) (UNFCCC, 1992, EU, 1999, UNECE, 2002).

According to the EMAP/CORINAIR Emission Inventory Guidebook 2005 non-road mobile machinery contributes on average with 13% of the overall emissions of nitrogen oxides in Europe for the year 1990, based on inventories from 28 countries (EEA, 2005). A more detailed inventory for the year 1996, for Austria, Denmark, France and the Netherlands, showed that the non-road mobile machinery sector was responsible for 20% of the overall emissions of nitrogen oxides (NO_x) (EEA, 2005). The single largest contributor to emissions of NO_x was road transport, which accounted for almost 50% of the overall emissions of NO_x. Compared with the on-road sector the non-road mobile machinery sector emits 85% less carbon dioxide while only 60% less NO_x. This can be explained by the low share of spark ignition engines in the non-road sector compared with the on-road sector. Another explanation is the late introduction of emission regulations for non-road mobile machinery.

Sweden's reporting of national air emissions to the UNFCCC and CLRTAP for non-road mobile machinery has been based on inventories carried through by IVL, Swedish Environmental Research Institute, for the recent years (Flodström et al., 2004). The inventories are chiefly based on statistics from the Swedish national vehicle register and an inquiry study (Persson & Kindbom, 1999). However, national emission data for non-road mobile machinery suffers from rather large uncertainties and errors, especially concerning the age distribution and variation of annual working hour with machine age.

The inventory made by IVL includes about 230 000 non-road mobile machinery with a rated engine power of 37 to 560 kW, 110 000 non-road mobile machinery with a rated engine power less than 37 kW or fed with petrol. Moreover, the inventory also includes 150 000 snowmobiles (Flodström et al., 2004). Estimated fuel consumption and emission data for non-road mobile machinery with a rated engine power of 37 to 560 kW included in the IVL study are presented in table 1.

Table 1. Fuel consumption and emissions amounts for large non-road mobile machinery in Sweden 2002 (Flodström et al., 2004)

Pollutant	Unit	Amount
Machines	Units	229 000
Fuel consumption	Ton	940 000
CO	Ton	19 000
HC	Ton	7 300
NO_x	Ton	43 000
PM	Ton	4 100

Many of the data necessary in order to perform an accurate estimate of the overall emissions from non-road mobile machinery are difficult to obtain due to the lack of general statistics. Most emission inventories are therefore based on simplified assumptions for example regarding annual work hours and populations data. However, a Swedish project, Development of relevant work cycles and emission factors for off-road machines, has presented extensive data regarding operation specific emissions, machine population and annual work hours as function of age in Sweden (Hansson et al., 2002).

This report is an integral part of two different projects. Firstly, as a partial report within project EMMA 7, Optimal national economic measures in order to reduce emissions from non-road mobile machinery, with funding from the emission research programme, EMFO. EMFO is a sector-wide research competence to develop vehicles and vehicle components with emission levels that are sustainable in the long term. Members of this programme include: Saab Automobile AB, Scania CV AB, AB Volvo, Volvo Car Corporation AB, Scandinavian Automotive Suppliers AB, the Swedish Energy Agency, the Swedish National Environmental Protection Agency, VINNOVA (Swedish Agency for Innovation systems) and the Swedish National Road Administration.

The main objective of project EMMA 7 is to estimate future fuel consumption and emission amounts from the non-road mobile machinery sector in Sweden and propose cost-effective measures in order to reduce emissions. Secondly as a sub-part of a final report to the Swedish Environmental Protection Agency regarding compilation of fuel consumption and emissions from non-road mobile machinery at present time.

OBJECTIVES

The objective of this work was to estimate the annual fuel consumption and emission amounts from the non-road mobile machinery sector in Sweden for year 2006. A further objective was to develop a computer model that accounted for the age distribution of different types of machines and the corresponding changes in workload and emission with age.

MATERIALS AND METHODS

This report comprises of both inventory data of non-road mobile machinery in Sweden and a model for estimation of annual fuel consumption and emission amount from those machines. With non-road mobile machinery this report refers to any mobile machine not intended to carry goods or passengers on the road in which a compression ignition engine, diesel, is installed. The following types or categories of non-road mobile machinery were included in the study:

Tractors

- Agricultural and forestry tractors
- Residential tractors
- Industry tractors

Combined harvesters

- Combined harvesters

Forestry machines

- Forwarders
- Harvesters

Construction equipment

- Wheel loaders
- Backhoe loaders
- Crawler excavators
- Wheeled excavators
- Skid steer loaders
- Articulated haulers
- Mobile cranes
- Trucks
- Other

Furthermore, each category was divided into 3 different groups depending on net power ranging from 37-75 kW, 75-130 kW and 130-560 kW except for crawler excavators. For crawler excavators a fourth power range was also include, less than 37 kW. Many of the crawler excavators used within the construction sector has an engine power less than 37 kW, thus still equipped with a diesel engine (Wetterberg et al., 2007). Crawler excavators with a rated engine power less than 37 kW are often called or classified as miniature excavators. The power interval was chosen to harmonise with the net power presented in European emission regulations.

Both the total number of non-road mobile machinery and the age distribution for each type machine or the number of machines of different model years was estimated for each model year from 2006 to 1982. All machines older than 25 years, with a model year of 1981 or less, was consolidated into the model year 1982 group thus causing this group to represent machines with and age of 25 years or more. In total the project included 46 different categories of machines divided into 25 model years thus resulting in 1 150 different sub-categories of non-road mobile machinery

For each sub-category *i.e.* type of machine, power region and model year, annual hours was estimated based on inventory data obtained within the project. The calculations of fuel consumption and emission amount were individually performed for each sub-category rather than just for an average value, which normally is the case due to limited amounts of data. All individual calculations were conducted in agreement with the advanced approach according to CORINAIR (EEA, 2005). The following basic equation is used for deriving fuel consumption and emissions (E) in gram:

$$E = N \times Hr \times P \times Lf \times Be \qquad \text{Equation 1}$$

where N was number of vehicles, Hr was annual use in hours, P was rated power in kW, Lf was annual average load factor and Be was brake specific emissions and fuel consumption in g kWh^{-1}.

Though the approach with age dependent sub-categorise all individual variables in equation 1 could be exactly match to the different prerequisite in the individual sub-categories, for example annual work hour is strongly dependent on both type of machine and the age of the machine while emission factors shows a major dependency to the model year of the machine.

Instead of executing thousands of individual calculations the proposed model was based on several matrices, one for each variable in equation 1. Figure 1 illustrates how the different matrices were connected to each other.

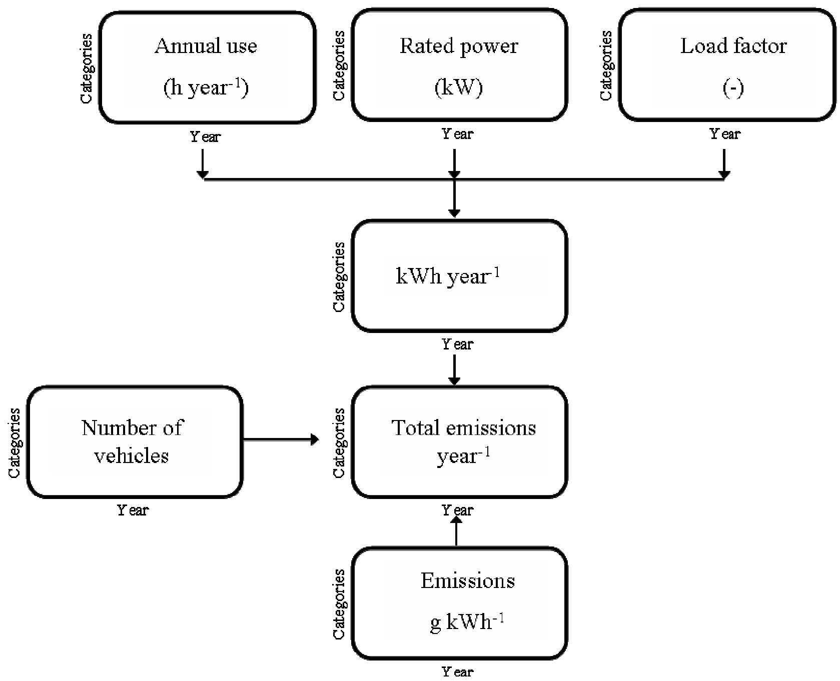

Figure 1. Structure of fuel consumption and emission model.

Each row in the matrices described different types or categories of non-road mobile machinery and each column an age category or model year, see table 2 for an example of a matrix representing number of different categories of non-road mobile machinery.

Table 2. Example of matrix describing the number of different categories of non-road mobile machinery

Category	Net power	Model year					
	kW	1982	1983	1984	1985	…	2006
Agr. tractor	37-75	42 929	2 939	3 395	3 276		1 223
Agr. tractor	75-130	3766	452	450	562		705
Agr. tractor	130-560	255	47	28	26		171
…							
Mobile crane	130-560	9	9	11	13		93

The annual amount of emissions and fuel consumption from the included non-road mobile machinery were calculated as the sum of the product of matrices describing number of non-road mobile machinery, specific emissions, annual use, rated power and load factor.

Number of machines

Data about the number of non-road mobile machinery were obtained from several different sources. Often several source needed to be combined in order to obtain sufficient amount of data on total amount of different categories of machines and the age distribution of that particular category. The matrix was fixed in size to 46 rows, and 25 columns. The 25 columns represented the time span that the age distribution covered while the 46 rows were based on the 15 machinery categories each divided into the three net power intervals, except for crawler excavators which were divided into four power intervals as explained above.

Tractors

Highly detailed data about tractors, both agricultural, forestry, residential and industry tractors were obtained from statistics about Swedish registered vehicles (Statistics Sweden, 2004). The report consists of all vehicles that according to Swedish law must be registered *i.e.* all vehicles that is or can be operated on public roads. The register includes all kinds of on-road vehicles such as passenger cars, trucks and busses. However, the register does not include any significant amount of data about non-road mobile machinery except from tractors. By combining the data about Swedish registered tractors with information from the Swedish business register, also kept by Statistics Sweden, the tractors can be divided into three major classes depending on the business affiliation of the owner. The three major classes were

- Agricultural and forestry tractors,
- Residential tractors, and
- Industry tractors.

Several different branches of business occur within the business register that has been allocated to one of the three major classes shown above. In table 3, the number of units for each of the individual branches are presented and consolidated into the major classes.

Table 3. Number of tractors in different branches of business

Branch of business	Agriculture and forestry	Industry	Residential
Fishery	93		
Agriculture and forestry	113559		
Construction		6594	
Electric-, gas-, heat- and water purification plants		137	
Real estate		4413	
Financial activity		34	
Hotel and restaurant		316	
Other		3508	
Retail trade		5158	
Manufacturing industry		3317	
Transport, and communication		2297	
Winning of mineral		294	
Social and private service			2463
Health and medical service			1622
Public administration and defence			103
Private			51062
Education			609

Quite half of all tractors registered were to be found within the agriculture and forestry while about 30% operates within some sort of industrial activity. For the residential class, most of the tractors were registered on individual private persons.

