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TNO report

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Emissions of two-wheeled vehicles

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Summary

One of the tasks of the Netherlands Emissions Registry (Pollutant Release and Transfer Register, PRTR) is to calculate emissions caused by road traffic using up to date methods. Since stricter emission limits have been set and new vehicle technology have been introduced new updated calculation methods were needed for two-wheeled vehicle emissions. Research was done to update two-wheeled vehicle emission factors and to renew the model calculating the yearly number of kilometres driven by motorcycles and mopeds. In addition, new VOC profiles and PAH emission factors were developed.

The following goals were achieved:
- development of emission factors of motorcycles and mopeds,
- development of a model to calculate the distribution of the two-wheeled vehicle fleet and,
- development of VOC profiles and PAH emission factors.

Development of emission factors for motorcycles and mopeds
The set of HC (hydrocarbons), CO, NO_x and PM10 (particulate matter) emission factors for powered two-wheeled vehicles was updated based on literature and emission measurements. Also preliminary CO_2 emissions factors are presented. The new emission factors are a comprehensive condensation of the newest measurements and insights, since most measurements found in literature were used in the development of the emission factors for powered two-wheeled vehicles for the COPERT 4 emission model. The new emission factors are shown in Table 5 to Table 9 (pages 22 to 23).

Development of the model to calculate the distribution of the vehicle fleet
A new emission model for the calculation of two-wheeled vehicle tailpipe emissions of HC, CO_2, CO, NO_x, SO_2, PM10, Pb and other metals was developed. The new model allocates the annual total amount of vehicle kilometres to the different vehicle- and road types.

The model was based on assumptions on median lifespan and removal rate of the two-wheeled vehicles, modelled with a Weibull distribution, combined with two-wheeled vehicle sales data (RAI/BOVAG, 2010c). Statistics about the vehicle fleet were used for the model calibration in any given year. The vehicle kilometres were calculated by multiplying average travelled kilometres by road type fractions and age distributions. Statistical data supplied by Statistics Netherlands (CBS, 2010) was used to calibrate the vehicle kilometres. The model generates an output file containing driven kilometres per vehicle- and road type for the total Dutch two-wheeled vehicle fleet for the total time series 1990 -2010. Each year the model will be updated to include the succeeding year, based on statistical data.

Total emissions
The emissions of regulated pollutants and the pollutants related to the fuel consumption were calculated using the current and updated method.
The following trends (for the regulated pollutants) were observed:

- HC emissions, for 90% produced by mopeds, decrease from 25 kiloton to around 5 kiloton from 1990 to 2009. The new and old method calculated similar emissions for mopeds, only the distribution over the years is different in the new method, indicating that the previous emission factor was an average for all moped types.

- The new method calculates lower HC emissions for motorcycles. Stricter emission regulations resulting in improved technology cause the HC emissions to decrease.

- The total CO emissions remain relatively constant from 1990 to 2005, even though emission factors have decreased over time. Modern motorcycles seem to emit less CO than was assumed with the previous method. For mopeds CO parallels the trend observed for HC.

- PM10 emissions, for 90% produced by mopeds, decrease over time for mopeds, while motorcycles PM10 emissions remain fairly constant. PM10 emissions for mopeds are much higher with the new calculation method. Especially older vehicles seem to emit more PM10 than was assumed with the previous method.

- The increase in NO_x emissions, caused by both vehicle types, is due to the technological adjustments aimed at the reduction of HC and CO emissions. The NO_x emissions have increased (250 ton in 1990 to more than 1000 ton in 2009). For motorcycles the NO_x emissions are higher with the new method. The emissions from mopeds decrease in the early 90^ties^, while for more recent years the emissions increases compared tot the old model.

- Based on preliminary CO_2 emission factors, emissions of CO_2 continue to rise, from 100 kiloton in 1990 to more than 250 kiloton in 2009, mainly caused by the expansion of the motorcycle vehicle fleet and increased total mileage of the motorcycles. Overall motorcycle CO_2 emission factors are lower with the new method. Older mopeds seem to emit more CO_2 than was assumed in the previous method.

Development of VOC profiles and PAH emission factors
The new VOC profiles and PAH emission factors are based on a literature research. New VOC[1] profiles were derived from literature for mopeds and 4-stroke motorcycles. The results show that both profiles have a high similarity with the passenger cars VOC profile (without catalyst). No data was found on 2-stroke motorcycles, but in order to calculate speciated VOC emissions for this type of vehicle it was suggested to use the moped VOC profile.

[1] VOC are the same substances as HC, with the exception of methane.

For mopeds, a new set of PAH (polycyclic aromatic hydrocarbons) emission factors was compiled. For motorcycles, not enough data was found for calculating a new profile, neither for using new absolute emission factors. It was therefore decided to use the existing profiles for motorcycles.

Despite several uncertainties, the emission factors in combination with the model will add accuracy to the emission calculations of two-wheeled vehicles. It is therefore recommended to apply the approach laid down in this report in the Dutch PRTR.

Acronyms and Glossary

ACEM	Association des Constructeurs Européens de Motocycles
AECC	Association for Emissions Control by Catalyst
CBS	Statistics Netherlands
cc	cubic centimetres, measure for engine volume
CI	Compression ignition, usually engines on diesel
CO	Carbon monoxide
CO_2	Carbon dioxide
CORINAIR	CORe emission INventories AIR
DI	Direct injection
EF	Emission factor
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt
HC	Hydrocarbons
HDV	Heavy duty vehicles
IDI	Indirect injection
IPN	International Projects Network
JRC	Joint Research Centre
LAT	Laboratory of Applied Thermodynamics
LDV	Light duty vehicles
N_2O	Nitrous oxide
NH_3	Ammonia
NMVOC	Non-methane volatile organic compounds
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PI	Positive ignition, usually engines on gasoline or natural gas
PM10	Particulate matter with maximum diameter of 10µm
PM2,5	Particulate matter with maximum diameter of 2,5µm
PRTR	Pollutant Release and Transfer Register
RAI/BOVAG	Rijwiel en Automobiel Industrie/Bond van Autohandelaren en Garagehouders
RPM	Rounds-per-minute, used as measure for engine speed
SD	Standard deviation
SO_2	Sulphur dioxide
VOC	Volatile organic compounds
WMTC	World Motorcycle Test Cycle

Contents

1 Introduction

One of the tasks of the Netherlands Emissions Registry (PRTR) is to calculate emissions caused by road traffic. To achieve this, a ‘bottom-up’ method is applied (besides a top-down approach). The bottom-up method consists of calculation the total of emissions by multiplying emission factors per substance by the yearly number of kilometres driven per vehicle category.

The PRTR emission calculation is in use for a long time and depends on a set of bottom-up emission factors and a dedicated two-wheeled vehicles fleet model (mopeds and motor cycles). There are indications that both these emission factors and the model are not up-to-date anymore, mainly because emission limits for powered two-wheeled vehicles have become stricter during the past decade. Also, there are some new insights on the annual mileage and active stock of two-wheeled vehicles. These new developments are not yet integrated in the current emission calculations.

This report documents both the update of relevant emission factors and the new emission calculation model for two-wheeled road traffic. These developments constitute the basis for a recalculation of the national emissions from two-wheeled vehicles.

Revised emission factors for CO, NO_X, PM10 (particulate matter) and HC (hydrocarbons) were established based on data from literature and actual measurements. Also preliminary emission factors for CO_2 were established. These emission factors are presented in chapter 2.

The new emission factors together with revised activity data feed into the new emission calculation method. However, official data about annual travelled kilometres per vehicle type is lacking in the Netherlands; plus, no comprehensive dataset on the composition of the two-wheeled vehicle fleet exists. Therefore a new two-wheeled vehicle fleet-model was developed with the goal of allocating travelled kilometres to motorcycles and mopeds equipped with technologies that meet the different emission limits. This fleet-model is described in chapter 3.

Applying the new model and updated emission factors results in changes in total emissions of the two-wheeled vehicle fleet compared to previous calculations. These updated emissions are presented and compared to the emissions according the current method in chapter 4.

In chapter 5 new VOC-profiles and PAH emission factors of the HC emissions of powered two-wheeled vehicles are displayed.

In the last chapter conclusions are presented, as well as recommendations and a short evaluation of the reliability of the presented data.

2 Emission factors of regulated components

In this chapter first the vehicle categories used are introduced. Then, for each vehicle category, emission factors are determined based on measurements in literature.

2.1 Determination of vehicle categories based on legislative categories

The study object is two-wheeled vehicles powered with reciprocating engines. These two-wheeled vehicles can be divided into two groups: mopeds and motorcycles. Mopeds have an (cylinder) swept volume smaller than 50cc and motorcycles an (cylinder) swept volume equal to or greater than 50cc. This classification is implemented in the European legislation on powered two-wheeled vehicles.

Recently a proposal for the renewal of the legislation for the emissions of powered two-wheeled vehicles was published and will come into force from 2014 onwards if the legislation is accepted. In the legislation the classification into mopeds and motorcycles is maintained.

