Memorandum

Traffic & Transport
Anna van Buerenplein 1
2595 DA Den Haag
Postbus 96800
2509 JE Den Haag

www.tno.nl

T +31 88 866 00 00

To
Ministerie van Infrastructuur & Waterstaat directie Duurzame Mobiliteit

From
Norbert E. Ligterink
Emiel van Eijk,
Geoff C. Holmes

Subject
MaVe Action Emission Monitoring and Periodic Inspection of Mobile Machines

Date
8 October 2021

Our reference
2021-STL-MEM-100341925

Direct dialling
+31611700533

Projectnumber
060.39406

Summary

This memorandum provides an estimate of the environmental impact of setting emission criteria for the use of mobile machines in public tenders by Dutch governmental organisations and when granting construction permits. It is also indicated here which additional environmental effect can be achieved if the emissions are monitored and enforced by means of the proposed Emission Monitoring and Periodic Inspection (EMPI) system. By monitoring and inspecting the machines that are used and the functioning of the emission reduction systems such as particulate filters and SCR catalytic converters it is possible to ensure proper compliance with the emission criteria. In addition, a reduction in emissions can be achieved by switching off machines instead of leaving these machines on standby for a longer period of time.

Table 1 below shows an estimate of the environmental effect for setting emission criteria and the additional environmental effect of inspection and enforcement by means of the EMPI. This is based on the (draft) proposal for SRP criteria (socially responsible procurement in English and m*aatschappelijk verantwoord inkopen* in Dutch) for emissions from mobile machines at three levels. The levels relate to a minimum emission limit set for the emission class. Each increase to a higher level leads to a higher reduction of NO_x and PM (particulate matter) emissions. Table 1 also clearly shows that setting emission criteria in the SRP criteria has a larger effect when combined with EMPI.

Table 1: Reduction potential as a result of setting emission criteria and the additional effect of EMPI in 2025 and 2030

	NO_x [ton]		PM [ton]	
	2025	2030	2025	2030
Level I - reduction without EMPI [ton]	286	142	28	15
Level I - extra reduction EMPI [ton]	1208	1111	30	18
Level I total reduction [ton]	1494	1253	59	33
Level II - reduction without EMPI [ton]	339	180	43	22
Level II - extra reduction EMPI [ton]	1287	1169	45	25
Level II total reduction [ton]	1626	1349	89	47
Level III - reduction without EMPI [ton]	824	620	50	24
Level III - extra reduction EMPI [ton]	1971	1777	53	28
Level III total reduction [ton]	2795	2396	103	52

A considerable reduction in NO_x emissions can be realized for machines with SCR systems (Stage IV and V) by reducing the standby time of these machines. Reducing the standby time of these machines can lead to an estimated 483 ton reduction in NO_x emissions in 2025 and 560 ton reduction in 2030. Monitoring NO_x emissions, registering and assessing the actual use of machines, as is proposed in the EMPI, contributes to limiting idling time.

The emission estimates in this study were made with the emission model mobile machinery (EMMA model) (Hulskotte & Verbeek, 2009) and emission forecasts are calculated for the Climate and Energy Outlook (KEV) using MEPHISTO (Machinery Emissions Prognosis Helped by Information on Sales of Technology and Oils). It should be noted that in recent months, among other things through analysis of registration data from the RDW, it has become apparent that the numbers of machines and the actual emissions may be considerably higher than the emissions calculated with these models. As a result, the environmental impact of setting emission criteria and monitoring and enforcement may also be higher.

1 Introduction

There is currently no registration and periodic environmental inspection for mobile machines. As a result, any defects or manipulation of emission control systems are not detected and criteria for emissions, specified in environmental permits, on construction sites are hardly checked. Without registration and inspection, it is not well known what the total emissions are from mobile machines.

At the request of the Ministry of Infrastructure and Water Management (IenW), TNO has made an estimate of the environmental impact of the widespread introduction of enforcement and inspection of emissions from mobile machines via the emission monitoring and periodic inspection (EMPI) system. This concerns monitoring and inspection linked to the setting of SRP criteria (Socially Responsible Procurement) in public tenders and the setting of emission criteria in environmental permits by the competent authority. This concerns mobile machinery in the construction sector, which is responsible for approximately half of the total emissions from all mobile machinery in the Netherlands. This inspection could also become relevant at a later date for checking possible environmental zones for mobile machines. For this it is necessary to have a good registration of machines and their environmental stage.

Unlike the PTI (periodic technical inspection) for road traffic, it is not expected that the EMPI will become a legal requirement, given the current lack of registration of machines and the lack of a legal basis in the European PTI Directive. Given this situation, there are no legal permanent criteria for the emissions during the use of mobile machines in the EMPI. The use of clean machines can be stimulated and enforced through tendering criteria and construction permits. Thereby providing the basis for inspection and enforcement. The estimates of environmental effects are made on the basis of the EMMA model that is used for the national Emission Registration in the Netherlands. This model may underestimate the real emissions of mobile machines and overestimate the autonomous emission reduction of the machinery in the coming years.

The results in this memo are therefore a conservative estimate of the effects of the EMPI system, because the missing sources cannot be accounted for. Practical experience and other data sources indicate that there are more and more old machines in reality than is used in the models.

This memo estimates the particulate matter (PM) and NO_x reduction potential of setting emission criteria and the additional effect of an EMPI for mobile machinery.