The statistic included data about production year and rated power for each individual tractor, which made it possible to obtain a detailed age distribution for the three different net power ranges. All tractors with a production year of 1982 or less were consolidated into one single group, 1982. The age distribution of agricultural and forestry tractors for year 1982 to 2006 are shown in figure 2.

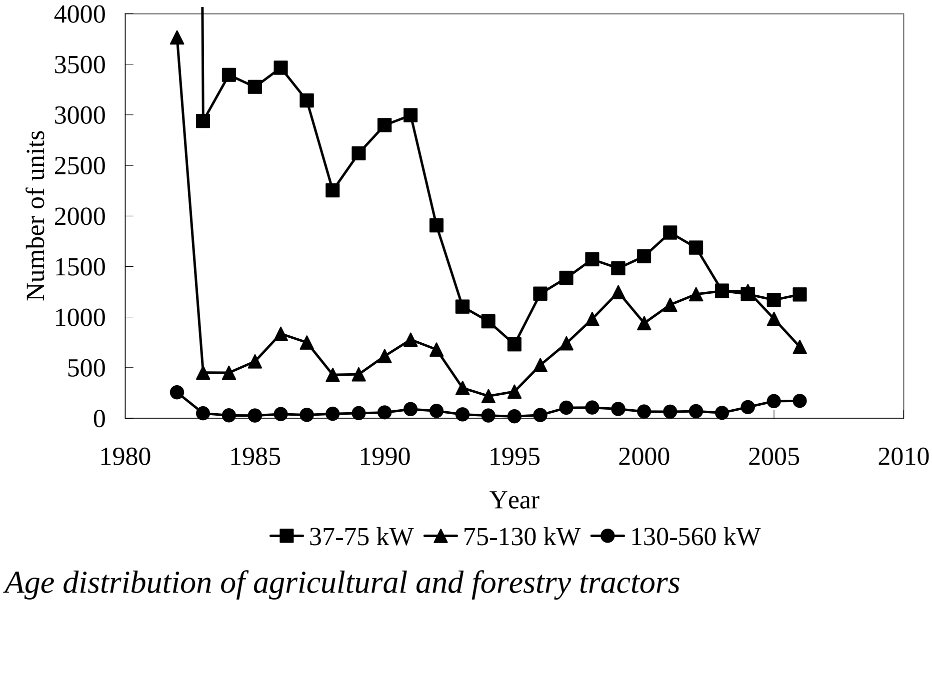

Figure 2. Age distribution of agricultural and forestry tractors

The age distribution for both residential and industry tractors were derived by the same method as for agricultural and forestry tractors.

Construction equipment

The Swedish Machinery Testing Institute has presented data about the number and age distribution of several different non-road mobile machinery not covered by the statistics from Statistics Sweden (Wetterberg et al., 2007; Wetterberg, 2002). Many of the different construction equipment or machinery are obligated to undergo inspection at yearly basis. Other construction equipment undergoes different safety inspections such as fire-protection on a voluntary basis. The Swedish Machinery Testing Institute perform about 10 000 different inspection of construction equipment each year. Data from those inspections has been reported by Wetterberg (2002) for the years 1999 to 2002 and by Wetterberg et al. (2007) for the years 1999 to 2006. However, some of the construction equipment is not obligated to undergo annual inspections for the first five years, only year three and five. Therefore, the data reported from the inspections were combined with annual sale returns from trade associations, which are presented in table 4.

Table 4. Annual sale returns of different construction equipment

Construction equipment	1998	1999	2000	2001	2002	2003	2004	2005	2006
Wheel loader	463	575	527	551	562	629	581	775	897
Backhoe loader	208	197	213	199	178	176	194	218	254
Miniature excavator	180	216	235	320	341	310	311	416	595
Crawler excavator	296	394	339	319	343	409	426	520	613
Wheeled excavator	217	282	320	267	191	219	348	375	393
Skid steer loader	72	89	81	80	82	67	78	56	56
Articulated hauler	96	36	23	20	38	43	51	60	46
Truck		776	657	677	648	592	610	737	859
Other	131	200	207	169	139	153	172	161	165

The Swedish trade association for suppliers of mobile machines, Maskinleverantörerna, supplied statistics over sale returns for the last 9 years. The statistical processing of the sale return data is described in more detail by Wetterberg et al. (2007).

The state of the market for non-road mobile machinery and especially for construction equipment has shown major variation during the 1990's, which for example has resulted in a major drop in the number of units from around 1990 to 1995 as shown in figure 3. In the same figure, annual sale returns for the last years are included in order to compensate for scarcity of new construction equipment in the inventory data.

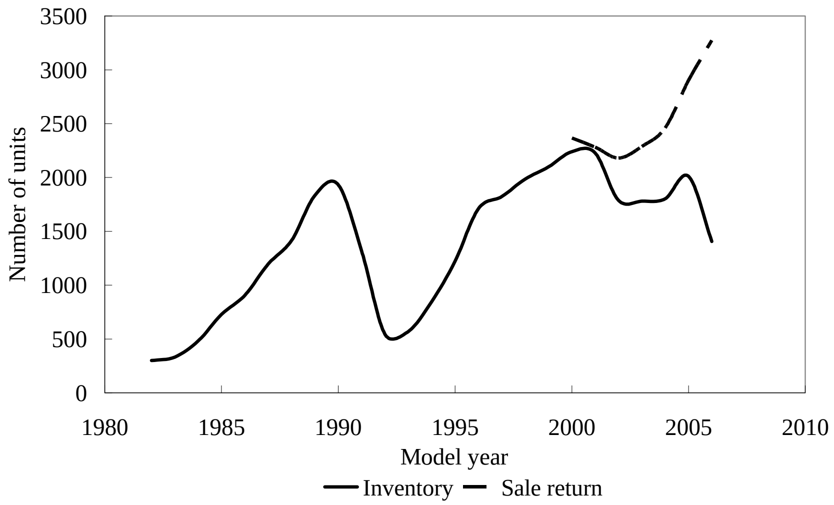

Figure 3. Age distribution for construction equipment

The estimated numbers of different construction equipment are presented in table 5. Besides those in table 5 presented construction equipment an additional 5 466 units of crawler excavators with a rated engine power of less than 37 kW was included in the data.

Table 5. Estimated total number of different construction equipment

Construction equipment	37-75 kW	75-130 kW	130-560 kW
Wheel loader	1518	4355	3636
Backhoe loader	327	7086	0
Crawler excavator	1727	2998	2475
Wheeled excavator	685	5999	0
Skid steer loader	1370	0	0
Articulated hauler	0	77	1021
Mobile crane	0	223	666
Truck	5868	2233	1142
Other	2011	1256	749

In figure 4, the resulting age distribution data, independent of rated engine power, for all types of construction equipment included in the project are presented. Detailed information about the age distribution including tables was described by Wetterberg et al. (2007).

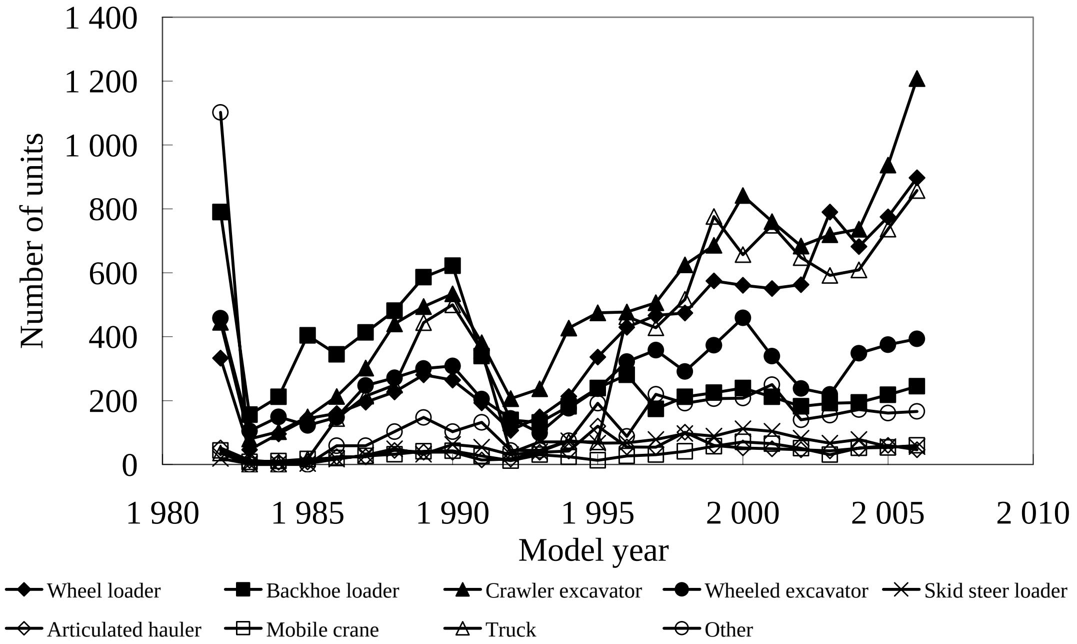

Figure 4. Age distribution data for construction equipment

Data on age distribution was obtained from Wetterberg (2002) and Wetterberg et al. (2007), inventories of the number of units of different non-road mobile machinery was obtained from Wetterberg (2002), Wetterberg et al. (2007) and statistics on sales returns from trade associations such as The Swedish Trade Association For Suppliers of Mobile Machines and the Swedish Association for Construction Equipment. The age distribution and data collection is thoroughly described in Wetterberg et al. (2007)**.**

Combine harvester

For combined harvesters there are no up-to-date statistics available concerning number of units, the most recent survey was performed in 1999 and only accounted for the total number of units not age, size or annual work (Statistics Sweden, 2005a; 2005b).

In order to get an accurate estimate of the resulting fuel consumption and emission amounts from combine harvesters the number and age distribution was approximate from sales returns, statistics over total number of units, statistics over areas under cereals and annual workload of combined harvesters (Statistics Sweden, 2000; Lindgren et al., 2002; Statistics Sweden, 2005c). In Sweden the areas under cereals including leguminous and oleiferous plants amounted to approximately 1 147 100 hectares in 2005 (Statistics Sweden, 2005c). Lindgren et al. (2002) has shown that a combine harvester harvests about 1.85 hectare per hour or $2.27 * 10^{-2}$ ha per kWh which results in an accumulated harvest time of 620 000 hours in total equivalent 50.6 million kWh for harvesting cereals in Sweden each year.

According to Agriwise (2006) a combined harvester has an annual work hour of 100 to 200 hours, which results in an estimated theoretical requirement of combined harvesters between 3 100 and 6 200 units. However, in Sweden there are a lot of holdings, approximately 75 000, with more than 2.0 hectares of arable land (Statistics Sweden, 2005c). Many of those holdings are assumed to own or be part-owner in a combined harvester and thus contributes to an increase number of combined harvesters compared with the theoretical requisite number.

According to data over sale returns about 200 combined harvesters has been sold annually for the last years. Today, mainly large combined harvesters are sold, of the 200 units sold 68% was assumed to have a rated engine power of 130 kW or more, 28% with a rated engine power between 75 and 130 kW and only 4% with a rated engine power less than 75 kW. It was further assumed that combined harvesters had a fairly long useful life, about 20 year or 4 000 hours. However, the average size of combined harvesters has increased significantly during last decades. It was assumed that the sale returns were valid for the last 6 years. For the remaining years, from 2000 to 1982, it was assumed that the age distribution for combined harvesters could be approximated with the age distribution for agricultural tractors. Furthermore, the age distribution were reduced in order for the sum to equal the estimated number of combined harvesters, 35 000, see figure 5.