2.1.1 Emission regulation for motorcycles

Emissions regulations for 2- and 4-stroke motorcycles were first introduced in June 1999 (Euro 1), when Directive 97/24/EC came into force. The Directive imposed emission limits for 2- and 4-stroke vehicles. In 2002, Regulation 2002/51/EC introduced the Euro 2 (2003) and the Euro 3 (2006) standards for motorcycles with differentiated speed limits depending on engine size. Together with the mopeds new legislation for emissions of motorcycles is foreseen to come into force in 2014. This will be standards for Euro 4 (2014) and Euro 5 (2017) motorcycles.

Table 1: European emission limits for motorcycles

stage and starting date	**technical specifications**	**CO mg/km**	**HC mg/km**	**NO_x mg/km**	**PM10 mg/km**
Euro 1	2-stroke motorcycles	8000	4000	100	
(17/6/1999)	4-stroke motorcycles	13000	3000	300	
Euro 2	motorcycles <150 cc	5500	1200	300	
(1/4/2003)	motorcycles ≥150 cc	5500	1000	150	
Euro 3	motorcycles <150 cc	2000	800	150	
(1/1/2006)	motorcycles ≥150 cc	2000	300	150	
Euro 3 WMTC[2]	PI[3] & max speed less than 130 km/h	2620	750	170	
(18/8/2006)	PI & max speed more than 130 km/h	2620	330	220	
Euro 4	PI & max speed less than 130 km/h	1970	560	130	
(1/1/2014)	PI & max speed more than 130 km/h	1970	250	170	
	CI[4] / hybrid	1000	100	570	100
Euro 5	PI & max speed less than 130 km/h	1140	380	70	
(1/1/2017)	PI & max speed more than 130 km/h	1140	170	90	
	CI / hybrid	1000	100	300	80

[2] The manufacturer can choose to use these limits, the test cycle to be driven must be the WMTC
[3] PI vehicles: usually gasoline or natural gas vehicles
[4] CI vehicles: usually diesel vehicles

Compliance with the standards can be demonstrated by either the Euro test cycle (from Euro 3 and higher) or the alternative World Motorcycle Test Cycle (WMTC). If a manufacturer chooses to use the latter cycle, slightly different standards apply.

2.1.2 Emission legislation for mopeds

In June 1999, multi-directive 97/24/EC (Euro 1) introduced the first emission limits for mopeds. An additional stage of the legislation came into force in June 2002 (Euro 2). New Euro 3 and 4 emission limits for mopeds are currently being prepared by the European Commission and will probably come into force from 2014 on. In Table 2 the consecutive standards are presented:

Table 2: European emission limits for mopeds

stage and starting date	**technical specifications**	**CO mg/km**	**HC mg/km**	**NO_x mg/km**	**HC+NO_x mg/km**
Euro 1 (17/6/1999)	Mopeds	6000			3000
Euro 2 (17/6/2002)	Mopeds	1000			1200
Euro 3 (1/1/2014)	Powered cycle (max 25 km/h) Two-wheel moped (max 45 km/h)	560 1000[4]	100	130	 1200[5]
Euro 4 (1/1/2017)	Powered cycle (max 25 km/h) Two-wheel moped (max 45 km/h)	560 1000	100 630	70 170	

For Euro 5 (coming into force from 1/1/2020 on) also new limits are proposed for different categories, including on-board-diagnostics requirements. Because of the difference in systemic categories in the Euro 5 standards these are not included in the table. No standards for PM10 are set for mopeds.

Emission regulations for other pollutants or CO_2 are not included in European or national laws for powered two-wheeled vehicles.

2.1.3 Vehicle classes

It is expected that the legislation for the powered two-wheeled vehicles affects the way manufacturers will take measures to reduce the emissions for each group of vehicles (vehicle classes). For this reason the analysis in the emission model is based on the following vehicle classes used in the legislation:

Table 3: Motorcycle vehicle classes used in the emission model

Engine size (cc)		**Stroke-cycle**	**Euro stages[6]**
min	**Max**		
50	-	2	0[7], 1, 2 and 3
50	250	4	0, 1, 2 and 3
250	750	4	0, 1, 2 and 3
750	-	4	0, 1, 2 and 3

[5] These seem to be the same limits as for Euro 2, but the difference is how the test cycle is driven. From Euro 3 on the cycle should start with a cold instead of a warm engine.
[6] All euro stages are separate vehicle categories
[7] Pre-Euro 1 vehicles are often referred to as Euro 0 vehicles

Table 4: Moped vehicle classes used in the emission model

Maximum speed	Stroke cycle	Euro stages[8]
25 km/h	2	0[9], 1 and 2
	4	0, 1 and 2
45 km/h	2	0, 1 and 2
	4	0, 1 and 2

The vehicle classes are determined on legislative and technological grounds. Introduction of a new Euro stage usually is accompanied by a step in technology. The engine volume indicates the difference between mopeds and motorcycles in legislation, but in motorcycles no further distinction is made in legislation. 2- or 4-stroke engines are different engine technologies, independent of Euro stages. The maximum speed in mopeds also is determined by legislation.

Two-wheeled vehicles powered by diesel fuel and electricity are disregarded, because of the low number of vehicles sold until now or zero emission. The determination of the vehicle classes was also affected by the availability of measurements and data on kilometres driven. This means for example that there was not enough data found to distinguish between 2- and 4-stroke mopeds, although on technical grounds different emission factors are to be expected. Also the classification couldn't diverge too much from the categories currently used, because of the availability of other data, for example from Statistics Netherlands (CBS).

2.2 Determination of the emission factors

Compared to passenger cars and trucks not a lot of attention is paid to mopeds and motorcycles in traffic-related emissions in the scientific world. This is probably because of the relative small contribution of these vehicles to total traffic related NO_2 and PM10 emissions. Comprehensive surveys on powered two-wheeled vehicles, particularly on mopeds are rare. Still there are some researchers that have investigated emissions of two-wheeled vehicles and their findings are described here.

For the determination of the emission factors, literature is selected which meets the following criteria:
- emissions were measured for mopeds and / or motorcycles, or
- measurements were collected and emission factors were developed for mopeds and / or motorcycles

The goal is to determine emission factors for all categories of two-wheel vehicles for CO, HC, NO_x and PM10 for urban, rural and highway (only motorcycles) driving. Also preliminary CO_2 emission factors are developed.

First a description of the characteristics of motorcycles and mopeds that influence the exhaust emissions is given, in order to determine which characteristics are of importance in determining emission factors of powered two-wheeled vehicles.

[8] All euro stages are separate vehicle categories
[9] Pre-Euro 1 vehicles are often referred to as Euro 0 vehicles

2.2.1 Influences on the emissions of motorcycles

HC and CO emissions of motorcycles
HC and CO emission factors of modern motorcycles are high compared to emission factors of modern passenger cars. In chapter 5 a new VOC profile of the HC emissions is presented for powered two-wheeled vehicles. Most new motorcycles are equipped with a catalyst to reduce these emissions. According to ACEM (ACEM, 2002) reduction of emissions by catalysts is extremely dependent on the type of motorcycle and on the combustion scheme used (rich, lean or stoichiometric). The catalyst is able to reduce HC's and CO under a lean mixture and NO_x under a rich mixture.

The current emission control technologies applied to motorcycles are for example secondary air injection, electronic fuel injection, three way catalysts (TWC), oxidation catalyst, hot tube catalysis and stroke direct fuel injection (Hews et al, 2004).

According to Hews (Hews et al, 2004) two-stroke motorcycles with carburettors are unlikely to meet the HC and CO requirements even with high levels of exhaust gas after-treatment such as multiple catalysts and secondary air injection. A shift towards 4-stroke motorcycles has already started also because these engines are more robust when it comes to complying with the emission limits.

Enough information was gathered to develop CO and HC emission factors, see paragraph 2.2.3.

PM10 emissions of motorcycles
In general particle emissions from modern motorcycles are low. The particles consist of mainly unburned fuel (HC's) and some soot. Although according to IPN (IPN 2004) old motorcycles, such as pre-Euro1 motorcycles with conventional 2-stroke engines, emit high masses and numbers of particulate matter, the PM10 emission has been reduced during the past decades using 2-stroke engines with direct fuel injection and/or catalysts. PM10 emission factors of 4 stroke motorcycles, even the older types, are comparable to emission factors observed at gasoline fuelled passenger cars.

Particle number emissions from eleven motorcycles tested by ACEM (ACEM, 2002) appear to be strongly related to motorcycle engine operating temperature. This generally is related to engine tuning, but may also be related to combustion technology, number of strokes, indirect (IDI) / direct (DI) injection and the presence or absence of after-treatment. Generally, rich fuel mixture maintains low combustion and exhaust temperatures, while lean combustion elevates these temperatures. In 4-stroke motorcycles PM10 numbers can be slightly lowered by a catalyst according to Czerwinski (Czerwinski et al, 2002).

For PM10 fewer measurements were available, but enough to develop PM10 emission factors, see paragraph 2.2.3.