The additional reduction potential of EMPI for mobile construction machines is estimated based on three factors:

- Checking whether the machines that are used meet the criteria proposed, so that no other machines are used;
- for machines with an SCR installation, adaptation of the use (in particular less idling), and;
- the guarantee for correctly tuned engines and properly functioning after-treatment systems (no defects, manipulation, etc.).

A large part of the tenders, which can be subject to environmental criteria, concerns construction-related contracts, while agriculture, trade and industry generally do make use of tendering procedures. That is why in this study the construction sector has been taken as the basis for determining the effect. Other tenders and projects requiring permits, such as festivals, can also make use of this scheme. But it is difficult to assign an effect to this, because no data is known about the use and the environmental impact of mobile machines in these cases.

More generally, lack of registration of mobile machines has created a great deal of uncertainty in the EMMA model for estimating the size and emissions of the mobile machines fleet. Recent information such as the obligation to register mobile machines on the road and ongoing TNO research projects have provided better insights into the current machinery and the real-world emissions (Vermeulen, 2021). These insights have been incorporated in the uncertainties in this memo. It is expected that the numbers of smaller and older machines will be significantly underestimated in the emission models used. Both have correspondingly higher emissions than the machines that are well represented in the emission models.

2 Current emissions from mobile machinery

The fleet composition and emissions of mobile machines were calculated for the Dutch national emission registration in the emission model mobile machinery (EMMA model) (Hulskotte & Verbeek, 2009). Emission forecasts are calculated for the Climate and Energy Outlook (KEV) using MEPHISTO (Machinery Emissions Prognosis Helped by Information on Sales of Technology and Oils). The underlying data is limited, and the results of the model should be considered indicative and conservative.

At the end of 2020, a calculation was made of the total emissions from mobile machines, which included reduced performance of the emission reduction systems (due to manipulation or aging).

The starting point for this calculation is that for 10% of the Stage IV and Stage V machines the SCR system does not work and for 5% of the Stage V machines the particulate filter does not work. These are conservative estimates based on discussions with the industry and the actual percentage may be higher.
In this model run, the emissions are calculated for 2020, 2025 and 2030 using the EMMA model. The following are the analyses of both NO_x and particulate matter.

Figure 1 shows the total NO_x emissions of mobile machines and construction machines in 2020, 2025 and 2030 according to the EMMA model. The division of sectors is not always easy to make, as in the case of agricultural tractors. Mobile machines in the construction sector roughly account for about 42% of total NO_x emissions from mobile machinery in 2020. As previously mentioned, this is likely an underestimate.

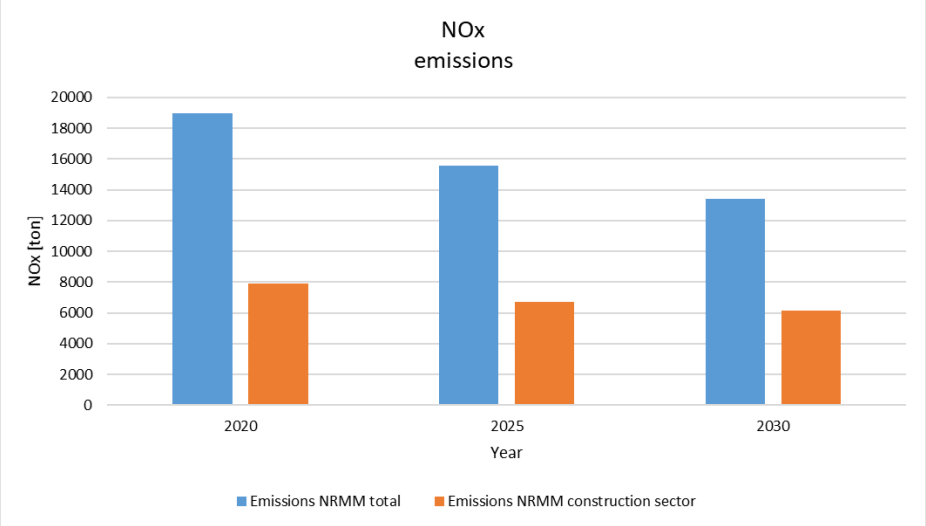

Figure 1: NO_x emissions from mobile machines (Hulskotte & Verbeek, 2009) based on the EMMA model.

Figure 2Figure 2 shows the distribution of NO_x emissions per engine type in 2020, 2025 and 2030, based on the model forecast. The largest part (95%) of the emissions is caused by machines with diesel engines. Of these machines, the largest part of the NO_x emissions is again caused by large machines with a capacity of 56 kW or more (69% in 2020, 65% in 2025, 63% in 2030). This share is decreasing, in particular because the most modern smaller machines (<56 kW for NO_x and
< 19 kW for particulate matter) are subject to less strict emission criteria and the emission performances of these improves less. In addition, the number of large machines decreases slightly and the number of small machines increases slightly (Figure 4).