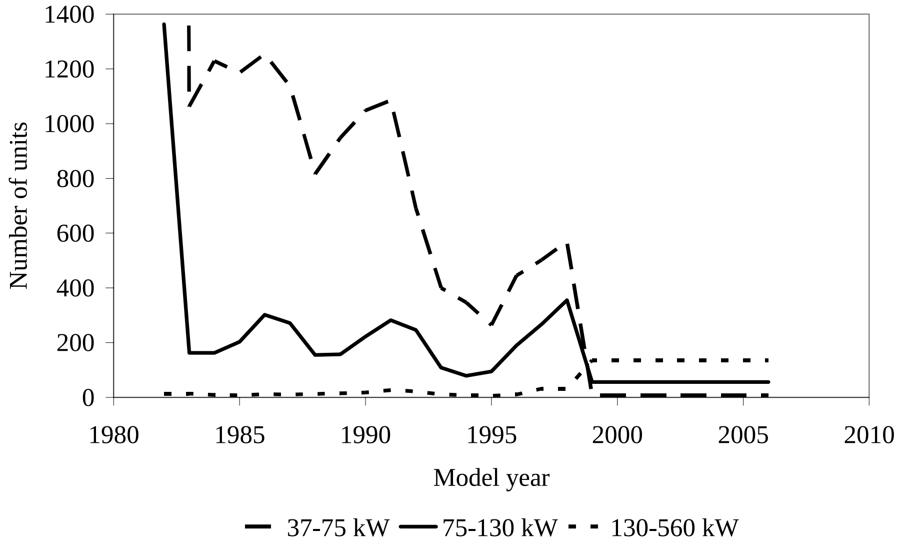

Figure 5. Estimated age distribution for combined harvesters

Forestry machinery

As with combined harvesters, only limited amounts of data were available on forestry machines such as harvesters and forwarders. However, data on sale returns for the last seven years for both harvesters and forwarders were presented by Wetterberg et al. (2007) as shown in table 6.

Table 6. Annual sale returns of harvesters and forwarders in Sweden

	2000	2001	2002	2003	2004	2005	2006	Average
Harvester	289	268	224	250	254	327	238	264
Forwarder	284	274	276	267	265	370	301	291

According to Wetterberg (2002) harvesters and forwarders are used intensively for about 7 years within the forest industry. Besides those machines, several older machines are used less intense for example within combined agricultural and forestry units. It was assumed that the age distribution of forest machines older than 7 years followed a general scrappage curve. The USEPA (2005) has presented a scrappage curve, which was adapted to the data of sale returns of forest machinery, *i.e.* harvesters and forwarders, se equation 2 and table 6.

$$N_i = 1 - \frac{1}{1 + \left[\frac{i}{b - x}\right]^d}$$ Equation 2.

where N_i was the fraction of units of model year i still in service at base year b, i was year, x was the average lifetime in years and d was a dimensionless slope constant. The dimensionless slope constant, d, was set to a fixed value of 1 500. For each of the years 1982 to 1999, N_i was multiplied with the average sale return in table 6. The resulting age distribution is shown in figure 6.

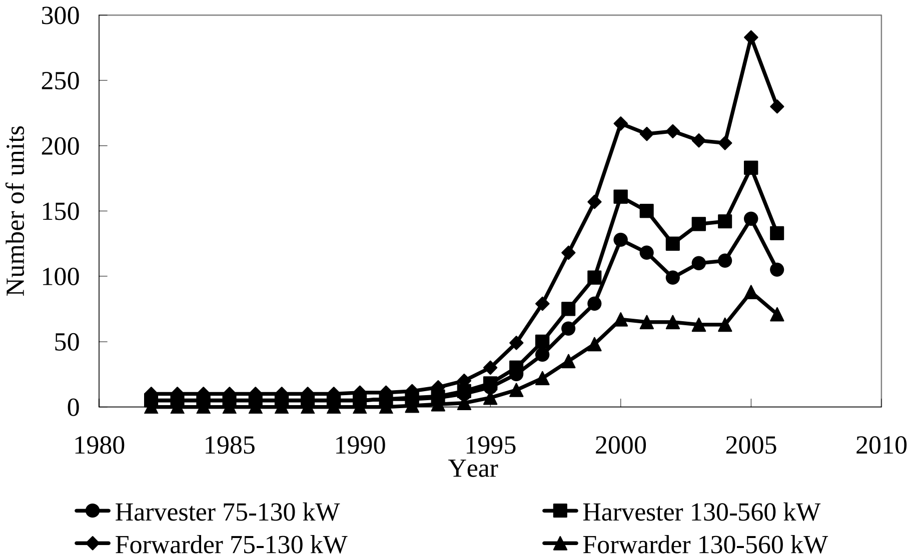

Figure 6. Age distribution of harvesters and forwarders for the time period of 1982 to 2006.

The age distributions presented in figure 6 were also divided into different engine power region according to Wetterberg et al. (2007).

Annual work hour

The annual activity or use in hours per year is closely related to type of machine and age of the machine. Wetterberg (2002) and Wetterberg et al. (2007) has presented annual work hour as function of the age of the machinery. The data was based on annual inventories of engine hour positions of individual non-road mobile machinery obtained over a time period of almost eight years, from 1999 to 2006. For each year and individual machine a difference in engine hour position compared with the preceding year was derived. The resulting annual work hour was also coupled together with the age of the machine in years. Details about the data selection and procession are described by Wetterberg (2002).

The annual use as a function of machine age shows a fairly linear trend as shown in figure 7.

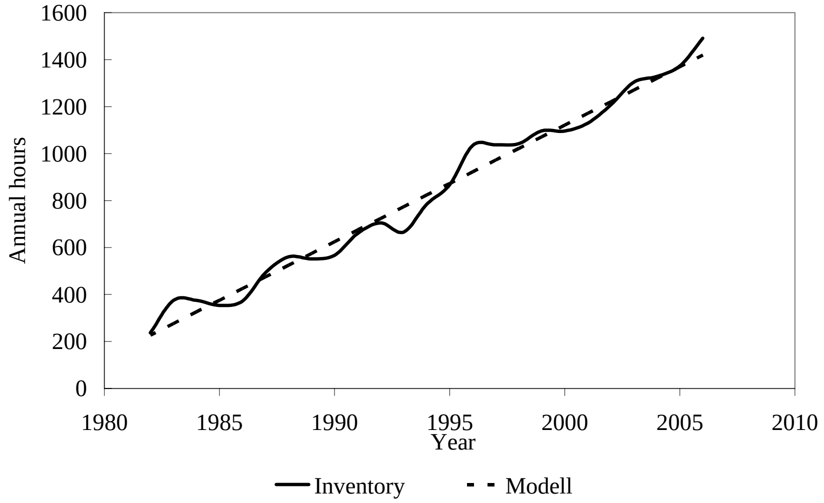

Figure 7. Annual use in hours for wheeled loaders

The initial value or annual use of new machines and the angle of inclination where individually obtained for each type of non-road mobile machinery through linear adaptation of inventory data. Table 7 shows initial value (α) and angle of inclination (θ) for all types of machines included in the project divided in different net power rages. The initial value and the angle of inclination was individually estimated for each type of machine due to limited amount of data.

Table 7. Annual use in hour for new machines as a function of net power range

Category	37-75 kW		75-130 kW		130-560 kW	
	α	θ	α	θ	α	θ
Wheel loader	1 400	3.3	1 400	3.3	1 400	3.3
Backhoe loader	1 300	3.6	1 300	3.6		
Miniature excavator[a]	560	4.8				
Crawler excavator	1 300	3.5	1 300	3.5	1 300	3.5
Wheeled excavator	1 300	3.3	1 300	3.3		
Skid steer loader	560	4.8				
Articulated hauler			1 800	3.1	1 800	3.1
Mobile crane			1 800	3.1	1 800	3.1
Truck	1 200	5.0	1 200	5.0	1 200	5.0
Other	1 200	1.9	1 200	1.9	1 200	1.9

[a] Miniature excavators has a rated engine power of less than 37 kW

According to the US EPA diesel engines in the net power range from 37 to 130 kW has an expected engine life at full load of approximately 4 700 hours while the corresponding value for larger engines, net power range from 130 to 560 kW is 6 500 hours (USEPA, 2004). No distinctions in annual work hour for machines with different rated engine power could be found based on the data presented by Wetterberg et al. (2007) and Wetterberg (2002). In Figure 8, annual work hour for four different models of crawler excavators with altered engine powers are presented.

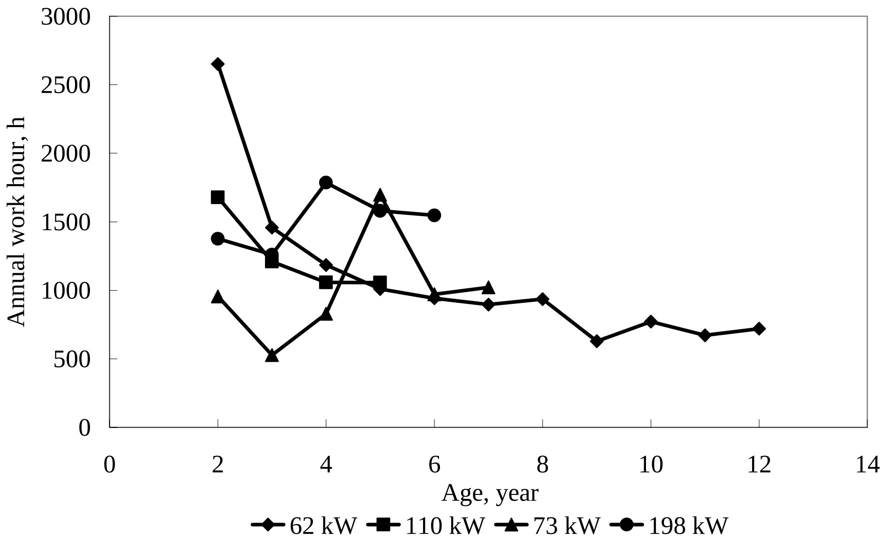

Figure 8. Annual work hour for crawler excavators with different rated engine power

Based on the data presented in figure 8, no distinction in annual work hour as a function of rated engine power could be established. One reason for the difficultness to interpret the data presented by Wetterberg et al. (2007) was the limited amount of data for different engine sizes in the inventory of annual work hour. The inventory contained over 40 000 data points over annual work hour while the data in figure 8 was based on only 170 data points. The average annual work hours presented by Wetterberg et al. (2007) was assumed to be representative for all engine sizes of a specific type of machinery as shown in table 7.

Inventory data on annual use for tractors, combined harvesters, forwarders and harvesters show a different pattern compared to the other non-road mobile machinery studied, see figure 9.