NO_x emissions of motorcycles
Higher speeds and loads will increase NO_x emissions and possibly CO emissions (Hews et al, 2004). In a study of ACEM (ACEM, 2002) eight of the ten motorcycles tested had very low NO_2 emissions. The absolute NO_x emission factors of

motorcycles are low, especially compared to NO_x emission factors of diesel vehicles, although they are higher with higher speeds and with higher Euro stage. The NO_x emission factors are higher with higher Euro stage, because the engine is tuned to reduce HC and CO emissions ever more, automatically resulting in higher NO_x emissions.

NO_x emission factors could be developed as well, see paragraph 2.2.3.

Cold start
Cold start is a term usually used for indicating that the engine of the vehicle is at ambient temperatures and not at optimal operating temperatures. This affects the emissions produces during warm-up of the engine. Emissions are also influenced by the ambient temperature: at lower temperatures not only the engine is colder, but the lower temperatures also influence the type of emissions due to reactions in the exhaust gasses.

Emissions are generally elevated during a cold start, so when engine (and after-treatment systems if present) are not at optimal operating temperatures yet. A lot of measurements show increased or doubling of the CO and HC emissions with cold start (Hews et al, 2004 and Czerwinski et al, 2002). In a study performed by AECC (AECC 2008) Euro 3 motorcycles were tested with and without a cold engine. Although emissions were elevated during cold start, most emissions stayed under the emission limits. In motorcycles equipped with catalyst the maximum catalysing rate was not reached under cold start conditions (Czerwinski et al, 2002).

As indicated above, emissions also depend on ambient temperatures. Measurements performed by EMPA (EMPA 2004) at 5°C and 23°C showed increased emissions in the warmer ambient temperature.

The cold start effect on emissions is incorporated into the emission factors, see paragraph 2.2.3. If more information would become available about for example trip length, also different cold and hot emission factors could be developed as is done for passenger cars already. At this moment there is not enough information to incorporate the effect of low ambient temperatures on emission factors.

Deterioration
AECC tested Euro 3 motorcycles on durability (AECC 2008). CO emissions didn't exceed the Euro 3 limit until a total of 2000 km was driven and NO_x limits were exceeded after 5000 km of driving. With catalytic systems the deterioration of the CO-conversion is a problem. This is partly caused by the fact that incomplete oxidation of a large amount of HC may produce CO in the catalyst (Rijkeboer 2002).

Not enough information is found to incorporate the effects of deterioration into the emission factors.

Alternative fuels
A motorcycle was tested by Jia (Jia et al, 2005) at different speeds on regular gasoline and on E10 (gasoline with 10% ethanol). The emissions of CO, HC and NO_x were measured. All emissions were elevated when reaching higher speeds (15-35 km/h). When driving constant at 50 km/h the emissions of HC and CO went down and the emissions of NO_x rose. The HC emissions of the motorcycle were slightly lower when driving on E10 compared to driving on gasoline.

The effect on emissions of alternative fuels was outside the scope of the project.

2.2.2 Influences on the emissions of mopeds

HC, CO, PM10 and NO_x emissions of mopeds
HC and CO emissions of mopeds are high, especially related to their fuel consumption. This is mainly due to rich fuel mixture. Therefore HC's consist mainly of products of incomplete combustion. In chapter 5 a new VOC profile is presented for powered two-wheeled vehicles. CO emissions also emerge from incomplete burning of fuel. NO_x emissions are low due to rich combustion, not allowing the oxidation of nitrogen from the air.

PM10 emission factors are low compared to diesel vehicles and consist of aerosols of unburned fuel contrary to mainly soot in diesel vehicles. PM10 emissions occur mainly during the acceleration phase which corresponds to a very rich combustion mixture (Prati et al, 2009). According to Czerwinski blending of ethanol in gasoline has positive effects on PM10 emission reduction (Czerwinski et al, 2008).

Enough information was gathered to develop emission factors for all pollutants, see paragraph 2.2.3.

Catalysts for mopeds
In the past catalyst were not required to meet moped emission standards. The emission limits were easily met by engine calibration alone. Now the emission limits become stricter more and more mopeds are equipped with catalyst to reduce the emissions.

Czerwinski tested two mopeds with and without an oxidation catalyst. It was found that the oxidation catalyst reduced the emissions of PM10, CO and HC for a DI moped with around 50%. For a carburation moped the HC and CO emissions dropped to almost zero and PM10 was reduced as well (Czerwinski et al, 2008). Spezzano found comparable results, but argued that this could also be because of the reduced fuel consumption of the catalyst equipped moped (Spezzano et al, 2008). The ten vehicles tested by Spezzano had such a different fuel consumption that the difference in emissions could not be explained by the presence or absence of catalysts only. HC conversion rates for oxidation catalysts were reported ranging from 10-80% (IPN 2004). Prati measured particles with a larger diameter in the absence of the oxidation catalyst (Prati et al, 2009). But also some studies show that emissions rise after the catalyst: for some driving conditions and vehicles, the post catalyst CO and NO_x concentrations were higher than before the catalyst (IPN 2004).

Although catalysts have a high emission reduction potential, in practice they prove to be not that reliable (break down easily and are probably not robust enough for practical circumstances). In the case of 2-stroke engines with oxidation catalyst, durability can be a relatively critical aspect. The high temperatures of the exhaust gas can, in the long term, decrease the conversion rate and increase the light-off temperature (Rijkeboer 2002). In a study performed by EMPA, four of six scooters tested failed the legislative test direct following purchase from the seller. It could not be ruled out that some catalyst were already broken before delivery (IPN 2004).

The effects of catalysts are incorporated into the emission factors using measurements results from mopeds with catalysts, see paragraph 2.2.3.

Cold start
Several studies report higher emissions from mopeds during cold start. The starting phase of the engines contributes significantly to the total emissions and should be taken into consideration since frequent cold starts are common in typical moped use patterns.

In a study JRC performed on three mopeds with oxidation catalyst (Adam et al, 2010), the HC emissions were four times higher during cold start compared to normal operation conditions. In the carburation mopeds the PM10 emissions were two times as high and the CO emissions more than two times as high. NO_x emissions remained the same compared to DI engines. For a Direct Injection (DI) engine the PM10 emissions were 35% less during cold start and the NO_x emissions 20% less. Spezzano (Spezzano et al, 2008) found that during hot running the HC emissions were 20% lower for Pre-Euro 1 mopeds and 40-50% for Euro 1 mopeds compared to cold start emissions. Czerwinski (Czerwinski et al, 2002) reported doubling of CO- and HC-emissions in the first 1.5 min after the start and also higher particle mass and nanoparticulates emissions. In later phases no differences were found between cold start and hot start emission. Czerwinski also measured the PM10 emissions during cold start. The PM10 emissions increased in peaks during cold start and increased as the engine became warmer and the operation more dynamic (Czerwinski et al, 2003).

The cold start effect is incorporated in the emission factors, see paragraph 2.2.3.

Direct injection
In general, in gasoline passenger cars equipped with direct injection (DI), CO and HC emissions decrease, while NO_x emissions increase compared to cars without DI. In mopeds the same is true according to a small number of studies.

In a study performed by JRC the engine with carburettor showed the highest emissions of HC and CO, while the DI engine showed the highest NO_x and PM10 emissions (Adam et al, 2010). Two mopeds tested by ACEM (ACEM, 2002) appeared to have very different NO and NO_2 emissions. The 2-stroke DI moped equipped with an oxidation catalyst had relatively high emissions, while the carburetted moped had relatively low emissions. One exception was reported by Prati, who found that the mopeds equipped with electronic fuel injection (EFI) produces the lowest emissions (Prati et al, 2009).

Adam has suggested that measures lowering the HC emissions also reduce the PM10 emissions, but it was not sure this would be enough for DI engines to comply with the emission limits (Adam et al, 2010). According to Rijkeboer (Rijkeboer 2002) 2-stroke DI mopeds have a performance benefit over classical 2-strokes, plus a fuel consumption benefit over both classical 2-strokes (large) and 4-stroke (smaller). Oil consumption is better than on a classical 2-stroke, although not zero as on a 4-stroke. The tampering risk is much less, since the system relies even less on after-treatment.

There was not enough information to split the emission factors into emission factors for direct and indirect injected mopeds.

Oil dosing and type
Especially in 2-stroke mopeds the oil consumption is high and a lot of PM10 appears to be oil-related. Adam proved that 2-stroke engines’ main contributor to PM10 is lubricant oil mixed with gasoline. As a consequence, the soluble organic fraction of 2-stroke PM10 can be up to 90% (Adam et al, 2010). Czerwinski performed measurements on two mopeds (DI and carburettor), but with variation in oil dosing and oil type. The lowering of oil dosing rate appeared to be a relatively simple way to meet the emission limits. The oil quality could lower the particle emission level by 20-40% (Czerwinski et al, 2008).

Although the influences on the amount of emissions are obvious not enough data was available to differentiate the emission factors.

4-stroke versus 2-stroke
Emissions of 2-stroke (2-stroke) mopeds are different from 4-stroke (4-stroke) mopeds because of the differences in techniques used for propulsion. 2-stroke mopeds (but also in general all vehicles equipped with this technique) have richer operating conditions, resulting in higher HC and CO emissions. On the other hand 4-stroke engines have a much lower HC-emission and consequently less fuel consumption, but produce relative more NO_x because of lean operation.