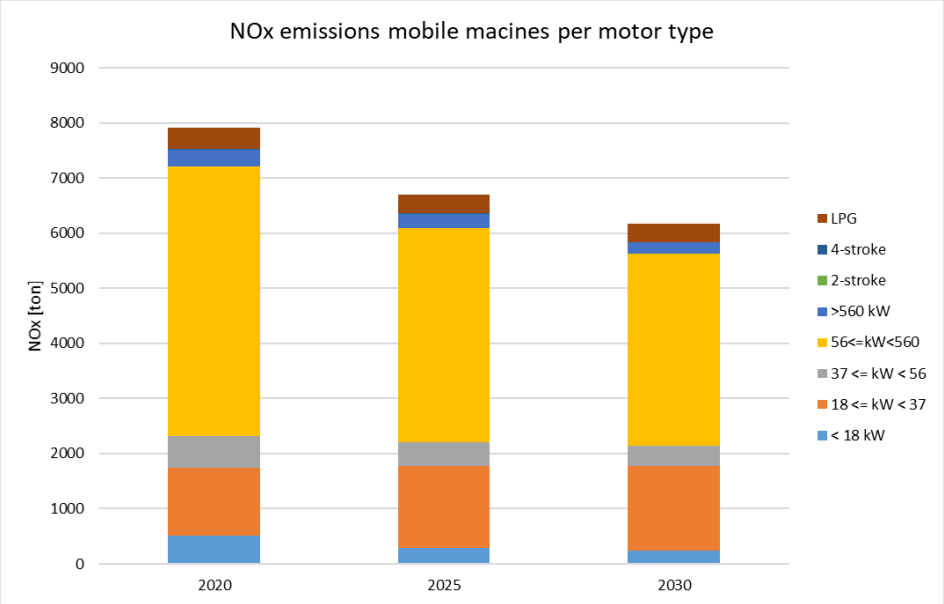

Figure 2: NO_x emissions of mobile machines in the construction sector distributed over various motor types in EMMA.

Figure 3 shows the modelled active number of construction machines per engine type. In 2020, 2025 and 2030 about 63% of the machines will be larger than 56 kW.

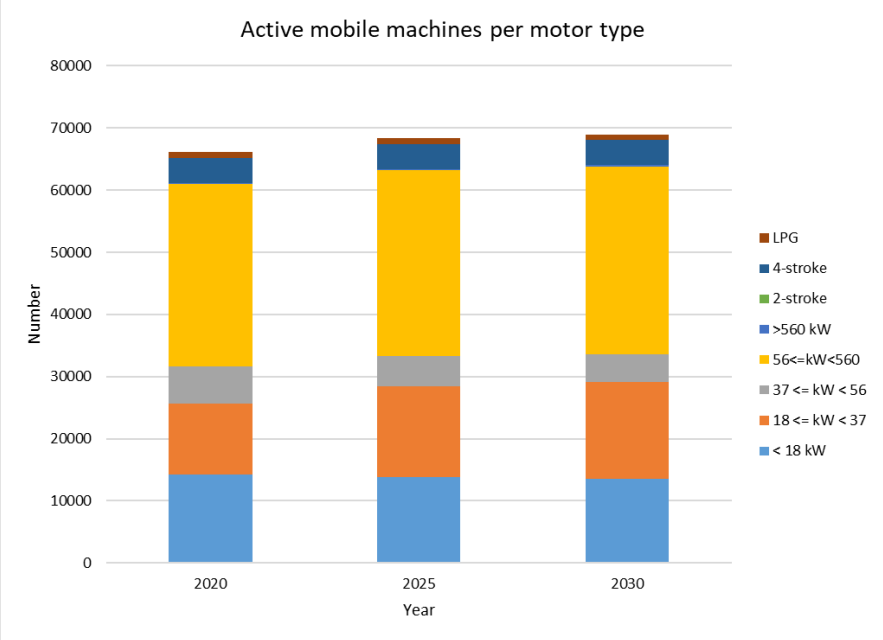

Figure 3: Number of active mobile machines in the construction sector per motor type in EMMA/MEPHISTO.

Figure 4 shows the particulate emissions of mobile machines and the share used in the construction sector. In 2020, the share of particulate matter emissions of mobile machines used in the construction sector will be approximately 43% of total particulate emissions of all mobile machines. Renewal of the fleet will reduce this to approximately 37% in 2030. The total particulate matter emissions from construction machinery will decrease by approximately 73% between 2020 and 2030.