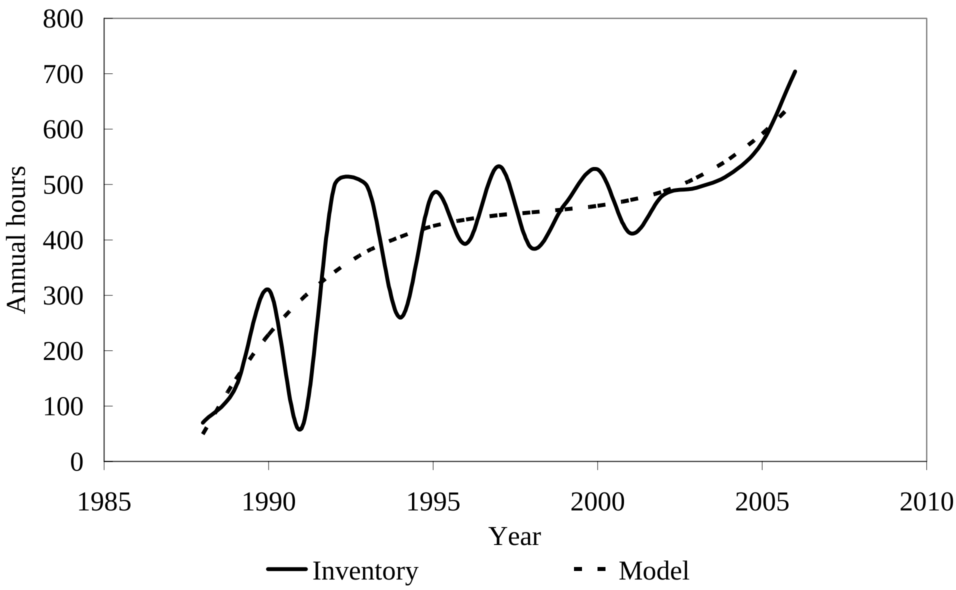

Figure 9. Annual use in hours for tractors

The model shown in figure 9 was based on a polynomial, adapted to the inventory data by the least square method. It was assumed that the polynomial in equation 3 was representative for all types of tractors, agricultural and forestry machines.

$$Hr_i = \left(B_3(b-i)^3 + B_2(b-i)^2 + B_1(b-i) + B_0\right)\frac{Y}{500} \qquad \text{Equation 3}$$

where Hr_i was annual work hour in hour for a machine of model year i, at base year b, B_3, B_2, B_1, and B_0 was equation dependent constants and Y was annual use in hour for new machines. The equation dependent constants are presented in table 8 and the annual use in hour for new machines is presented in table 9 for tractors, agricultural and forestry machines.

Table 8. Equation dependent constants

Variable	Value
B_3	-0.39
B_2	9.44
B_1	-78.2
B_0	666

For machine with an age of 19 year or more, equation 3 resulted in an annual use of less than zero hours per year, which would be inconsistent with the reality. Therefore, a restriction of a minimum use of 5 hours per year was incorporated in the model for all types of machines and net power ranges.

The average annual work hour for tractors, forwarders and harvesters with an age of up to 10 years are shown in table 9. The annual use for agricultural tractors was obtained from Agriwise (2003) while data for the remaining machines where obtained from Wetterberg et al. (2007), Wetterberg (2002), Flodström et al. (2004) and Persson and Kindbom (1999).

Table 9. Annual use in hours for new machines

	37-75 kW	75-130 kW	130-560 kW
Agricultural and forestry tractors	500	500	500
Residential tractors	270	516	800
Industry tractors	800	800	1 250
Combined harvesters	175	175	175
Forwarder		2 550	2 550
Harvester		2 550	2 550

The high annual use of both forwarders and harvesters was an effect of the highly industrial forestry in Sweden. Most of the new forwarders and harvesters are owned by large forest companies, which utilises the machines rather intensively. Old forwarders and harvesters were assumed to be sold on the second-hand market to private owners, who use the machines more occasionally.

Rated power

The rated power for each net power region and type of machine describes the average rated power of all units within that specific category. For tractors, which are obligated by law to be registered, average rated engine power can be calculated for each type of tractors and net power region (Statistics Sweden, 2004). For other types of non-road mobile machines several different literature sources has been used, e.g. Wetterberg et al. (2007), Wetterberg (2002), Flodström et al. (2004) and Persson and Kindbom (1999). Besides the literature sources data on sale returns from trade associations and manufacturers has been utilised. The average rated power for each type of machine and net power region is shown in table 10.

Table 10. Average rated power as a function of type of machine and net power region

Category	37-75 kW	75-130 kW	130-560 kW
Agricultural and forestry tractors	62	100	170
Residential tractors	60	99	176
Industry tractors	60	101	171
Combined harvesters	61	100	208
Forwarder		116	151
Harvester		101	151
Wheel loader	69	101	199
Backhoe loader	71	93	
Miniature excavator[a]	29		
Crawler excavator	42	96	151
Wheeled excavator	61	101	
Skid steer loader	41		
Articulated hauler		91	201
Mobile crane		118	254
Truck	64	103	162
Other	61	103	180

[a] Miniature excavators has a rated engine power of less than 37 kW

The average rated power for tractors shows a minor increase with age, see figure 10. In average, the increase in rated power corresponds to 0.25 kW per year. The same increase in average rated engine power has been used for all types non-road mobile machinery, not only tractors.

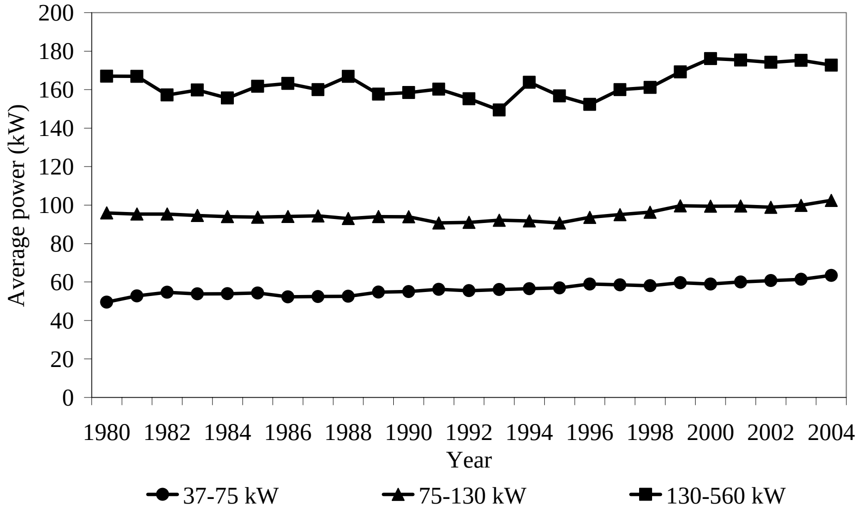

Figure 10. Average rated engine power for tractors as a function of model year

Load factor

Non-road mobile machinery is used for a range of different operations with varying engine load characteristics and only for a limited amount of time at full or rated load. In order to take the actual engine load into consideration a load factor is added to adjust the rated engine power to the average power used. The load factor accounts for the varying load conditions and operations performed with different non-road mobile machinery including operation at idle load.

The load factor is often estimated from average fuel consumption. However, many equipment users estimate the average fuel consumption while operating the machine, thus omit the idle portion and thereby overestimate the load factor. Hansson et al. (2001) has compared different methods of calculating average engine power and emissions for agricultural tractors. They showed that the average load factor for the intermediate tractor at a farm was about 33% and for the largest tractor at a farm about 40%. Corresponding literature data indicates a load factor around 50% and sometimes up to 70% (Bang, 1993; Persson and Kindbom, 1999; Flodström et al., 2004; EEA, 2005). The US EPA (2004) has calculated load factors for various non-road mobile machinery based on several transient test cycles. The test cycles describes typical operation with crawler tractor, agricultural tractor, backhoe loader wheel loader, arc welder and skid steer loader (Starr et al., 1999; Ullman et al., 1999). The resulting load factor from the above mentioned studies were rather high especially for agricultural tractors, 78% probably due to the test conditions in the study. The data acquisition for the agricultural tractor activities were obtained during the spring and mainly included heavy soil cultivation operation on a very large field with a limited amount of turn around and almost no idle at al. Moreover, the operation preformed cannot be representative for Swedish conditions. However, for other types of equipment such as backhoe loaders and wheel loaders the recorded activities are more likely to be representative of industrial use. For example a trenching operation is preformed in the same manner independent of culture, feed choice, climate and other aspects that affects the agriculture.

The load factors used in this study are presented in table 11. Load factors for agricultural and forestry tractors and residential tractors were based on data from Hansson et al. (2001). Starr et al. (1999) and Ullman et al. (1999) was used for estimating the load factors for wheel loaders, backhoe loaders and skid steer loaders. Based on studies performed by The Forestry

Research Institute of Sweden, load factors for both forwarders and harvesters could be estimated (Löfgren, 2002). The vehicles were operated according to well-established test cycles used for evaluate forest equipment in various application. The test cycles were representative for the average use of forwarders and harvesters respectively.

The remaining load factors were obtained from Persson and Kindbom (1999), Flodström et al. (2004) or Lindgren et al. (2002). However, the data presented by Persson and Kindbom (1999) are partly inconsistent especially when comparing load factor, rated power and fuel consumption.

Table 11. Load factor as a function of type of machine and net power region

Category	37-75 kW	75-130 kW	130-560 kW	Source
Agricultural and forestry tractors	33	33	40	Hansson et al.
Residential tractors	33	33	40	Hansson et al.
Industry tractors	40	40	57	Persson & Kindbom Flodström et al.
Combined harvesters	35	35	35	Lindgren et al. Flodström et al.
Forwarder		20	20	Löfgren
Harvester		30	30	Löfgren
Wheel loader	48	48	48	US EPA
Backhoe loader	21	21	21	US EPA
Crawler excavator	40	40	40	Persson & Kindbom Flodström et al.
Wheeled excavator	40	40	40	Persson & Kindbom Flodström et al.
Skid steer loader	23			US EPA
Articulated hauler		21	21	US EPA
Mobile crane		40	40	Persson & Kindbom Flodström et al.
Truck	40	40	40	Persson & Kindbom Flodström et al.
Other	33	38	34	Average

It was assumed that the load factor for miniature excavators, *i.e.* crawler excavators with a rated engine power of less than 37 kW, corresponded to the load factor of larger crawler excavators, about 40%.

Brake specific emissions and fuel consumption

Emission data presented in table 12 are based on the European legislation to regulate emissions from non-road mobile machinery, Directive 97/68/EC, Directive 2000/25/EC, Directive 2004/26/EC and Directive 2005/13/EC (EU, 1997; 2000; 2004a; 2004b; 2005).

Non-road mobile machinery is used for a variety of different operations and the real fuel consumption and emission amounts are dependent on the actual use of the engine (Lindgren, 2004). Hansson et al. (1998) has also shown that emission values cannot be reasonable accurately calculated from average emission factors such as data presented in table 12 or by the Emission Inventory Guidebook without account being taken of the type of load on the engine.