Two studies investigated the differences in emissions. Czerwinski tested one 4-stroke and one 2-stroke DI moped, to measure the impact of the number of strokes. There were differences in the amount and weight of the emissions of PM10. The PM10 from the 2-stroke engine was mainly oil-related and consisted of more and smaller particulates than the PM10 from the 4-stroke moped (Czerwinski et al, 2003). According to Prati, 4-stroke mopeds have lower HC and CO emissions, but higher NO_x emissions than 2-stroke mopeds, while the 2-stroke mopeds have very high PM10-numbers during acceleration (Prati et al, 2009). Hews states that carburetted 2 stroke machines are unlikely to meet the HC and CO requirements even with high levels of after-treatment such as multiple catalysts and secondary air injection (Hews et al, 2004).

According to Rijkeboer (Rijkeboer 2002) environmental benefits of 4-stroke mopeds are better durability of the after-treatment system and reduced fuel and oil consumption in comparison to the 2-stroke. The disadvantages are lower performance and relatively high cost.

Although the influences on the amount of emissions are obvious, not enough data was available to split the emission factors into 2-stroke and 4-stroke emission factors.

Tampering
Tampering is the adaption of the vehicle usually to increase maximum speed and often increases noise emission. There is no literature found on the effect of tampering on emissions. No measurements were found to compare regular emissions of a moped to those of a tampered moped. As mentioned above, EMPA tested some mopeds where it could not be excluded that some catalyst broke already before delivery (IPN 2004). The emissions of these mopeds might be comparable to those tampered with, because one way of tampering is removing the catalyst to improve drivability.

According to Rijkeboer (Rijkeboer 2002) and Spezzano (Spezzano et al, 2008) readjustments and a change of exhaust are very easy. This obviously influences the emissions. The real-world durability is in this way far from guaranteed in the case of a classical 2-stroke with extensive after-treatment.

There was not enough data available to differentiate in emission factors between tampered and regular mopeds. Even if this was available it would be hard to find data about how many mopeds are tampered in practice.

2.2.3 Data used for the determination of the emission factors

A lot of literature on the development of emission factors was based on the same measurements. In a paper of Ntziachristos (Ntziachristos et al, 2006) combined with a report written by Samaras (Samaras et al, 2009) most recent measurements found in the papers above were combined to produce emission factors developed for COPERT 4 version 7.1. The Greek institution LAT, where both Samaras and Ntziachristos are employed, developed the model COPERT to calculate emissions from road traffic.

The experimental data from the ARTEMIS project, reviewed and extended with new experimental information submitted by ACEM and EMPA, has been used by LAT for the development of CO, NO_x, PM10 and HC emission factors and fuel consumption factors for motorcycles and mopeds. Like for other vehicles in the COPERT model for motorcycles a dependency of emissions on speed was established using measurement data.

Although not all desired categories were included, the main reason for using the COPERT 4 emission factors is that it is the most complete set of comprehensive emission factors available from literature. Other reasons are:

- combination of almost all found recent measurements
- emission factors in g/km
- emission factors for future legislative classes[10]
- differentiation into mopeds and motorcycles
- differentiation into Euro classes
- differentiation into urban, rural and highway
- differentiation into engine capacity classes for motorcycles
- pollutants CO, HC, PM10, NO_x and fuel consumption
- including cold start emissions

CO_2 emission factors were calculated from the fuel consumption factors. This was not planned at the beginning of the project, so they weren’t researched as well as the other pollutants. For this reason the CO_2 emission factors are preliminary.

The emission factors developed for COPERT4 are shown in the following tables for motorcycles and mopeds.

[10] Not needed for PRTR yet

Table 5: Emission factors for 2-stroke motorcycles (g/km)

Road type	Euro stage	HC	CO	NO_x	PM10	CO_2[11]
urban	0	11,1	22,3	0,03	0,20	101
	1	5,9	8,8	0,02	0,08	72
	2	1,8	6,0	0,07	0,04	66
	3	0,7	1,5	0,20	0,01	50
rural	0	8,5	25,1	0,07	0,20	99
	1	6,1	13,2	0,03	0,08	82
	2	1,8	9,1	0,10	0,04	75
	3	0,7	2,2	0,28	0,01	58
highway	0	8,3	26,8	0,12	0,20	112
	1	5,7	14,5	0,05	0,08	89
	2	1,7	9,9	0,20	0,04	81
	3	0,7	2,4	0,55	0,01	63

Table 6: Emission factors for 4-stroke motorcycles with an engine capacity of max 250cc (g/km)

Road type	Euro stage	HC	CO	NO_x	PM10	CO_2[12]
urban	0	2,2	26,9	0,11	0,02	87
	1	1,2	12,3	0,22	0,02	72
	2	1,1	6,5	0,19	0,01	72
	3	0,4	4,5	0,14	0,01	63
rural	0	1,0	26,3	0,24	0,02	84
	1	0,9	14,6	0,42	0,02	93
	2	0,6	6,0	0,27	0,01	93
	3	0,2	4,3	0,27	0,01	59
highway	0	1,6	41,1	0,39	0,02	118
	1	0,9	15,5	0,79	0,02	126
	2	0,6	9,3	0,53	0,01	126
	3	0,2	6,6	0,47	0,01	85

Table 7: Emission factors for 4-stroke motorcycles with an engine capacity of 250 to 750cc (g/km)

Road type	Euro stage	HC	CO	NO_x	PM10	CO_2[13]
urban	0	1,8	24,0	0,11	0,02	114
	1	1,1	9,0	0,26	0,02	98
	2	1,1	6,5	0,19	0,01	98
	3	0,5	3,7	0,14	0,01	141
rural	0	0,9	21,5	0,25	0,02	91
	1	0,8	13,3	0,48	0,02	93
	2	0,6	6,0	0,27	0,01	93
	3	0,2	1,2	0,12	0,01	92
highway	0	1,0	26,8	0,40	0,02	114
	1	0,8	21,3	0,82	0,02	141
	2	0,6	9,3	0,53	0,01	141
	3	0,2	1,5	0,24	0,01	111

[11] Preliminary emission factors
[12] Preliminary emission factors
[13] Preliminary emission factors

Table 8: Emission factors for 4-stroke motorcycles with an engine capacity of 750cc and higher (g/km)

Road type	Euro stage	HC	CO	NO_x	PM10	CO_2[14]
urban	0	3,4	17,5	0,12	0,02	147
	1	1,4	9,1	0,17	0,02	157
	2	1,1	6,5	0,19	0,01	157
	3	0,4	3,1	0,08	0,01	181
rural	0	1,6	18,0	0,27	0,02	109
	1	0,7	6,9	0,52	0,02	115
	2	0,6	6,0	0,27	0,01	115
	3	0,1	0,9	0,04	0,01	118
highway	0	1,1	25,5	0,42	0,02	126
	1	1,0	12,1	1,22	0,02	135
	2	0,6	9,3	0,53	0,01	135
	3	0,1	0,8	0,28	0,01	119

Table 9: Emission factors for mopeds for both urban and rural road types in g/km

Euro stage	HC	CO	NO_x	PM10	CO_2[15]
0	13,9	13,8	0,02	0,19	79
1	2,7	5,6	0,02	0,08	47
2	1,6	1,3	0,26	0,04	38

All emission factors decrease with higher Euro stage, except for NO_x. The step from stage 0 (before legislation) and Euro stage 1 has the biggest effects. CO and HC emission factors are lower, because of the better calibration of the vehicles, induced by lower emission limits. PM10 decreases automatically with decrease of HC, since most PM10 of powered two-wheeled vehicles consists of HC aerosols. NO_x emission factors are higher with higher Euro stage, because of the measures taken to lower HC and CO emissions. The vehicles with higher Euro stage are usually tunes to drive on leaner mixtures, thus producing less CO and HC but more NO_x.

The emission factors for CO_2 were calculated from the fuel consumption emission factors provided for by LAT. The emission factors of mopeds seem to be lower than one would expect from common knowledge about fuel consumption. Further investigation is needed to determine whether the emission factors used here are representative to real world driving. For this reason the emission factors presented here are preliminary emission factors for both mopeds and motorcycles.

[14] Preliminary emission factors
[15] Preliminary emission factors

2.3 Update of the emission factors

Although the above indicates a lot of differentiation between categories, still more differentiation would be desired. The following options would help to further improve the emission calculations and could be investigated in the future:
- CO_2 emission factors
- NO_2 emission factors
- differentiation for 2- and 4-stroke mopeds
- differentiation into max 25 km/h and max 45 km/h mopeds
- differentiation into cold and hot start
- effects of tampering on emissions

The proposed emission factors should be updated in the future as soon as:
- measurements on powered two-wheeled vehicles are performed within TNO that give reason to change the emission factors,
- new measurements are published that show results that are not in line with the emission factors,
- new technologies become common amongst powered two-wheeled vehicles, such as diesel, hybrids, new Euro classes, shifts in 2 versus 4 stroke, technologies to reduce emissions, etc.