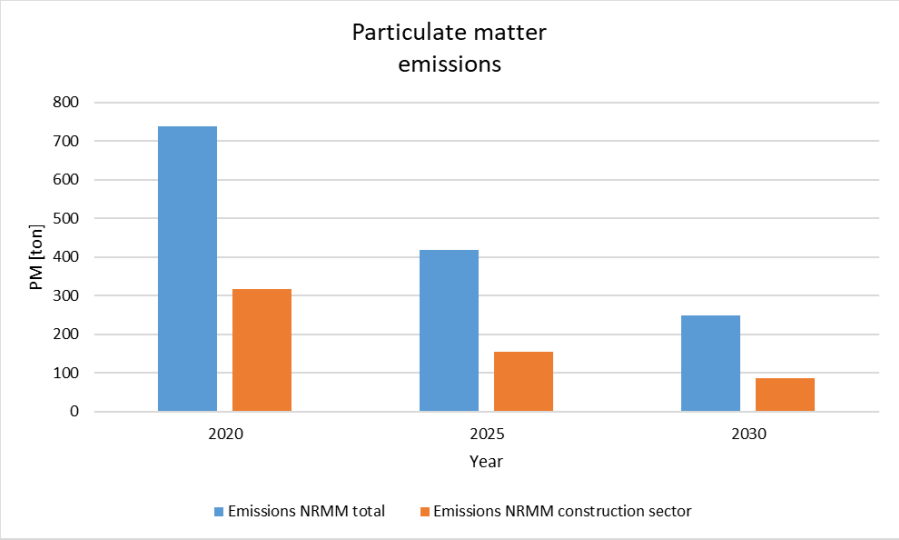

Figure 4: Particulate matter emissions from mobile machines according to EMMA

Figure 5 shows the distribution of particulate matter emissions from construction machinery by power class. For particulate matter, most of the emissions (approx. 50-55%) are caused by machines with a power of less than 56 kW. A decrease in particulate matter emissions can be observed across all power classes but is smallest for the very largest machines (>560kW) (-22%). In the other asset classes, the decrease is 50% or higher. Due to the application of particulate filters on Stage-V machines with powers between 19 kW and 560 kW, the particulate emissions of this group are lower, and the decrease is greater, than currently estimated on the basis of the standards. The same trend has been seen in road traffic in recent years. Future measurements should confirm that picture. On the other hand, the tightening of criteria for particulate emissions from small machines is very limited. Additional research should show whether this leads to an actual improvement. The PM emission criteria are a factor of ten higher than for large machines. But these large machines also have a particle number limit, PN, which means that the particulate emissions are often well below the limit.

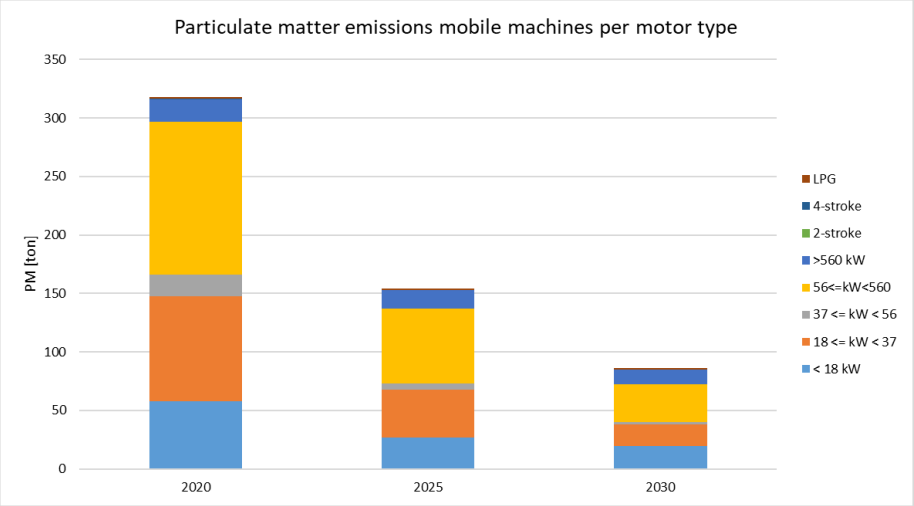

Figure 5: Particulate matter emissions from construction machinery by engine type according to EMMA.

The EMMA model now lacks certain small machine types, such as light towers and compressors. These machines generally have a more continuous usage and many operating hours relative to other machines. The high number of operating hours per day results in substantial total emissions. A comparable study into cooling units showed that this large group of very small diesel engines is responsible for approximately 4.3 ktonnes of NO_x emissions per year. This is a quarter of all NO_x emissions of total group mobile machines where cooling units are also included. Similarly, machines above 560 kW are also a concern, because of the lagging emission legislation here too.

The research into cooling units also showed that they are responsible for the emission of 110 tons of particulate matter per year. That is one sixth of the particulate matter emissions that are now attributed to a broad group of mobile machines. For example, an underestimation of the number and operating hours of small machines can lead to a substantial underestimation of the particulate emissions, because large machines, Stage V with 19 to 560 kW, have much lower particulate emissions due to the particulate filter application.

3 Influence of government agencies on the emissions of the machinery

The reductions determined for the above scenarios have been calculated on the basis of the entire machine fleet in EMMA. In reality, the Ministry of Infrastructure and Water Management, provinces, regions, municipalities and environmental services have different instruments at their disposal to influence different parts of the machine fleet. The SRP criteria can only be used to influence the fleet used in government projects. Another possibility is to influence a larger part of the fleet by including specific environmental criteria in project grants, such as the construction of housing. In terms of turnover, the government is not a major player (Visser and Nicholas, 2020), but when looking specifically at activities that may involve heavy construction machines with high emissions, the government appears to play a larger role.

When mobile machines are used in construction, the excavators, loaders and agricultural tractors are responsible for a large share of the total harmful emissions (Van Eijk, 2020). This deployment in ground, water and road construction (GWW) is generally a government task, and therefore SRP criteria can be applied. A rough estimate, which requires further substantiation, is that three quarters of the NO_x and particulate matter emissions fall under government tasks and tenders.

In addition to the so-called earthmoving, the government also issues permits for events, such as festivals. The associated emissions are unknown, but here too the government can achieve an emission reduction using SRP criteria.

4 Use of cleaner machines

This chapter calculates the effect of excluding machines with low emission classes in public tenders and for construction permits. For this purpose, the division into emission stages, used in Table 2, is based on the memorandum “Emission Monitoring and Periodic Inspection (EMPI) of mobile machines” drawn up by the Ministry of Infrastructure and Water Management.