Table 12. Emission standards for non-road mobile machinery and agricultural and forestry tractors

Net power	Implementation date	CO	HC	NO_x	PM
kW		g/kWh			
Stage I					
37≤ P< 75	1999.04/2001.07[a]	6.5	1.3	9.2	0.85
75≤ P< 130	1999.01/2001.07[a]	5.0	1.3	9.2	0.70
130≤ P< 560	1999.01/2001.07[a]	5.0	1.3	9.2	0.54
Stage II					
37≤ P< 75	2005.01/2004.01[a]	5.0	1.3	7.0	0.4
75≤ P< 130	2003.01/2003.07[a]	5.0	1.0	6.0	0.3
130≤ P< 560	2002.01/2002.07[a]	3.5	1.0	6.0	0.2
Stage III A					
37≤ P< 75	2008.01	5.0	4.7[b]		0.4
75≤ P< 130	2007.01	5.0	4.0[b]		0.3
130≤ P< 560	2006.01	3.5	4.0[b]		0.2
Stage III B					
37≤ P< 56	2013.01	5.0	4.7[b]		0.025
56≤ P< 75	2012.01	5.0	0.19	3.3	0.025
75≤ P< 130	2012.01	5.0	0.19	3.3	0.025
130≤ P< 560	2011.01	3.5	0.19	2.0	0.025
Stage IV					
56≤ P< 130	2014.10	5.0	0.19	0.4	0.025
130≤ P< 560	2014.01	3.5	0.19	0.4	0.025

[a] Agricultural and forestry tractors
[b] sum of HC and NO_x

The emission data for stage III B, net power interval 37 to 75 kW are equal to the data given in the Stage III B net power interval 56 to 75 kW in order for the emission data to harmonise with net power intervals given in the model. A similar approach is used for the emission data for stage IV. In the model, emission data corresponding to stage IV, net power intervals 37 to 75 kW and 75 to 130 kW are equal to the amounts given in table 12, stage IV net power interval 56-130 kW.

Fuel consumption data and emissions data for uncontrolled non-road mobile machinery, i.e. pre-stage I engines, was derived from Emission Inventory Guidebook (EEA, 2005). Moreover, fuel consumption data for stage I to stage II engines was also obtained from the Emission Inventory Guidebook and presented in table 13. Data for stage III A was set to the same value as for stage II.

Table 13. Fuel consumption data in g/kWh for uncontrolled engines and for stage I to IV engines

Net power kW	Uncontrolled	Stage I	Stage II	Stage III A	Stage III B	Stage IV
	g/kWh					
37≤ P< 75	265	265	265	265	265	265
75≤ P< 130	260	260	260	260	260	260
130≤ P< 560	254	254	254	254	254	254

Uppenberg et al. (2001) has shown that for each MJ of diesel fuel, environmental class 1, combusted 73 g of carbon dioxide (CO_2) is released to the surrounding air. The average energy density of an environmental class 1 diesel fuel from Preem Petroleum (Preem, 2006) is 43.1 MJ/kg fuel, thus results in 3146 g of carbon dioxide per kg of fuel combusted. Emission data in g/kWh for uncontrolled engines is presented in table 14.

Table 14. Emission data for uncontrolled engines in g/kWh

Net power kW	CO	HC	NO_x	PM
	g/kWh			
37≤ P< 75	5.1	2.3	14.4	1.51
75≤ P< 130	3.8	1.7	14.4	1.23
130≤ P< 560	3.0	1.3	14.4	1.10

Emissions of carbon monoxide are lower for the uncontrolled engine compared with the stage I engine. The Emission Inventory Guidebook (EEA, 2005) recommends using the same carbon monoxide emission level for both categories of engines. In this study the stage I value has been chosen despite the higher emission. However, all emission levels are adjusted before use as shown below.

The basic emission data presented in tables 12 and 14 were modified several times due differences:

- in the characteristics of the reference diesel fuel specified in the certification process and the diesel fuel used in Sweden, i.e. differences in cetane number, density, sulphur content and aromatics,
- between the emission amounts stipulated in the emission regulations and emission amounts obtained during engine certification, and
- in the engine load characteristics between the test cycle used stipulated for use in the emission regulation and the actual use of the vehicle.

Furthermore, a degradation factor was included in order to comply with the effects of wear and aging on both fuel consumption and emission. The degradation factors used were obtained from the Emissions Inventory Guidebook (EEA, 2005), see table 15 and figure 11.

Table 15. Degradation factor for fuel consumption and emissions

	FC	CO	HC	NO_X	PM
Degradation factor (% year^{-1})	1	1.5	1.5	0	3

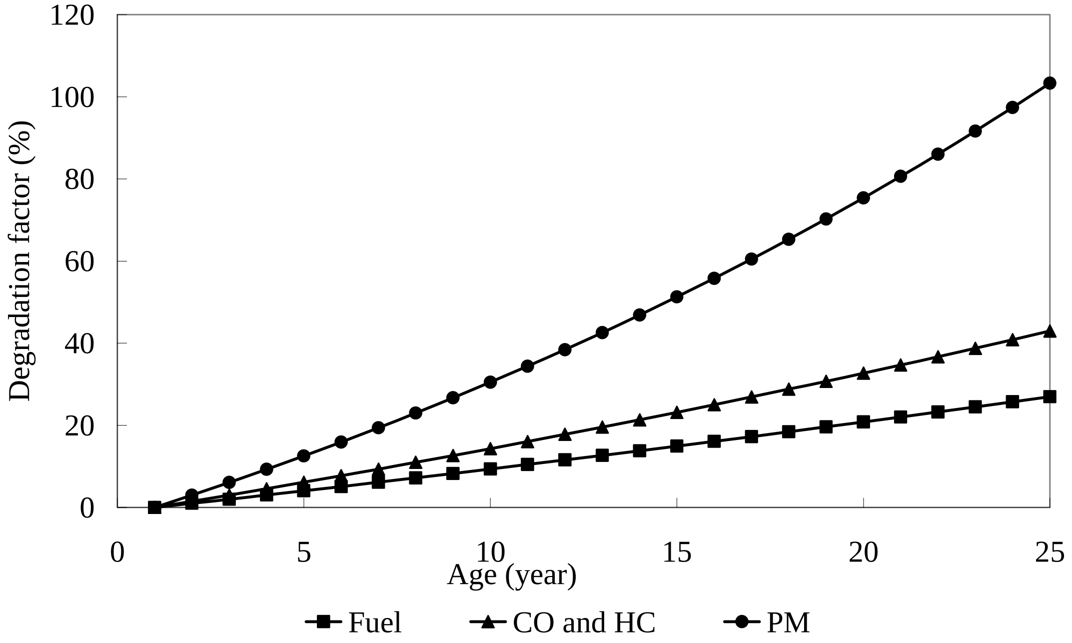

Figure 11. Degradation factor in percent for fuel consumption, emissions of particulate matter (PM), CO and hydrocarbons (HC) as a function of age

Fuel

Baseline emission data for uncontrolled diesel engines as presented by the Emissions Inventory Guidebook (EEA, 2005) and regulated emission amounts stipulated in the emission regulation for Stage I, II and III A were modified due to the differences in fuel quality or specification between the reference fuel and the fuel used during real-use of the vehicle, se table 16 for fuel specifications.

Table 16. Fuel specification for reference diesel fuel used in stage I, II, III A and Swedish environmental class 1 diesel fuel (EC 1)

	Stage I-II	Stage III A	Stage III B and IV	EC 1
Cetane number	45-50	52-54	<54	52
Sulphur content (ppm)	1500	300	<10	10
Aromatics (ppm)	20-30	-	-	5
Polycyclic aromatics (ppm)	3-6	3-6	3-6	0.02
Density (kg/m^3)	835-845	833-837	833-837	800-820

For stage I and stage II specifications for reference diesel fuel stipulated for use at the type approval is regulated in Directive 97/68/EC (EU, 1997). According to Directive 2004/26/EC the sulphur content of the reference fuel for stage III B and stage IV should be reduced and the definition of the reference fuel must reflect the fuel market situation in the member states at the time for different emission stages to be forced in (EU, 2004a). A maximum sulphur content of 10 ppm was set for both stage III B and stage IV (EU, 2004a).

According to data presented by Volvo (Mårtensson, 2003) and Euromot (Stein, 2002) fuel quality plays an important role on the resulting emission amounts. The relative effects on engine exhaust gas emissions when changing from the different reference diesel fuels to Swedish environmental class 1 diesel fuel are presented in table 17.

Table 17. Relative effects on engine exhaust gas emissions between reference diesel fuel and Swedish environmental class 1 diesel fuel (EC 1)

	Stage I-II	Stage III A
CO	1	1
HC	1.05	1.05
NO_x	0.93	0.93
PM	0.7	0.8

The differences in specifications between Swedish EC1 diesel fuel and the non-road mobile machinery reference diesel fuel for type approval to meet stage III B and stage IV limit values *i.e.* cetane number and sulphur content were only of minor importance and thus it was assumed that the emissions would be comparable.

Engine certification

The emission regulations stipulate a maximum amount of emissions that must not be exceeded. However, most engines emit less pollutants and the difference can be significant. Based on about 16 500 engine certification data for non-road compression ignition engines presented by the US environmental protection agency from 1998 to 2006 weighting factors for regulated emissions has been derived for Tier 1 to 3 (US EPA, 2006) and adopted for European conditions. The weighting factor presented in table 18 was derived as the quotient between certification and legislation values as a function of net power for each step in the emission regulation.

Regulatory authorities in the European Union and in the USA are cooperating in order to harmonise the emission standards. The US regulation Tier 1 and 2 are in parts harmonised with European regulation Stage I and II while the US Tier 3 and 4 limits are harmonised with the European Stage III and IV limits. Therefore, the engine certification data obtained from the US EPA where transferred to the European Stage I to III A regulations. Weighting factors for Stage III B and IV was assumed to be equal to one *i.e.* recorded emissions would be equivalent to the type approval limits except for carbon monoxide, which was set to the same level as for stage I to III A.

Table 18. Weighting factors for baseline emission data for stage I to IV

Net power	Observations	Stage I	Stage II	Stage III A	Stage III B	Stage IV
Hydrocarbons						
37-75	770	0.50	0.40	0.70	1.00	1.00
75-130	518	0.40	0.35	0.70	1.00	1.00
130-560	2615	0.30	0.25	0.40	1.00	1.00
Nitrogen oxides						
37-75	1704	0.80	0.80	0.95	1.00	1.00
75-130	848	0.80	0.80	0.95	1.00	1.00
130-560	2609	0.80	0.80	0.95	1.00	1.00
Carbon monoxide						
37-75	778	0.30	0.30	0.30	0.30	0.30
75-130	514	0.30	0.30	0.30	0.30	0.30
130-560	2512	0.30	0.30	0.30	0.30	0.30
Particulate matter						
37-75	737	0.50	0.70	0.85	1.00	1.00
75-130	492	0.40	0.70	0.85	1.00	1.00
130-560	2439	0.40	0.70	0.85	1.00	1.00

Baseline emission data for uncontrolled engines was adjusted with the same weighting factors as used for stage I.