3 Two-wheeled vehicle model

The main goal of the model is to allocate the total amount of vehicle kilometres per year to different vehicle categories and road types. The emission factors depend on these types and need this detailed data (see chapter 2, Table 5 to Table 9). However, the required details are not available in official statistics. With the model presented here, the total vehicle kilometres can be allocated to the different vehicle categories and road types.

In paragraph 3.1, the calculation steps in the model are described, while in paragraph 3.2 the input data is described. The yearly update of the model is described in paragraph 3.3.

3.1 Model description

Figure 1 shows the steps used to allocate the total vehicle kilometres to the vehicle categories and road types. The calculation starts with statistics on motorcycle and moped sales per year of sale (box I1).

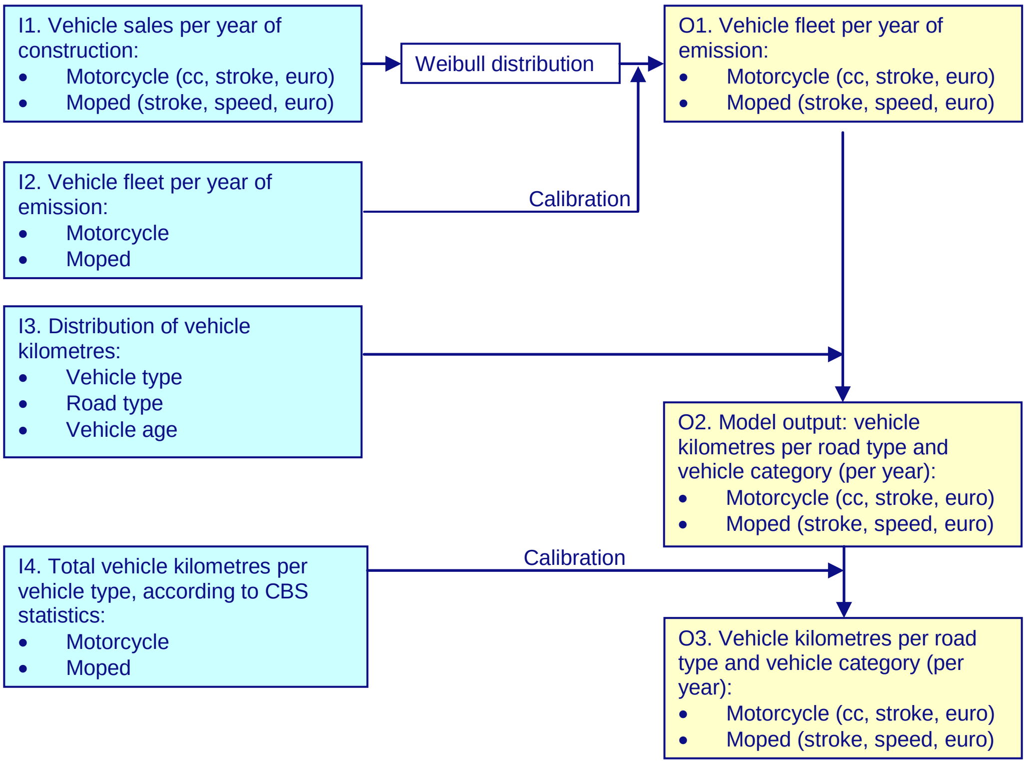

Figure 1: Flowchart, describing the calculation steps of the model (starting from the top). The boxes on the left show the model input (I1-I4), while the boxes on the right show the model output (O1-O3)

Assuming a median life span and a removal (scrap) rate of the motorcycles and mopeds, the two wheeled vehicle fleet can be modelled for every (emission) year (box O1). The median life span and the removal rate are modelled with a Weibull distribution. Statistics on the fleet per (emission) year are used to calibrate the model (box I2). For each emission year, the calculation of this step is shown in equation 1.

$$Fleet_{VehicleCategory} = \sum_{Year} Sales_{VehicleCategory,Year} \times (1 - RemovalRate_{VehicleCategory,Year}) \qquad (1)$$

Where:

$Fleet_{VehicleCategory}$	= Vehicle fleet in the year for which emissions are calculated
$Sales_{VehicleCategory,Year}$	= Vehicle sales per construction year and per vehicle type
$RemovalRate_{VehicleCategory,Year}$	= Removal rate of vehicles, depending on the age of the vehicle

After calculating the motorcycle and moped fleet per (emission) year for each vehicle category, the next step is to calculate the vehicle kilometres for each vehicle category and for each road type. For this, average vehicle kilometres are combined with information about the contribution of vehicle categories to the total vehicle kilometres, the share of kilometres on each road type and the influence of age (box I3). Within this step, the amount of (modelled) kilometres is calculated for every (emission) year (box O2). The calculation for the modelled kilometres per vehicle category and road type for each emission year is shown in equation 2.

$$ModelKm_{VehicleCategory,RoadType} = Fleet_{VehicleCategory} \times Km_{VehicleCategory} \times F_{RoadType} \times F_{age} \qquad (2)$$

Where:

$ModelKm_{VehicleCategory,RoadType}$	= Modelled kilometres per year and per road type
$Fleet_{VehicleCategory}$	= Vehicle fleet in the year for which the emissions are calculated
$Km_{VehicleCategory}$	= Average vehicle kilometres per vehicle category
$F_{RoadType}$	= Fraction of the kilometres driven per road type
F_{Age}	= Distribution of kilometres over age classes

An important precondition for the model is the compatibility with the official reported statistics by Statistics Netherlands (CBS) for the entire motorcycle and moped fleet (box I4). Therefore, in the last step, the modelled kilometres are used to calibrate the CBS statistics, resulting into vehicle kilometres per vehicle category (box O3). In equation 3 the calculation is shown for each emission year.

$$Kilometres_{VehicleCategory,RoadType} = ModelKm_{VehicleCategory,RoadType} \times F_{CBS} \qquad (3)$$

Where:

$Kilometres_{VehicleCategory,RoadType}$	= Kilometres per year and per road type
$ModelKm_{VehicleCategory,RoadType}$	= Modelled kilometres per year and per road type

F_{CBS} = Calibration factor used to distribute the total CBS kilometre statistics over the vehicle categories and road types

The vehicle kilometres per road type and per vehicle category will be combined with the emission factors (see chapter 2) in order to calculate the total emissions (see chapter 4).

3.2 Data and assumptions

The model, as described in the previous paragraph, needs input data from official statistics or expert estimates. This paragraph describes the information sources used to build the model. The description will start with statistics on motorcycle/moped sales and motorcycle/moped fleet which is needed in box I1 and I2 of figure 1 (paragraphs 3.2.1 and 3.2.2) and the Weibull distribution used for modelling the removal rate (paragraph 3.2.3). Furthermore, the distribution of vehicle kilometres are described which is needed in box I3 of figure 1, being the average vehicle performance per age class (paragraph 3.2.4) and the share of kilometres per road type (paragraph 3.2.5). Finally, the CBS statistics on vehicle kilometres, which is needed in box I4 of figure 1 will be discussed (paragraph 3.2.6).

The emission factors have been determined for several vehicle categories. These vehicle categories have also been used in the fleet model. Table 3 and Table 4 in chapter 2 show the vehicle categories used in the model.

3.2.1 Motorcycle and moped sales
The necessary sales data include:
- Motorcycles: Total sales and private import of motorcycles, the proportion of cylinder volume category, stroke and Euro class.
- Mopeds: Total sales and proportion of speed, stroke and Euro class.

First the information and the assumptions used are described for motorcycles and mopeds, then the sales figures as used in the model are shown in figure 2 and figure 3.

Motorcycles
Total vehicle sales for the years 1975-2009 are available from RAI/BOVAG (RAI-BOVAG, 2010a). For the years 1960-1974, it is assumed that sales increased linearly (assuming sales in 1960 to be half of the sales in 1974). Private import of motorcycles is available from RAI/BOVAG (RAI/BOVAG, 2010b) for the years 2005-2009. For earlier years, it is assumed to increase linearly.

The proportion of the several cylinder volume categories for the years 1989-2009 are available from RAI/BOVAG. For earlier years, it is assumed that the proportion remained constant. The motorcycle sales have been split into 3 cylinder volume categories (<250cc, 250-750cc and >750cc).

Detailed sales and fleet figures from RAI/BOVAG (RAI/BOVAG, 2010c) have been used to determine the proportion of 2-stroke and 4-stroke motorcycles. This information on motorcycle type has been used to find information on cylinder volume and stroke. For about 75% of the motorcycles, the details were sufficient.

For the other 25%, the proportion of 2-stroke and 4-stroke motorcycles was estimated based on the proportion in other motor types from the same brand. Table 10 shows the resulting proportions for the sales in 2009, while table 11 shows the resulting proportions for the fleet in October 2009. The fact that the proportion of 2-stroke motorcycles is higher in the fleet than in the sales figures suggests that the sales of 2-stroke motorcycles were higher in earlier years. Therefore, for the 2009 sales, the proportion of 2-stroke motorcycles has been used from table 10. For earlier years, it is assumed that the proportion of 2-stroke motorcycles almost halves between 1975 and 2009.