For each minimum criteria (Level), the effect is calculated if only vehicles of this emission stage or higher are allowed. The effects are calculated relative to the starting situation for 2025 and 2030.

A distinction is made herein for different asset classes in:

I. Level I is the exclusion of the most old and polluting machines.
II. Level I machines can reach Level II by using a particulate filter that is controlled using a PN limit < 10^6 [#/cm^3] (or the factory Stage V limit of < 10^{12} #/kWh). The NO_x emissions thus remain at Level I.
III. All machines can reach Level III through the use of a particulate filter (with the limit such as Level II) and an SCR installation. For machines above 56 kW, these machines must meet a type approval limit of NO_x < 0.4 [g/kWh] (similar to Stage V). For machines below the maximum power (P_{rated}) of 56 kW, the limit is progressively weaker to 2.4 g/kWh for the smallest machines in case of retrofit SCR: NO_x < 2.4 – 2 * (P_{rated} [kW]/56) [g/kWh]. Stage V machines between 56 and 560 kWh and electrical machines fall under Level III, without modification.

The PN limit or NO_x limit of 2.4 g/kWh, or less, guarantee that a machine is equipped with a closed particulate filter and an SCR installation. In the past, a low PM limit was a reason to install a particulate filter, but that need has not lasted. For this reason, a PN limit for particulate matter has been introduced from Stage V onwards.

Table 2: Minimum criteria for stage standards and emission classes for draft SRP criteria.

Electric Stage V Stage IV Stage IIIB Stage IIIA Stage II Stage I	Level III Level I High emissions				
Power	<19 kW	19-37 kW	37-56 kW	56-560 kW	>560 kW

For Stage IIIB and IV machines with power ratings 37-56 kW, there are substantially stricter criteria for particulate matter than Stage IIIA (from 0.4 to 0.025 g/kWh) and earlier, but not for NO_x (all 4.7 g/kWh). These NO_x criteria do not require the use of an effective SCR catalytic converter. In the calculation in this study, Stage IIIB and Stage IV with a capacity of 37-56 kW are therefore considered to be emission level I.

If a particulate filter is factory fitted for Stage IIIB between 37-56 kW, individual machine emission level II applies. In the same way, for individual Stage IIIB and Stage IV machines with a power output of 56-560 kW, emission level III applies if a properly functioning diesel particulate filter is factory fitted.

For the different Stages of machines, the NO_x and PM criteria both become stricter over time. For a retrofit particulate filter or an SCR retrofit, only the PM or the NO_x emissions are substantially lower, but the other emissions are still at the original high value. By making a classification according to these 2 different emission species, mobile machines can be transferred to a higher emission category by installing a retrofit particulate filter and/or retrofit SCR.

Table 3: Level adjustment if a machine, original or after retrofit, meets the criteria for particulate matter (Level II) or particulate matter and NO_x (Level III).

Limit	**MVI Level**
High emissions	Excluded in MVI
Moderate emissions	Level I
PN limit (1 x 10^{12} #/kWh of 10^6 #/cm^3)	Level II
PN-limit (1 x 10^{12} #/kWh of 10^6 #/cm^3) and NO_x limit (0,4 g/kWh) or electric	Level III

The following assumptions are made in this analysis:

- Three quarters of the emissions from the fleet of mobile machines in the construction sector can be allocated to projects that can be influenced by applying SRP criteria and in building permits issued by the government.

- If a machine does not meet the minimum criteria, the work delivered for that machine is divided among the other machine groups that do meet the criteria.
- If there are no stage standards for a certain machine type that meet the criteria, a retrofit facility is installed, or replaced by electric.
- The effectiveness of a retrofit particulate filter and retrofit SCR is equal to that of machines with factory fitted reduction systems. The emission factors of mobile machines with a retrofit particulate filter and retrofit SCR are therefore the same as those of vehicles from the emission standard equipped with these technologies as standard.
- Proper registration ensures that the specified machines actually meet the criteria.

Setting emission criteria without monitoring and enforcement is likely to be of limited effectiveness. If there is no inspection on the use of machines, an older, more polluting, machine is easily used. And if there is no inspection of the operation of the machine's emission reduction technology, there is a higher chance that this technology will be disabled or removed during maintenance. This also creates a distortion of competition, because cleaner machines and good maintenance are simply more expensive. Inspection and enforcement are necessary for a level playing field and to prevent the race to the bottom. Therefore, the following assumption is also made in this analysis:

- If there is no enforcement and inspection:
    - Due to the use of older machines, defects or manipulation, the associated emissions are three to twenty times higher than the specified machines. This means that emissions can quickly double in the case of 5% to 15% violations of the MVI agreements. Comparable percentages were seen for SCR manipulation on trucks, APK particulate filter tests and violations of environmental zone rules. Half of the achievable effect is therefore achieved with enforcement and inspection. This is because a small proportion of machines with substantially higher emissions have a large effect on the average emissions.
    - Defects and tampering are still present in the machinery, especially in modern machines with complex emission control technology to achieve low emissions. Over the years, this problem will increase if repairs are not stimulated through inspection. The effects of this are therefore relatively greater with stricter criteria.