Engine load characteristics

The ISO 8178 standard stipulated for use in directives 97/68/EC, 2000/25/EC, 2004/26/EC and 2005/13/EC are not representative for the real use of non-road mobile machinery (ISO, 1996; EU, 1997; EU, 2000; EU 2004a; EU 2005). Data on average use of different non-road mobile machinery are reported by Hansson et al. (2001) and Lindgren et al. (2002) for agricultural tractors. Lindgren et al. (2002) also presents data on average use for several other non-road mobile machinery. Furthermore, in Stage III B a transient test cycle, the non-road transient cycle (NRTC) will be used for measurements of particulate matter. The NRTC is based on real-use engine load characteristics for several different operations and vehicles. The operations and vehicles studied are presented by Starr et al. (1999) and Ullman et al. (1999) and represents typical operations with non-road mobile machinery. By combining the engine load characteristics presented by Lindgren et al. (2002), Starr et al. (1999), and Ullman et al. (1999) for the different vehicles included in the model real-use emission factors can be calculated. Real-use emission factors are then compared with emission weighted according to the ISO 8178 standard as shown in equation 4:

$$W_{real-use} = \frac{E_{real-use}}{E_{ISO}} \qquad \text{Equation 4}$$

where $W_{real\text{-}use}$ is a dimensionless correction factor, $E_{real\text{-}use}$ is absolute emissions in g h^{-1} during average use of the vehicle and E_{ISO} is absolute emissions in g h^{-1} weighted according to the ISO 8178 standard for the same engine. The correction factors for real-use of the vehicle are presented in table 19.

Table 19. Correction factors for real-use different non-road mobile machinery

	Fuel	CO	HC	NO_x	PM
Tractor	1.07	1.27	1.18	1.00	1.07
Combined harvester	1.12	1.05	1.26	0.92	1.08
Forwarder	1.15	1.18	1.08	1.11	1.10
Harvester	1.15	1.18	1.08	1.11	1.10
Wheel loader	0.94	1.06	1.10	1.09	1.01
Backhoe loader	1.12	1.71	1.65	1.17	1.21
Crawler excavator	1.12	1.12	1.07	1.09	1.03
Wheeled excavator	1.12	1.12	1.07	1.09	1.03
Skid steer loader	1.18	1.75	1.83	1.09	1.28
Articulated hauler	1.06	1.83	1.34	1.01	1.10
Mobile crane	1.12	1.12	1.07	1.09	1.03
Truck	1.10	1.30	1.23	1.06	1.09
Other	1.10	1.30	1.23	1.06	1.09

Table 19 shows that emission regulations based on the ISO 8178 standard underestimates both fuel consumption and pollutants from non-road mobile machinery in most cases.

RESULT

Annual fuel consumption and emission amounts from the entire non-road mobile machinery sector in Sweden for year 2006 are presented in table 20. In the same table fuel consumption and emission amounts based on type approval limits only are presented, no adjustments in emissions due to the difference between type approval limit values and engine out emission values during type approval has been conducted. Moreover, the adjusted emission factors had also been modified due to the difference in engine load between type approval and average annual use of the machine.

Table 20. Overall annual emissions from non-road mobile machinery in Sweden based on both adjusted emission factors and on type approval limits

	Unit	Annual estimate	
		Adjusted ef[a]	Type approval
Number of units		290 000	290 000
Fuel consumption	Ton	880 000	820 000
CO_2	Ton	2 800 000	2 600 000
CO	Ton	6 000	17 000
HC	Ton	2 200	4 800
NO_x	Ton	23 000	27 000
PM	Ton	1 000	2 100
SO_x	Ton	1.8	1.6

[a] ef = emission factors

As shown in table 20, annual fuel consumption and emissions of NO_x were only marginally affected by the adjustment of emission factors. However, emission of CO approximately increased three times when using emission factors based on the type approval limits compared with the adjusted data. For emissions of HC and PM the use of type approval data increased the amounts twice fold. Moreover, the average annual fuel consumption per unit amounts to approximately 3 ton or almost 3.7 m^3 of diesel. For NO_x and PM the corresponding annual emissions were 80 and 3.6 kg respectively.

Most of the fuel consumed was used in rather new machinery, approximately 50% of the fuel was consumed in machinery with an age of 7 years or less as shown in figure 12. The same relation is valid for emissions of CO_2, CO, HC, NO_x and SO_x. For emissions of particulate matter, the contribution from older machinery is more pronounced. Still most of the emissions of PM arise from fairly new machinery, more than half of all emissions were emitted by machinery with an age of 9 years or less. Moreover, almost 40% of the total number of non-road mobile machinery in Sweden has an age of 24 years or more. However, those units were only responsible for a fraction of the total fuel consumption and emissions, less than 3% in average.

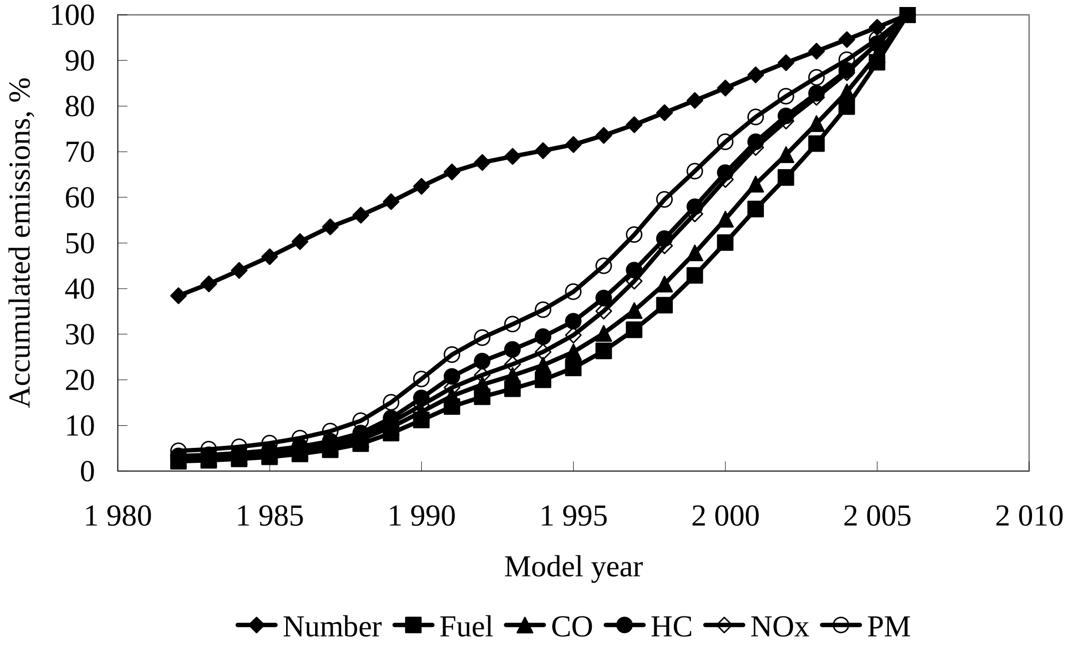

Figure 12. Accumulated annual number of units, fuel consumption and emissions as function of model year

Specific types of non-road mobile machinery, such as agricultural and industrial tractors slightly diverge from general trend. The age distribution of tractors showed a major increase in number of units for model years before 1994, which also results in a marked local peak in fuel consumption and emissions for those model years, especially for model year close to 1991 as shown in figure 13.

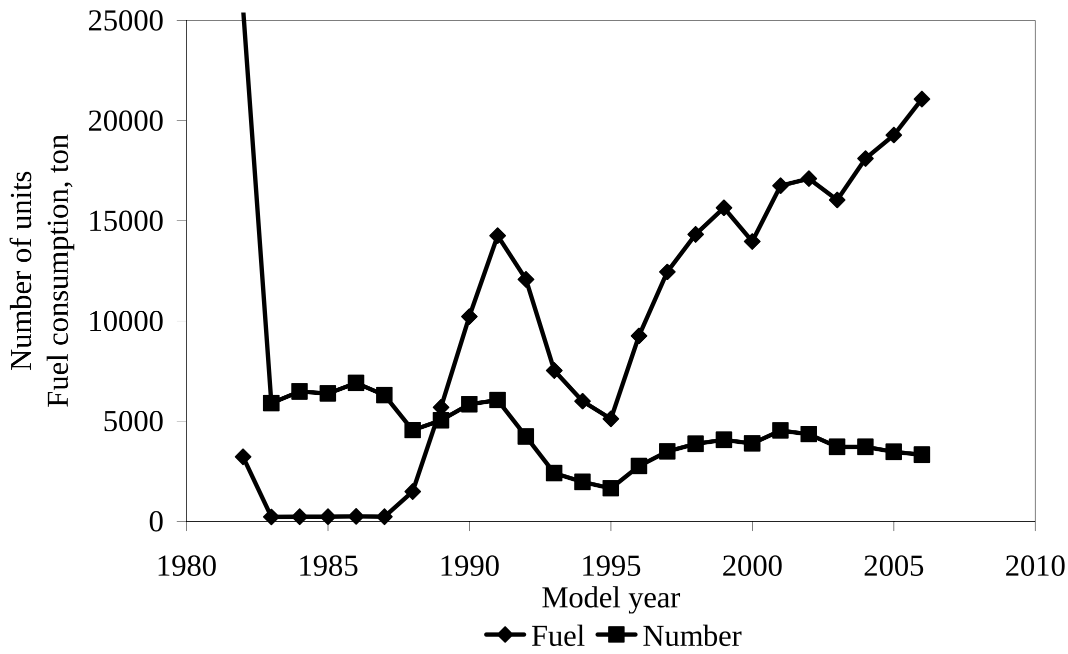

Figure 13. Number of tractors and annual fuel consumption for different model years

The number of units and annual fuel consumption from agricultural and forestry machinery including industry and residential tractors divided in different engine power regions are presented in table 21. Corresponding data for construction equipment are presented in table 22.

Table 21. Number of agricultural and forestry machinery, annual fuel consumption and emissions of CO_2 for year 2006

Category	Power kW	Machinery unit	Fuel ton	CO_2 ton
Agr. Tractor	37-75	90 000	67 000	211 000
	75-130	22 000	67 000	210 000
	130-560	1 900	13 000	42 000
Residential tractor	37-75	51 000	13 000	41 000
	75-130	4 900	13 000	41 000
	130-560	420	3 900	12 000
Industrial tractor	37-75	21 000	31 000	97 000
	75-130	3 900	19 000	59 000
	130-560	1 100	13 000	40 000
Combine harvester	37-75	29 000	5 800	18 000
	75-130	5 100	3 800	12 000
	130-560	1 300	4 800	15 000
Forwarder	37-75	0	0	0
	75-130	2 100	38 000	121 000
	130-560	610	15 000	46 000
Harvester	37-75	0	0	0
	75-130	1 100	26 000	81 000
	130-560	1 400	48 000	150 000

As shown in tables 21 and 22, the majority of machines were found within different types of tractors, about 68%. However, agricultural, residential and industrial tractors only contribute to about 27% of the total fuel consumption within the non-road mobile machinery sector. Wheel loaders and trucks, which are the two largest categories within the construction equipment, correspond to approximately 6.5% of the total units of machines. However, those machines also accounted for almost 27% of the total fuel consumption for the entire sector. Wheel loaders alone were responsible for approximately 20% of the overall fuel consumption.

The average annual fuel consumption per machinery shows major variation with type of machinery and power range, from less than 300 kg per year for small residential tractors up to about 38 ton per year for large mobile cranes. However, categories with a high number of old units and limited annual use, for example tractors, results in a rather low consumption per machine compared with large and heavy machines which are used intensively.