Table 10: Proportion of 2-stroke and 4-stroke in the 2009 sales, as estimated using the detailed sales information from RAI/BOVAG (RAI/BOVAG, 2010c)

cylinder volume category	**2-stroke**	**4-stroke**
<250cc	18.72%	81.28%
250-750cc	0.83%	99.17%
>750cc	0.00%	100.00%

Table 11: Proportion of 2-stroke and 4-stroke in the October 2009 fleet, as estimated using the detailed fleet information from RAI/BOVAG (RAI/BOVAG, 2010d)

cylinder volume category	**2-stroke**	**4-stroke**
<250cc	33.51%	66.49%
250-750cc	1.64%	98.36%
>750cc	0.00%	100.00%

It is assumed that the compliance with the different Euro classes is linked to the year in which the two wheeled vehicle was sold. Table 12 shows the link between the Euro class and the years when these motorcycles were sold.

Table 12: Euro classes for motorcycles and the years when these motorcycles were sold

Euro class	**Years**
Pre-Euro 1	<1998
Euro 1	1999-2002
Euro 2	2003-2005
Euro 3	>2006

Mopeds

Two types of mopeds are used in the Netherlands, each with a different maximum speed (25 km/h and 45 km/h). Sales statistics are available from RAI/BOVAG (RAI-BOVAG, 2010a and RAI-BOVAG, 2010e) for the years 2002-2009 for 45 km/h mopeds and for the years 2006-2009 for 25 km/h mopeds. For earlier years, it is assumed that sales increased linearly over time.

It is assumed that the compliance with the different Euro classes is linked to the year in which the two wheeled vehicle was sold. Table 13 shows the link between the Euro class and the years when these mopeds were sold.

Since the emission factors for 2-stroke and 4-stroke mopeds are the same and detailed information on 2-stroke or 4-stroke mopeds is not available for the vehicle fleet, this split has not been specified in the model.

Table 13: Euro classes for mopeds and the years when these mopeds were sold

Euro class	**Years**
Pre-Euro 1	<1998
Euro 1	1999-2001
Euro 2	>2002

Sales figures used in the fleet model

Figure 2 and figure 3 show the sales figures used in the fleet model. These sales figures include data from RAI/BOVAG statistics and some expert judgements.

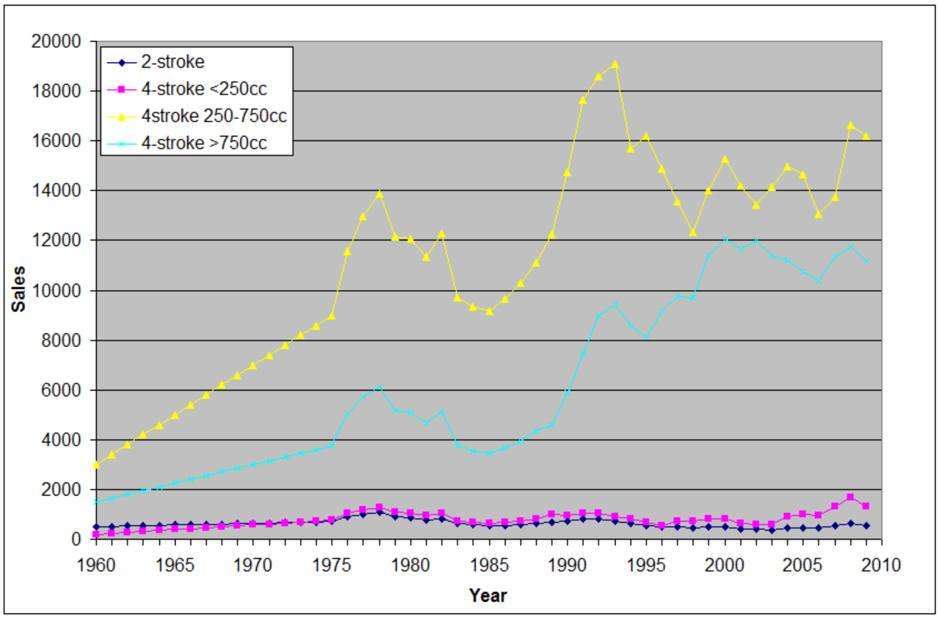

Figure 2: Motorcycle sales for the years 1960-2009, used as input for the fleet model

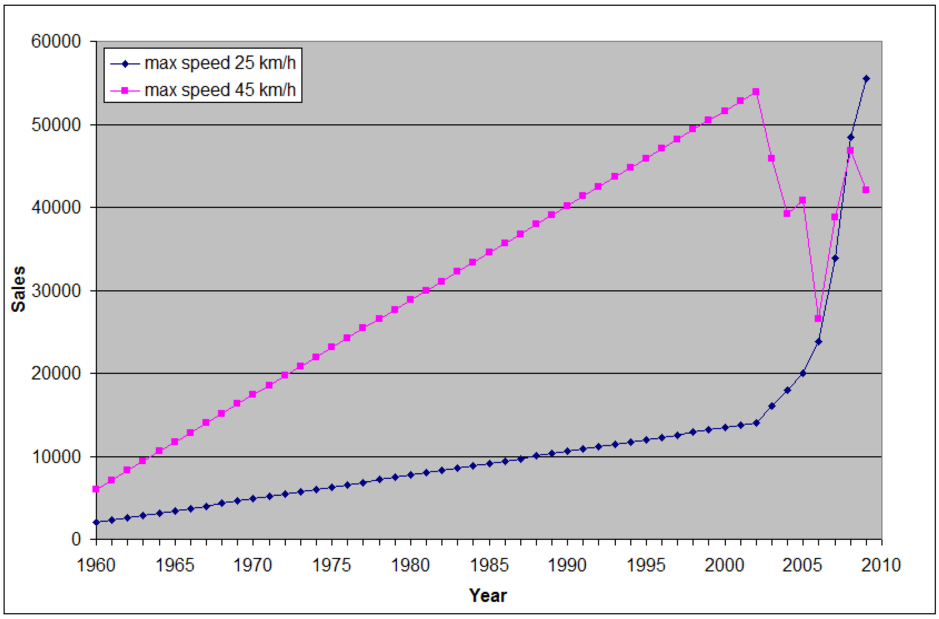

Figure 3: Moped sales for the years 1960-2009, used as input for the fleet model

3.2.2 *Fleet per year of emission*

The motorcycle and moped fleet is available in RAI/BOVAG statistics (RAI/BOVAG, 2010a) for the years 1975-2009 (motorcycles), 2001-2009 (45 km/h mopeds) and 2006-2009 (25 km/h mopeds). These values have been used to calibrate the model. In 2009 the two-wheel fleet consisted of 668.000 motorcycles and 989.319 mopeds (RAI/BOVAG, 2010a).

3.2.3 *Weibull distribution*

Figure 1 shows the steps used to allocate the total performance to the vehicle types and road types. The calculation starts with statistics on motorcycle/moped sales. Assuming a median life span and a removal rate of the motorcycles/mopeds, the fleet can be modelled for every year. The median life span and the removal rate are modelled with a Weibull distribution. A median life span of 22 years for motorcycles and 11 years for mopeds has been assumed. Figure 4 shows the Weibull distribution for motorcycles and mopeds. With the cumulative distribution function (equation 4), the removal rate for every age class can be calculated.

$$F(x,\lambda,\kappa) = 1 - e^{-\left(\frac{x}{\lambda}\right)^{\kappa}} \qquad (4)$$

Where:

x	= Age (years)
λ	= Scale parameter of the Weibull distribution
κ	= Shape parameter of the Weibull distribution

The used parameters are:

Motorcycles	κ = 4	λ = 24
Mopeds	κ = 3	λ = 12

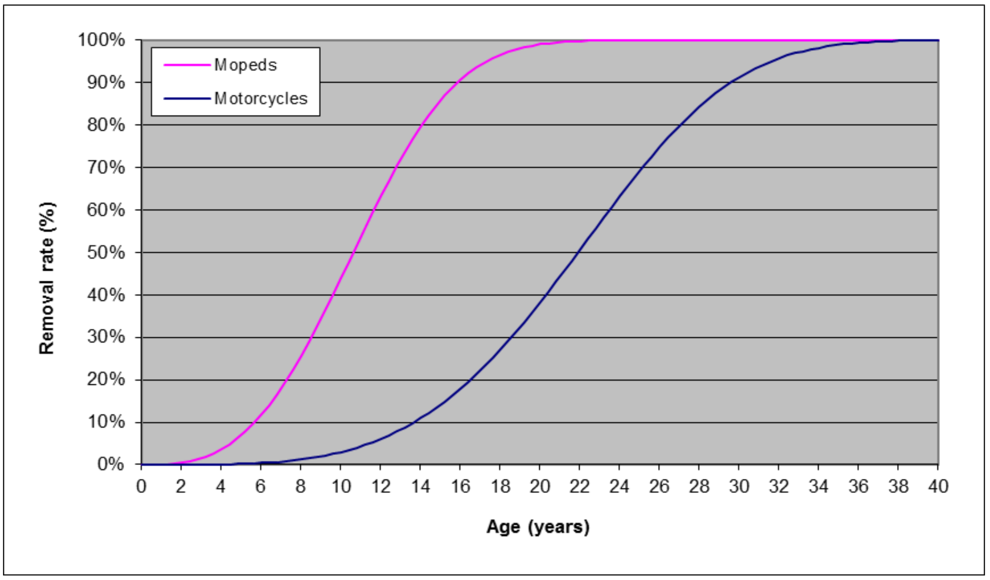

Figure 4: Weibull distribution for motorcycles and mopeds

3.2.4 *Influence of age on vehicle performance*

In 2003 and 2004, Statistics Netherlands (CBS) examined the average vehicle kilometres per age class and as a total for the entire vehicle fleet (CBS, 2010). For the model, these average kilometres have been used to determine the age influence on average vehicle kilometres, relative to the overall average vehicle performance (see table 14). From these results, it is clear that the oldest vehicles drive the least amount of kilometres per year.