Table 4 shows the reduction potential per level specified in the SRP criteria. The reduction potential is a comparison between the reference fleet and a fleet in which all machines that do not meet the emission limit are divided over the other emission classes that are permitted.

Table 4: Reduction potential scenarios without enforcement and inspection.

	NO_x		PM	
Year	2025	2030	2025	2030
Level I without enforcement and inspection [ton]	286	142	28	15
Level II without enforcement and inspection [ton]	339	180	43	22
Level III without enforcement and inspection [ton]	824	620	50	24

5 Enforcement and inspection through EMPI

Enforcement and inspection are suggested by implementing the EMPI. This concerns monitoring and inspection linked to the setting of SRP criteria in public tenders and the setting of emission criteria in environmental permits by the competent authority. As a result, the full effect of the minimum limit setting is achieved and there are no tampering and defects in the fleet. This requires regular and effective checks.

The effect of this measure was calculated by comparing the EMMA model runs with and without defects and manipulation.

The assumption made in EMMA for manipulation is:

- 10% of the diesel Stage IV and Stage V machines (30% of the fleet in 2020 and 74% in 2025 is Stage IV or V) has a non-functioning SCR installation.
- 5% of the diesel Stage V machines (10% of the fleet in 2020 and 62% in 2025) have a non-functioning or removed particulate filter.

In Table 5 shows for each scenario which additional reduction is achieved if enforcement and inspection are applied. This table shows that the potential effect of the EMPI is greater than the potential effect of only imposing criteria on the machines as in the levels above. This is because only half of the reduction by setting criteria can be achieved without enforcement and inspection. In addition, the effects of tampering and defects in this scenario are believed to be detected and addressed by the EMPI.

It can also be seen that as the criteria become stricter and the fleet becomes cleaner, the effect of the EMPI increases. This is because the scenarios with stricter criteria require more cleaner machines. Except for electrical machines, these machines are more susceptible to manipulation and failure of the emission reduction systems.

Table 5: Additional reduction potential EMPI in tons NOx and particulate matter

	NO_x		PM	
Year	2025	2030	2025	2030
Reference extra reduction EMPI [ton]	849	923	2	3
Level I extra reduction EMPI [ton]	1208	1111	30	18
Level II extra reduction EMPI [ton]	1287	1169	45	25
Level III extra reduction EMPI [ton]	1971	1777	53	28

A slight increase in the use of mobile machines is assumed with economic growth. The effect of the corona pandemic has not been included.

6 Adjustment in use

Mobile machines regularly run on standby (idling) for a large part of the time, i.e. the motor running but without the machine being actively used (Ligterink, 2018; Vermeulen, 2021). The share of standby time can differ greatly per machine type. For machines with SCR systems (Stage IV and V) stand-by will account for a substantial portion of the NO_x emissions (due to the SCR catalyst, which will not remain at operating temperature). The powertrain, or transmission, makes a difference here. In particular, most machines with hydraulic systems in standby continue to draw around 5%-10% engine load, with the SCR not working properly.

The following assumptions have been made for the effect calculation of adapting deployment behaviour:

- Machines are on standby 35% of the time on average;
- Unnecessary standby is used for an extended period of time in 15% of the time (5 minutes or longer);
- Running longer than 5 minutes can be avoided;
- For Stage IV and V machines are the running hours, and total NO_x emissions are therefore 15% lower. A substantial effect can also be expected for Stage IIIB with SCR;
- The effect of this measure is negligible for other Stages and for particulate matter.

Table 6 shows the reduction potential of less standby. In 2025 and 2030 this number has increased, and the effect is greater (-10% or 0.5 kton of NO_x in 2025 and -13% or 0.6 kton in 2030).

Table 6: Reduction potential of less standby time, by monitoring deployment.

	NO_x		PM	
Year	**2025**	**2030**	**2025**	**2030**
Reference fleet [ton]	4763	4375	115	63
Reduction through less standby [ton]	483	560	0	0
Reduction [%]	-10%	-13%	0%	0%

7 Uncertainty

In the previous chapters, the possible effects of EMPI of construction machinery on the total emissions, as calculated with the EMMA model, have been mapped out. In recent months, however, an analysis of the RDW's registration data has revealed that the actual emissions may be considerably higher than the emissions calculated using this model.

This is explained here on the basis of two findings:

- The age distribution of tractors;
- Missing machines in EMMA.

Age distribution of agricultural tractors

Agricultural tractors account for about 20% of the reported emissions from construction machines. This makes them by far the largest source of emissions from mobile machines (across all sectors, including agriculture). Agricultural tractors are also used in construction, for example for earthmoving.
Since January 1, 2021, there is a registration obligation for mobile machines that uses public roads. Owners have been given more than a year to register vehicles, and the number of registrations is already growing steadily. This means that since the beginning of this year, mobile machines that also travels on the road at low speed can be found in the open data of the *Rijksdienst voor het Wegverkeer* (RDW). At the moment (17-2-2021) 40,660 mobile machines are registered, of which 29,203 are agricultural or forestry tractors. This is just over 40% of agricultural tractors reported in EMMA. The number of these machines in EMMA may have been estimated at a lower value to compensate for reduced activity of older agricultural tractors. An emission class can be assigned to the tractors based on the year of manufacture of the tractor. In this case, a conservative estimate has been made whereby vehicles are assigned to a stage class from the year the first vehicles met a particular stage class. In reality, it took several more years before the emission criteria for all vehicle types were introduced. Table 7 show the assignment.