Table 22. Number of construction equipment, annual fuel consumption and emissions of CO_2 for year 2006

Category	Power kW	Machinery unit	Fuel ton	CO_2 Ton
Wheel loader	37-75	1 500	13 000	42 000
	75-130	4 400	56 000	175 000
	130-560	3 600	90 000	284 000
Backhoe loader	37-75	330	1 000	3 100
	75-130	7 100	28 000	87 000
	130-560	0	0	0
Crawler excavator	< 37	5 500	6 700	21 000
	37-75	1 700	7 500	23 000
	75-130	3 000	30 000	93 000
	130-560	2 500	38 000	119 000
Wheeled excavator	37-75	690	4 500	14 000
	75-130	6 000	65 000	205 000
	130-560	0	0	0
Skid steer loader	37-75	1 400	1 300	4 200
	75-130	0	0	0
	130-560	0	0	0
Articulated hauler	37-75	0	0	0
	75-130	77	500	1 600
	130-560	1 000	15 000	48 000
Mobile crane	37-75	0	0	0
	75-130	220	4 000	13 000
	130-560	670	25 000	80 000
Truck	37-75	5 900	36 000	112 000
	75-130	2 200	22 000	68 000
	130-560	1 100	17 000	53 000
Other	37-75	2 000	12 000	37 000
	75-130	1 300	14 000	44 000
	130-560	750	13 000	41 000

Annual emission amount of CO, HC, NO_x, PM and SO_x from tractors, agricultural and forestry machinery are presented in tables 23 and from construction equipment in table 24. The data in both table 23 and table 24 has been divided into different engine power regions, 37-75 kW, 75-130 kW and 130-560 kW except for crawler excavators which also include a power region of less than 37 kW.

Table 23. Annual Emissions for tractors, agricultural and forestry machinery 2006

Category	Power kW	CO ton	HC ton	NO_x ton	PM ton	SO_x ton
Agr. Tractor	37-75	580	290	1 900	130	0.13
	75-130	470	170	1 800	77	0.13
	130-560	81	20	320	12	0.03
Residential tractor	37-75	120	60	390	28	0.03
	75-130	93	34	360	15	0.03
	130-560	24	6	94	3	0.01
Industrial tractor	37-75	260	130	860	56	0.06
	75-130	130	46	480	21	0.04
	130-560	79	20	310	12	0.03
Combine harvester	37-75	43	32	170	15	0.01
	75-130	22	12	110	6	0.01
	130-560	22	7	94	3	0.01
Forwarder	37-75	0	0	0	0	0
	75-130	230	68	840	30	0.08
	130-560	74	18	300	9	0.03
Harvester	37-75	0	0	0	0	0
	75-130	160	46	570	20	0.05
	130-560	240	58	1 000	29	0.1

The single largest contributor to emissions of NO_x from the non-road mobile machinery sector were wheel loaders closely followed by agricultural tractors with 20 and 17% of the total amounts respectively, as shown in tables 23 and 24. For emissions of particulate matter the situations were the opposite, agricultural tractors accounted for approximately 20% of the overall emissions of PM from the non-road mobile machinery sector, while the corresponding data for wheel loaders were slightly under 17%.

The forestry sector, *i.e.* harvesters and forwarders, were responsible for approximately 12 and 9% of the overall emissions of NO_x and PM, respectively. Harvesters and forwarders only accounted for less than 2% of the total number of machinery. However, harvesters and forwarders were the two types of machinery with the highest annual use counted in hours of all machinery included in the study.

Table 24. Annual Emissions for construction equipment 2006

Category	Power kW	CO ton	HC ton	NO_x ton	PM ton	SO_x ton
Wheel loader	37-75	110	50	410	22	0.03
	75-130	370	140	1 600	61	0.11
	130-560	530	150	2 600	83	0.18
Backhoe loader	37-75	11	6	31	2	0
	75-130	260	100	860	41	0.06
	130-560	0	0	0	0	0
Crawler excavator	< 37	55	34	210	18	0.01
	37-75	53	23	190	11	0.01
	75-130	180	61	750	29	0.06
	130-560	200	51	930	32	0.08
Wheeled excavator	37-75	33	15	120	7	0.01
	75-130	390	140	1 800	71	0.13
	130-560	0	0	0	0	0
Skid steer loader	37-75	14	7	34	2	0
	75-130	0	0	0	0	0
	130-560	0	0	0	0	0
Articulated hauler	37-75	0	0	0	0	0
	75-130	5	2	15	1	0
	130-560	150	29	420	17	0.03
Mobile crane	37-75	0	0	0	0	0
	75-130	24	9	110	4	0.01
	130-560	140	36	650	22	0.05
Truck	37-75	290	120	870	48	0.07
	75-130	150	48	500	20	0.04
	130-560	100	26	380	13	0.03
Other	37-75	100	50	330	24	0.02
	75-130	100	39	390	19	0.03
	130-560	90	23	370	16	0.03

DISCUSSION

The results presented within this work showed substantial differences compared with the data from Sweden's reporting of national air emissions to the UNFCCC and CLRTAP. According to the Swedish environmental protection agency, the national annual emissions of nitrogen oxides in Sweden was 197 000 tonnes in 2004 (SEPA, 2006). The contribution of nitrogen oxides from non-road mobile machinery corresponded to approximately 10%, not 20% as the previous estimates indicated.

The model was based on data input in matrices, which easily can be updated when new inventory data are available.

Compared with the data reported the results from the present study showed 25% increase in the number of machines and more than 5% reduction in the overall fuel consumption. Only the categories of non-road mobile machinery presented in the present study and with a rated engine power between 37 and 560 kW were included in the comparison. The difference in size of population could mainly be attributed to tractors, were the present study included about 30% or 40 000 more units. At the same time, overall fuel consumption from tractors, the sum of agricultural and forestry, residential and industry tractors, was almost 40% lower than the data previously reported. The difference in overall fuel consumption could be explained by the consideration taken to the age distribution and variation in annual work hours with increasing age of the machines in the present study. Of the approximately 200 000 tractors registered in Sweden year 2004, 46% were 25 years old or more. As shown by Wetterberg (2002) and Wetterberg et al. (2007) the annual work hours decreases with increasing age of the machine thus making it impossible to make an accurate estimate of the overall fuel consumption and emissions without consideration taken to the age distribution.

For combined harvesters the situation was similar to that for tractors. According to the Swedish environmental protection agency, the number of combined harvesters in Sweden 1999 amounted to 35 168 units (Statistics Sweden, 2005b). A combined harvester with a rated power of 162 kW and 18 feet header harvested about 1.85 ha per hour or $2.27 \ast 10^{-2}$ ha per kWh (Lindgren et al., 2002). The data from Sweden's reporting of national air emissions are based on 35 000 units with a rated power of 100 kW, an average load of 30% and an average annual work hour of 100 hours (Flodström et al., 2004). The resulting work for those combined harvesters corresponds to 105 million kWh or 2.4 million hectares. According to Statistics Sweden (2005c) less than 1.2 million hectares of agricultural crops were harvested with a combined harvester in year 2005, thus resulting in an overestimate of approximately 100%. However, the contribution to the overall fuel consumption from combined harvesters was only about 2%.

The age distribution of tractors within the agricultural, residential and industrial sectors, mobil cranes, and articulated haulers were all based on statistics about Swedish registered vehicles. Moreover, the estimate over construction equipment were based on inventory data presented by Wetterberg et al. (2007), which covered the majority of construction equipment in Sweden. Thus, all resulting in very accurate estimates on both the age distribution and total number of units. For the remaining categories of machines *i.e.* combined harvesters and forestry machinery, the age distribution was above all based on a combination of inventory data presented by Wetterberg (2002), data over sale returns and on a mathematical scrappage function, which did not include the influence of state of the market. However, the estimated age distributions still gives a fairly accurate picture of the assembly of machines, especially for the last years. Moreover, the approach and model used can be adapted in order to include variations in the state of the market by including statistics over annual sales returns for the past 20 to 25 years.

The age distribution and annual working hours for construction equipment reported by Wetterberg et al. (2007) was based on a considerable amount of machines, about 60 000 individual observations were carried out. However, some of the categories, for example excavators, backhoe loaders and wheel loaders was occurring more frequently in the observations compared with other categories such as skid steer loaders. Unfortunately, older machines with an age of more than 5 years were overrepresented in that study since those machines that are subject for regular vehicle testing are tested annually first after the age of five years. Those machines are tested for the first time at an age of three years, a second time at an age of five and after that annually. By complementing the data presented by Wetterberg et al. (2007) with statistics over annual sales returns for the last few years, a truthful estimate of the age distribution of the machine population could be obtained.

Most of the annual work carried out by non-road mobile machinery was according to the model performed with rather new machines. About 50 percent of the annual work was performed with machines of an age of seven years or less and the machines with an age of more than nine years only contributed with less than 20 percent of the overall annual work. This will result in that old, high-polluting machines contribute only marginally to the overall emissions despite the fact that old machines have higher baseline emissions than new machines *i.e.* unregulated machines compared to machines that fulfil the type approval according to stage I and stage II. Moreover, emissions characteristics for machines are likely to deteriorate with increasing age, which was accounted for with different degradation factors. Nevertheless, the contribution to the overall emissions amounts from old machines was rather low. Due to the degradation emissions of for example particulate matter increases with almost 50 percent in 15 years, but the number of machines was reduced with almost eight times over the same time period.

Besides the earlier mentioned influence on fuel consumption due to of the age distribution emissions were also effected, especially emissions of particulate matter and nitrogen oxides. Moreover, the effect of annual work cycles, fuel specifications and the difference between measured emissions amounts during type approval and the limit values stipulated in the type approval regulations played an important roll in the estimated overall fuel consumption and emission amounts. Emissions of CO were strongly affected, as the average engine out emissions of CO during type approval only was about 30% of the limit value.

The overall effects of both the age distribution and adjustment of emission factors on the emission amounts were considerable, a more than 70% reduction in PM and a 40% reduction in NO_x compared with the data from Sweden’s reporting of national air emissions. For particulate matter emissions, the age distribution and the adjusted emission factors contributed equally while the difference in emission of NO_x almost solely could be attributed to the age distribution.

In order to accurately estimate the overall emissions from the non-road mobile machinery sector several different aspects must be taken into consideration, otherwise the resulting emission amounts will be impaired with significant errors as shown above. Some of those aspects are

- Age distribution
- Annual working hours as function of age
- Engine exhaust gas emission as function of
  - age
  - model year
  - type of machine and operation
  - rated engine power

This is in alignment with the detailed methodology as presented by EEA (2005) which stipulate that the machinery population is split into different age and power ranges. Annual working hours and emission factors should be presented as a function of age and rated engine power. However, the emission data prescribed are based on the limit levels at type approval in the emission regulations without any considerations taken to the actual emission levels obtained during the certification procedure or during real operation with the machine.

Load factors were used in order for adapting the rated engine power of specific machinery to the average power demand during annual operation. The load factor is often based on estimates of either fuel consumption in relation to the fuel consumption at full load or a direct estimate over the engine usage. However, both cases tends to overestimate the load factor as a consequence of the estimate being based on the condition during full operation of the machinery, omitting periods of idling and many low load operations.