Table 14: Age influence on motorcycle kilometres used in the fleet model (relative amounts of kilometres), based on CBS statistics for the years 2003 and 2004

	0 years	**1-2 years**	**3-4 years**	**5-6 years**	**7-8 years**	**9-10 years**	**>10 years**	**All ages**
<750cc	1.53	2.07	1.60	1.34	1.22	1.13	0.81	1.00
>750cc	1.39	1.74	1.45	1.22	1.04	0.98	0.67	1.00

3.2.5 *Road types*

Roads have been split up in three types of roads:
- Highways, with a maximum speed of 120 km/h
- Rural roads, with a maximum speed of 80 km/h
- Urban roads, with a maximum speed of 50 km/h

Table 15 shows the distribution of kilometres among the three road types, which has been used in the fleet model. Mopeds are not allowed on the highways, and it is assumed that the mopeds with maximum speed of 45 km/h are used more often outside cities than the mopeds with maximum speed of 25 km/h. For motorcycles, it is assumed that motorcycles with a larger cylinder volume are more often used on highways than the smaller ones. Most of the motorcycles with a 2-stroke engine have a cylinder volume of less than 250cc. Therefore, the distribution over the three road types is similar for motorcycles with a 2-stroke engine and motorcycles with a 4-stroke engine and a cylinder volume of less than 250cc.

Table 15: Distribution of vehicle performance over the three road types

Type	Highway	Rural	Urban
Motorcycle, 2-stroke	30%	50%	20%
Motorcycle, 4-stroke, <250cc	30%	50%	20%
Motorcycle, 4-stroke, 250-750cc	40%	45%	15%
Motorcycle, 4-stroke, >750cc	45%	40%	15%
Moped, max speed 45 km/h	0%	35%	65%
Moped, max speed 25 km/h	0%	25%	75%

3.2.6 Total kilometres, according to CBS statistics

Information from the previous paragraphs is used in the model to calculate vehicle kilometres for each vehicle category (see Table 3) and for each road type (see table 15). For this, it was assumed that the yearly average vehicle performance is 1500 kilometres for mopeds and 3000 kilometres for motorcycles. CBS statistics on annual national kilometres is available on an annual basis (CBS, 2010). The modelled vehicle kilometres are calibrated to the total CBS vehicle kilometres as shown in table 16. CBS is currently working on a new time series of these statistics. Until the new time series is available, the time series as available in table 16 is used.

Table 16: Annual national kilometres (in million kilometres) for motorcycles and mopeds in the Netherlands according to CBS (CBS, 2010) and calibration factors multiplied with the modelled vehicle kilometres, in order to arrive at the CBS vehicle kilometres

	Annual vehicle performance (million kilometres), CBS 2010		Calibration factors	
Year	Motorcycle	Moped	Motorcycle	Moped
1990	888	1 708	1.67	1.12
1991	977	1 311	1.55	0.86
1992	1 084	1 308	1.39	0.86
1993	1 338	1 308	1.42	0.86
1994	1 831	1 341	1.73	0.88
1995	1 357	1 326	1.26	0.87
1996	1 456	1 326	1.25	0.87
1997	1 522	1 057	1.18	0.70
1998	1 612	1 110	1.19	0.73
1999	1 646	1 112	1.16	0.73
2000	1 734	1 010	1.16	0.67
2001	1 826	910	1.16	0.60
2002	1 936	910	1.16	0.60
2003	2 049	910	1.18	0.60
2004	2 132	810	1.19	0.60
2005	2 198	1 010	1.20	0.71
2006	2 258	910	1.11	0.56
2007	2 321	910	1.12	0.51
2008	2 395	910	1.13	0.46
2009	2 374	1 010	1.09	0.47

3.3 Yearly update of the model

The Netherlands Emissions Registry needs a yearly update of the calculated emissions. The information needed for calculating the vehicle performance per vehicle type of new years are sales information and kilometre statistics.

The necessary sales data include:
- Motorcycles: Total sales and private import of motorcycles, the proportion of cylinder volume category, stroke and Euro class.
- Mopeds: Total sales and proportion of speed and Euro class.

Information on total sales of motorcycles and the distribution of cylinder volume classes can be obtained from RAI/BOVAG (future versions of RAI-BOVAG, 2010a). Also the information on total sales of mopeds and the classification by maximum speed can be obtained here. For the Euro class, it is assumed that this has been linked to the sales year directly. It is necessary to assess yearly whether new Euro stages have been implemented. When new Euro stages have been implemented, it is also necessary to implement new emission factors for this class.

The proportion of 2-stroke and 4-stroke can be determined by assessing the detailed RAI/BOVAG sales data (future versions of RAI-BOVAG, 2010c), combined with characteristics per vehicle type.

Vehicle kilometre statistics are updated yearly by CBS (CBS, 2010).

After adding of this these data it will be possible to calculate automatically the vehicle performance per vehicle type and per road type by means of the new model. The calculation of new emissions than also is enabled by the new model. First model results are discussed in chapter 4.

4 Total emissions of regulated components

In chapter 2 and chapter 3, the emission factors and the fleet model have been described. Emissions can be calculated by combining this information. In this chapter, the results of the vehicle fleet, the vehicle kilometres and the emissions are shown. Also a comparison of emissions between the new and the previous method is described. Paragraph 4.1 shows the vehicle fleet and vehicle kilometres for the motorcycles, and paragraph 4.2 shows the vehicle fleet and the vehicle kilometres for the mopeds. The resulting emissions and a comparison with the previous emission calculations is shown in paragraph 4.3. A complete table with emissions is shown in appendix A.

4.1 Motorcycles

4.1.1 Vehicle fleet

By means of the model described the vehicle fleet for the years 1990-2009 was calculated. The total vehicle fleet is equal to the RAI statistics. Most important is the contribution of the several vehicle categories to the total, since this is used for the allocation of the vehicle performance. In figures 5, 6, 7 and 8 the development of the relative contribution of the several vehicle types to the total fleet is shown.

For motorcycles, Euro 1 was introduced in 1999 into the model, followed by Euro 2 and Euro 3. Since the motorcycles have a long average life span, it takes a while before the older models are excluded from the model. For example, in 1998, all vehicles were Pre-Euro 1[16], while in 2009 still approximately 50% of the vehicles is Pre-Euro 1.

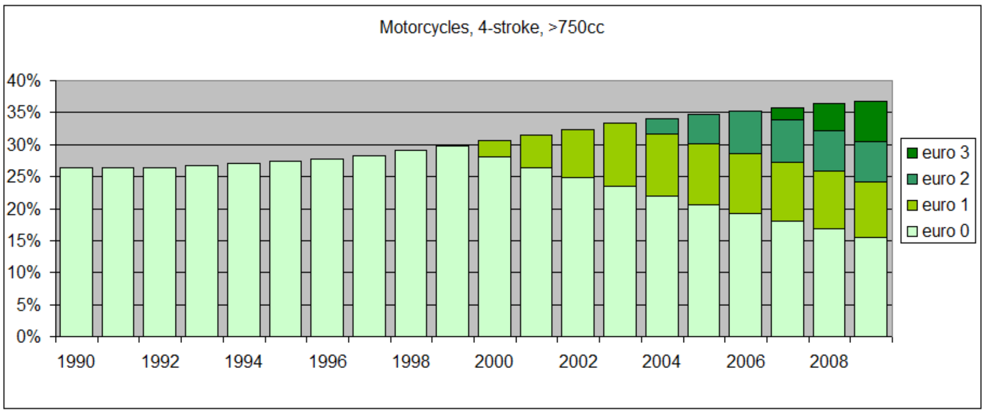

Figure 5: Relative contribution of vehicles (4-stroke, >750cc) to the total motorcycle fleet for the years 1990-2009