Table 7: Allocation of stages to tractors.

Stage	Model year from	Model year to
<=1980	0	1980
1981-1990	1981	1990
1991-STAGE I	1991	1998
STAGE I	1999	2002
STAGE II	2003	2005
STAGE IIIA	2006	2010
STAGE IIIB	2011	2013
STAGE IV	2014	2018
STAGE V	2019	2025

The numbers thus obtained per stage were compared with the same distribution of the EMMA model.

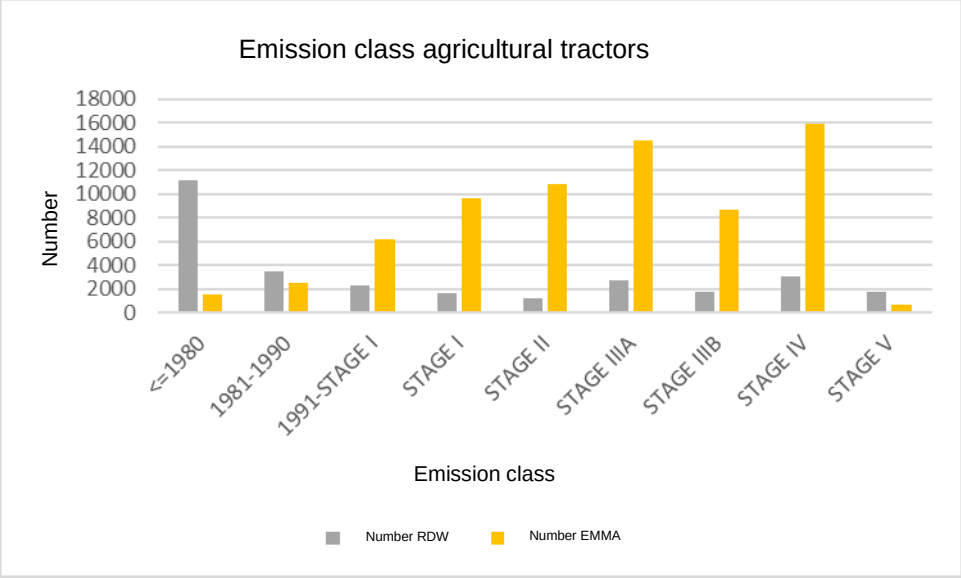

Figure 6: Agricultural tractors breakdown by emission classes.

Figure 6 shows that there are many older agricultural tractors than is calculated in the EMMA model. The number of tractors from before 1980 is already seven times higher than estimated, while the total number of registered tractors is only 40% of the total in EMMA. Of the registered vehicles, 58% are from before 1991 (i.e. without emission class) while this is only 15% in the EMMA fleet.
This could mean that the actual emissions from agricultural tractors are many times higher than estimated. The effectiveness of EMPI could therefore also be higher.

The most recent registration of mobile machines with the RDW, especially agricultural tractors, but also other machines that use public roads, show that the average age is around twenty years (Stage I). Older machines will probably be used less, but this active registration does shed a different light on the fleet than is used in EMMA, and the environmental impact for cleaning and checking the fleet may therefore be greater.

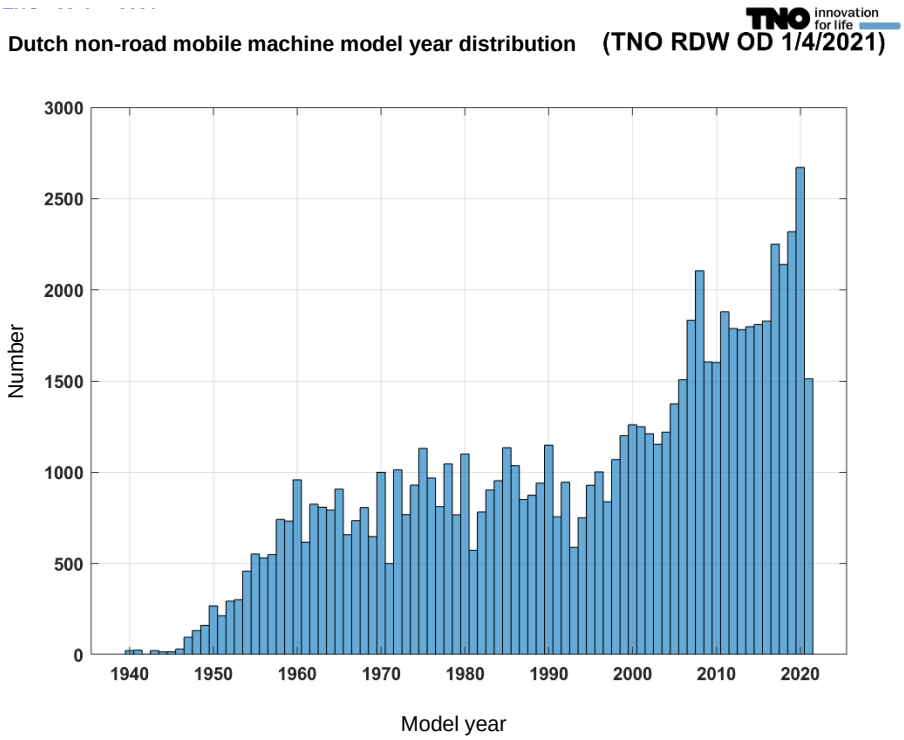

Figure 7: The age distribution, based on the date of first admission, of new registrations of mobile machines with the RDW as of 1 April 2021.