The data materials such as inventory and sale returns obtained in combination with the calculation model employed were assumed to result in very accurate results. Furthermore, the study gave a realistic estimate of the assembly of non-road mobile machinery in Sweden, annual use of different types of machines and thus the resulting fuel consumption and emissions from the non-road mobile machinery sector. However, all data contains some sources of error, independently of methodology and processing. The estimate of fuel consumption and emissions within this study were basically dependent on five different variables, namely; number of units, annual hour, rated engine power, load factor and emission factors each with it's own source of error of which the load factor was estimated to be the least accurate variable.

Data based on the inventory performed by Wetterberg et al. (2007) *i.e.* number of units and annual work hour as function of age was assumed to be very accurate. Still, the uncertainty probably increases with increasing age of the machinery. For example, it is most likely to believe that some old machines only were employed for a few hours per year at one contractor while other contractors utilises an equivalent machine more frequently. This could thus generate a considerable variation in annual work hour for older machinery, for example machinery with an age of more than 15 years. Furthermore, it is reasonably to think that the field of application for older machine also will differ to some extent from that of new machines.

Service and maintenance schemes and intervals for older machinery, that has been employed for a considerable number of hour during the lifetime of the machine, probably differs between different contractors which could cause excessive deterioration of the machine and especially the engine and consequently affect both the fuel consumption and emissions.

Despite the fact that the data employed was assumed to be very accurate it was generally based more on the conditions of newer machinery than on older units. However, much of the data utilised, for example number of units, annual hour, fuel consumption, and emission factors was acquired for both new and old machinery and consequently should be representative for the entire non-road mobile machinery sector.

Based on the results, machinery with an age of 7 years or less accounts for the majority of both the fuel consumption and emissions while the corresponding contribution from machinery with an age of 15 years or more only were about 15%. Even if the data obtained and the model employed for those machines was extremely uncertain the contribution to the overall fuel consumption and emissions would still be diminutive. An increase of the estimated fuel consumption and emission amounts from machines with an age of 15 years or more with 100% would only result in an increase of the overall amounts with less than 15%.

REFERENCES

Agriwise. (2003). Databok för driftsplanering 2003. Områdeskalkyler för 2003. Swedish University of Agricultural Sciences, Agriwise. Uppsala, Sweden

Agriwise. (2006). Databok för driftsplanering 2006. Områdeskalkyler för 2006. Swedish University of Agricultural Sciences, Agriwise. Uppsala, Sweden

Bang, J. (1993). Utslipp fra dieseldrevne anleggmaskiner, arbeidsredskaper, traktorer og lokomotivet. Statens forurensningstilsyn

EEA. (2005). EMEP/CORINAIR Emission Inventory Guidebook - 2005. Technical report No 30 European Environment Agency, Copenhagen Denmark

EU. (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. Official Journal of the European Union L 059, 1-86

EU. (1999). Council decision of 26 April 1999 amending Decision 93/389/EEC for monitoring mechanism of community CO2 and other greenhouse gas emissions. Official Journal of the European Union L117, 35-38

EU. (2000). Directive 2000/25/EC of the European Parliament and of the Council of 22 May 2000 on action to be taken against the emission of gaseous and particulate pollutants by engines intended to power agricultural or forestry tractors and amending Council Directive 74/150/EEC. Official Journal of the European Union L 173, pp 1-34

EU. (2004a). Directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004 amending Directive 97/68/EC 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. Official Journal of the European Union L 146, pp 1-110

EU. (2004b). Corrigendum to Directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004 amending Directive 97/68/EC 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. Official Journal of the European Union L 225, pp 3-107

EU. (2005). Commission directive 2005/13/EC of 21 February 2005 amending Directive 2000/25/EC of the European Parliament and of the Council concerning the emission of gaseous and particulate pollutants by engines intended to power agricultural or forestry tractors, and amending Annex I to Directive 2003/37/EC of the European Parliament and of the Council concerning the type-approval of agricultural or forestry tractors

Flodström, E., Sjödin, Å., Gustafsson, T. (2004). Uppdatering av utsläpp till luft från arbetsfordon och arbetsredskap för Sveriges internationella rapportering. Rapportserie SMED och SMED&SLU NR 2 2004. Sveriges Meterologiska och Hydrologiska Institut

Hansson P.-A., Haupt D., Holmgren K., Johansson B., Lindgren M., Löfgren B., Nord K., Norén O., Pettersson O., Wetterberg C. (2002). Utveckling av relevanta arbetscykler och emissionsfaktorer samt reducering av bränsleförbrukning för arbetsmaskiner (EMMA) [Development of relevant work cycles and emission factors and reduction of fuel consumption for working machines]. Report Agriculture and Industry 309, Swedish Institute of Agricultural and Environmental Engineering, Uppsala, Sweden.

Hansson, P-A, Lindgren, M., Norén, O, (2001). A comparison between different methods of calculating average engine emissions for agricultural tractors. Journal of Agricultural Engineering Research, pp 37-43

Hansson,. P-A., Burström, A., Norén, O., Bohm, M. (1998). Bestämning av motoremissioner från arbetsmaskiner inom jord- och skogsbruk [Engine emissions from agricultural tractors and forestry machines]. Report 232 Department of agricultural engineering, Swedish University of agricultural sciences

ISO. (1996). ISO 8178-4; Reciprocating internal combustion engines - exhaust emission measurements - Part 4: test cycles for different engine applications. International Organisation of Standardisation, Geneva, Switzerland

Lindgren M., Pettersson O., Hansson P.-A., Norén O. (2002). Jordbruks- och anläggningsmaskiners motorbelastning och avgasemissioner samt metoder att minska bränsleförbrukning och avgasemissioner [Engine load pattern and engine exhaust gas emissions from off-road vehicles and methods to reduce fuel consumption and engine exhaust gas emissions]. Report Agriculture and Industry 308, Swedish Institute of Agricultural and Environmental Engineering, Uppsala, Sweden

Lindgren, M. (2004). Engine exhaust gas emissions from non-road mobile machinery – effects of transient load conditions. Doctoral thesis, Agraria 481, Swedish University of agricultural sciences

Löfgren, B. (2002). Skogsmaskiners motorbelastning och avgasemissioner: en studie inom projekt EMMA. Arbetsrapport nr 523. Skogforsk

Mårtensson, L. (2003). Emissions from Volvo’s trucks (standard diesel fuel). Volvo Truck Corporation.

Persson, K. Kindbom, K. (1999). Kartläggning av emissioner från arbetsfordon och arbetsredskap i Sverige. IVL rapport B 1342. Institutet för vatten och luftvårdsforskning

Preem. (2006). Security sheet, diesel fuel EC1. Preem Petroleum AB

SEPA. (2006). Sweden’s National Inventory Report 2006. Submitted under the United Nations Framework Convention on Climate Change. Swedish environmental protection agency

SIKA. (2006). Fordon vid årsskiftet 2005/2006 [Vehicles at the turn of the year 2005/2006]. SIKA report 2006:5. Swedish Institute for Transport and Communications Analysis

Starr, M. Buckingham J. & Jackson Jr. C. (1999). Development of transient test cycles for selected nonroad diesel engines. The American Society of Mechanical Engineers, 32-1, 145-156

Statistics Sweden. (2004). Traktorer, motorredskap och terrängvagnar. Offert beteckning 849 369-4/157184

Statistics Sweden. (2005a). Yearbook of agricultural statistics 2005. Official statistics of Sweden, Statistics Sweden

Statistics Sweden. (2005b). Rapporter från lantbrukets företagsregister 1999. Sysselsatta m.m. i jordbruket 1999 [Farm labour force in 1999]. Publication JO 30 SM 0001, Official statistics of Sweden, Statistics Sweden

Statistics Sweden. (2005c). Use of agricultural land 2005, final statistics. Publication JO 10 SM 0601, Official statistics of Sweden, Statistics Sweden

Stein, J. (2002). European transportation fuels: Non-road and marine developments. The European Association of International Combustion Engine Manufacturers. Paper presented at the 4th European Fuels Conference, Rome

Ullman T., Webb C., Jackson Jr. C. & Doorlag M. (1999). Nonroad engine activity analysis and transient cycle generation. Society of Automotive Engineers, SAE Technical Paper Series No 1999-01-2800

Uppenberg, S., Almemark, M., Brandel, M., Lindfors, L-G., Marcus, H-O., Stripple, H., Wachtmeister, A., Zetterberg, L. (2001). Miljöfaktabok för Bränslen. Resursförbrukning och emissioner från hela livscykeln. (Environmental Factual Study

Book. Resource Consumption and Emissions from the Whole Life Cycle) (In Swedish). Del 1. Huvudrapport + Del 2. Bakgrundsinformation och Teknisk bilaga. IVL Svenska Miljöinstitutet AB, report B1334A-2 + B1334B-2, Stockholm, Sweden. 207 pp.
USEPA. (2004). Median life, annual activity, and load factor values for nonroad engine emissions modeling. Report EPA420-P-04-005, NR-005c. United States Environmental Protection Agency
USEPA. (2005). Calculation of age distribution in the nonroad model: growth and scrappage. Report EPA420-R-05-018, NR-007c. United States Environmental Protection Agency
Wetterberg, C. (2002). EMMA Emissioner från arbetsmaskiner, delrapport 1 från SMP svensk maskinprovning AB, Kartläggning av antal arbetsmaskiner och deras användning. SMP svensk maskinprovning AB
Wetterberg, C., Magnusson, R., Lindgren, M. Åström, S. (2007). Utsläpp från större dieseldrivna arbetsmaskiner – inventering, kunskapsuppbyggnad och studier om åtgärder och styrmedel. SMP Svensk Maskinprovning AB, rapport GE 99189/06

TIDIGARE PUBLIKATIONER

Examensarbeten

2006:01	Bengtsson, L. & Paradis, H. Miljöeffekter av alternativa system för behandling av hushållsavfall i Santiago, Chile – en jämförelse mellan deponering och förbränning med energiutvinning.
2005:01	Hårsmar, D. Bättre enskilda avlopp i Sigtuna kommun – möjligheter för bebyggelse i Odensala socken.
2005:02	Svensson, M. Desalination and the environment: Options and considerations for brine disposal in inland and coastal locations.
2005:03	Jakobsson, D. Retention av tungmetaller I en anlagd våtmark: studier av Vattenparken I Enköpings kommun.
2005:04	Leonardsson, J. & Östensson, E. Inverkan av torrsubstanshalt och temperatur på kompostens syrabildning.
2005:05	Ulff, D. Miljöpåverkansbedömning vid tillverkning av etanol från cellulosabaserade råvaror: ekologisk gård självförsörjande med drivmedel.
2004:01	Ericsson, N. Uthållig sanitet i Peru – En förstudie i staden Picota.
2004:02	Ekvall, C. LCA av dricksvattendesinfektion – en jämförelse av klor och UV-ljus.
2004:03	Wertsberg, K. Behandling av lakvatten med kemiska oxidationsmedel för att delvis bryta ned oönskade organiska föreningar – En studie utförd vid Hovgårdens avfallsanläggning i Uppsala.
2004:04	Degaart, S. Humanurin till åkermark och grönytor: avsättning och organisation i Göteborgsområdet.
2004:05	Westlin, H. Utvärdering av ett silotorksystem för spannmål utrustat med omrörare.

Rapport – miljö, teknik och lantbruk

2006:01	Kjellin, J. Low-velocity flows in constructed wetlands: Physico-mathematical model and computer codes in Matlab environment.
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