Missing machines in EMMA

In addition to the recent registration of mobile machines on public roads, mobile machines can also be found in the RDW registration of road vehicles, for example machines mounted on trailers. This also includes special vehicles such as mobile cranes and aerial work platforms. Some of these vehicles are registered as such in the RDW data (such as compressors on trailers), but some machines can only be found on the basis of the combination of make and model of the machine.

A quick scan in the RDW data has yielded the following numbers of machine types that are not included in EMMA:

- >3000 compressors;
- >2000 light poles;
- >1000 concrete pumps/concrete mixers;
- >3000 aerial platforms;
- >1000 other machines such as decontamination trucks, woodchippers, drilling trucks, high-pressure cleaners.

The machines found are mainly lighter machines, under 19 kW, for which less strict emission criteria apply. In the latest emission measurements, such a light pole was measured, which emits between 49 and 80 grams of NO_x per hour. With a low estimate of 500 operating hours per year, this light tower would emit about 35 kilograms of NO_x per year.

Considering there are more than 2,000 light poles, would alone this missing source additional 70 tons of NO_x emissions, at least 1% of the total emissions from all mobile machinery. For example, there are several dozen other missing emission sources in EMMA. The recently conducted survey for the Ministry of Infrastructure and Water Management to better map the fleet composition of mobile machines confirms that various machine types are missing from the EMMA model or are underestimated in terms of numbers. The findings lead to the expectation that smaller and older machines are underestimated in the model and the actual effectiveness of policy evaluated based on this may therefore be different. On the one hand, the use of cleaner machines can yield more because there are more old polluting machines. On the other hand, the effect of less idling and preventing deterioration and manipulation may be smaller. The latter measure mainly affects young vehicles. Some form of inspection will also provide better insight into the size and nature of the problem than is currently the case.

8 Limit values concept proposal SRP emission criteria

The draft proposal for SRP criteria for mobile machinery, which is assumed in this memo, is based on the legal emission criteria for mobile machinery, in a laboratory test. In practice, these emissions are higher. The table below shows the emission criteria for PM/PN and NO_x of the different Stages and power classes. The solid lines indicate the major steps in the criteria. Ultimately, level III is only for the strictest criteria for particulate matter and NO_x. A sole emission control technology, such as EGR, is necessary from level I. A particulate filter is necessary from level II. A closed particulate filter is only standard with a PN limit of 10^{12} particles per kWh. For smaller machines of the same class, criteria are generally less strict, and the implementation dates delayed.

Table 8: Legal NO x and PM criteria for the different stages and power classes.

Power [kW]	<19	19-37	37-56	56-75	75-130	130-560	>560
PM [g/kWh]							
V (2019)	0.4	0.015/PN	0.015/PN	0.015/PN	0.015/PN	0.015/PN	0.045
IV (2014)	-	-	-	0.025	0.025	-	-
IIIB (2011)	-	-	0.025	0.025	0.025	0.025	-
IIIA (2006)	-	0.6	0.4	0.4	0.3	0.2	-
II (2002)	-	0.8	0.4	0.4	0.3	0.2	-
I (1999)	-	-	0.85	0.85	0.7	0.54	-
NO_x [g/kWh]							
V (2019)	7.5	4.7	4.7	0.4	0.4	0.4	3.5
IV (2014)	-	-	-	0.4	0.4	0.4	-
IIIB (2011)	-	-	4.7	3.3	3.3	2.0	-
IIIA (2006)	-	7.5	4.7	4.7	4.0	4.0	-
II (2002)	-	8.0	7.0	7.0	6.0	6.0	-
I (1999)	-	-	9.2	9.2	9.2	9.2	-

The lack of strict NO_x criteria below 56 kW, but a tightening of the PM criteria, is the reason for making a distinction between Stage IIIA and Stage IIIB in the power classes 37 to 56 kW.

9 Follow up and future research

With this memo, a first step has been taken in determining the potential of an EMPI for mobile machinery. Further study into the size and age of the machinery is needed to properly map out the actual, likely larger, potential and effects.

Next steps include:

- Analysis of age distribution of construction machines other than agricultural tractors based on RDW registrations;
- Complete comparison between EMMA and RDW registration data;
- Emission measurements of mobile machines in use;
- Counts of mobile machines on construction sites;
- Collection of activity data from mobile machine activity;
- Improvement of the EMMA model based on the new insights.

References

Hulskotte, J., & Verbeek, R. (2009). Emissiemodel Mobiele Machines gebaseerd op machineverkopen in combinatie met brandstof afzet. Utrecht: TNO.

Visser, N., & Nicolas, R. (2020). Bedrijfseconomische kencijfers b&u en gww-bedrijven 2018. Economisch Instituut voor de Bouw.

Vermeulen, R.J. et al. (2021) Real-world emissions of non-road mobile machinery, TNO R10221.

Ligterink, N.E. et al. (2018) De inzet van bouwmachines en de bijbehorende NO_x- en CO_2-emissies, TNO R10465.

Van Eijk, E. (2020), Ruimtelijke verdeling bouwmachines, TNO R12319.