[16] Pre-Euro 1 vehicles are often referred to as Euro 0 vehicles

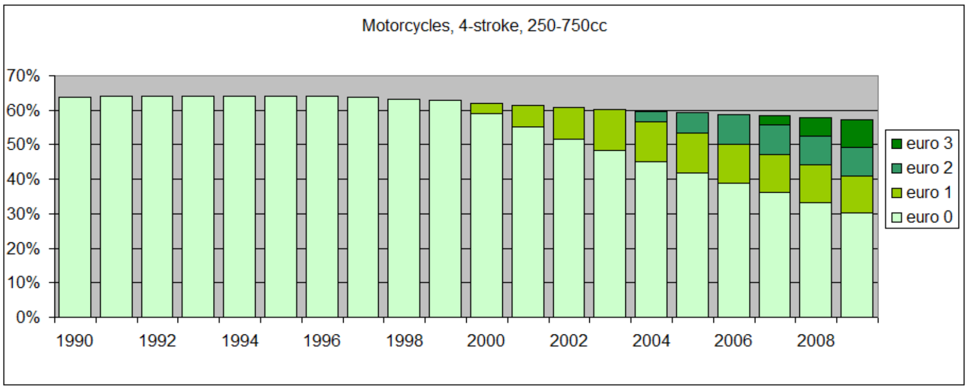

Figure 6: Relative contribution of vehicles (4-stroke, 250-750cc) to the total motorcycle fleet for the years 1990-2009

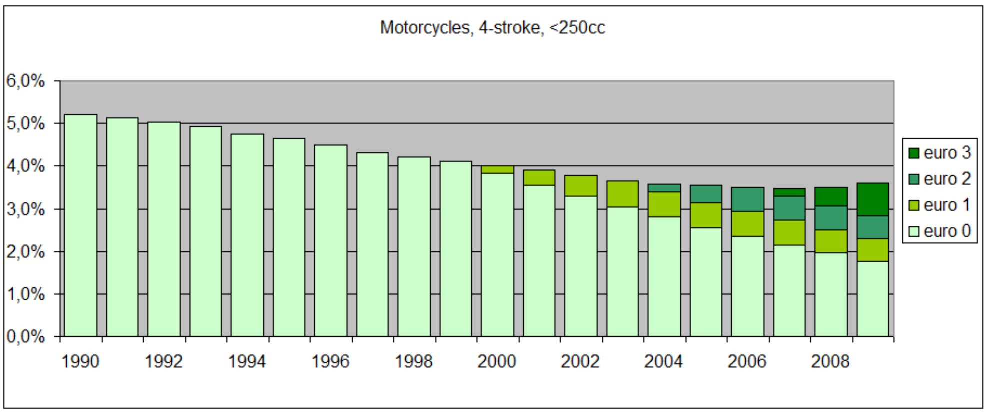

Figure 7: Relative contribution of vehicles (4-stroke, <250cc) to the total motorcycle fleet for the years 1990-2009

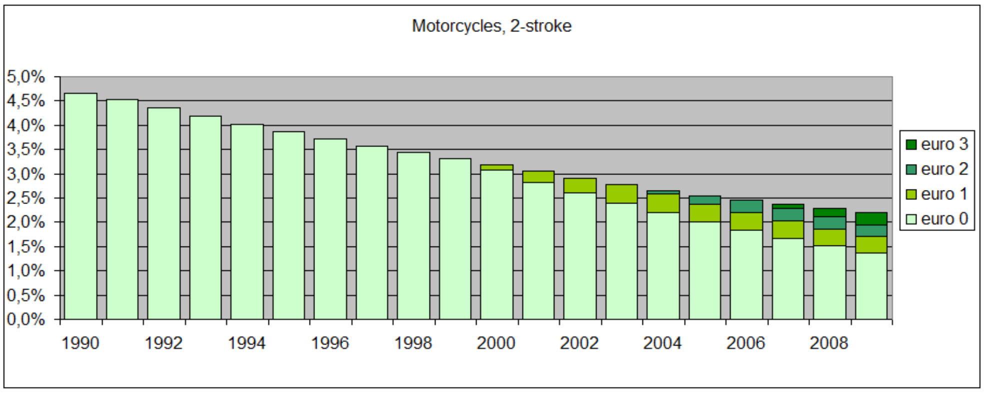

Figure 8: Relative contribution of vehicles (2-stroke) to the total motorcycle fleet for the years 1990-2009

4.1.2 Kilometres

Figure 9 shows the total vehicle performance according to Statistics Netherlands (CBS, 2010), split into the three road types (model output). The high value in 1994 is also visible in the time series of vehicle kilometres from CBS (table 16). CBS is currently working on a new time series.

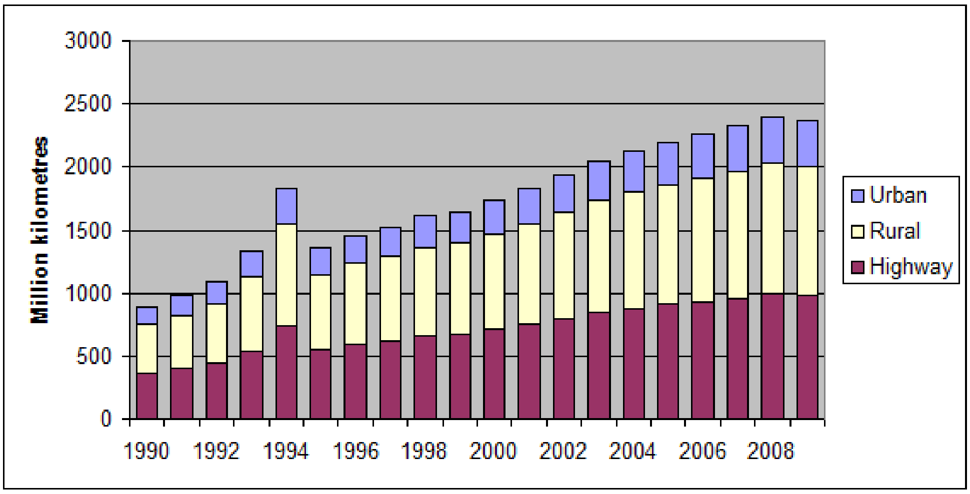

Figure 9: Vehicle kilometres of motorcycles per road type for the years 1990-2009

4.1.3 Fuel use

Fuel use by motorcycles has also been recalculated. Chapter 2 shows the fuel use per kilometre, which have been combined with the vehicle kilometres per vehicle category and road type from the model. In equation 5, the calculation of fuel use per road type is shown.

$$FuelUse_{RoadType} = \sum_{VehicleCategory} Kilometre_{VehicleCategory,RoadType} \times FuelFactor_{VehicleCategory,RoadType} \quad (5)$$

Where:

$FuelUse_{RoadType}$	= Total fuel use per road type (kg)
$Kilometre_{VehicleCategory,RoadType}$	= Vehicle performance per vehicle category and road type (km)
$FuelFactor_{VehicleCategory,RoadType}$	= Fuel use per kilometre per vehicle category and road type (kg/km)

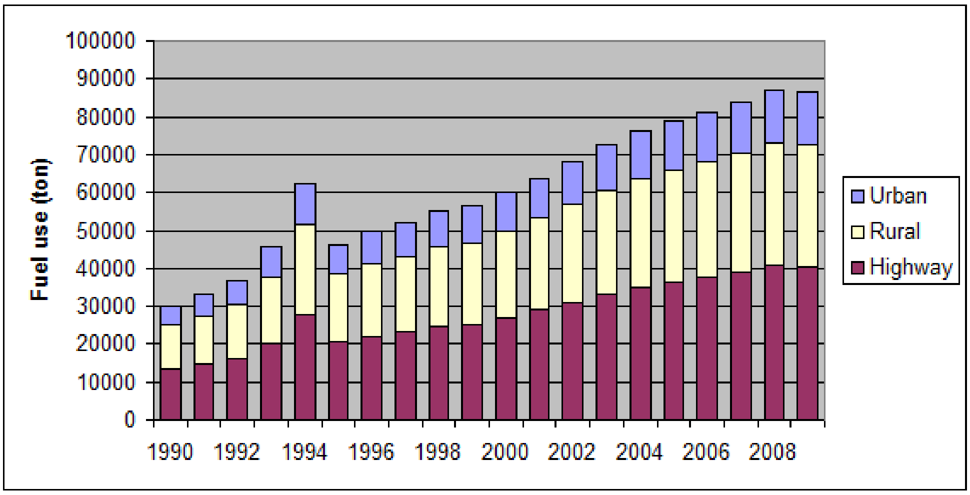

Figure 10: Fuel use (ton) by motorcycles per road type for the years 1990-2009, as calculated with the fleet model

Within the Task Group Traffic and Transport (Taakgroep Verkeer & Vervoer) fleet fuel consumption for all registered vehicles, including the powered two-wheeled vehicles (such as mopeds and motorcycles) is calculated on a regular basis. Fuel consumptions used in the emission model are based on the results of the Task Group Traffic and Transport.

4.2 Mopeds

4.2.1 Vehicle fleet

This model calculated the vehicle fleet for the years 1990-2009. The total vehicle fleet is equal to the RAI statistics. Most important is the contribution of the several vehicle categories to the total, since this is used for the allocation of the vehicle performance. In figure 11 a relative contribution of the several vehicle types to the total fleet is shown.

For mopeds, Euro 1 was introduced in 1999 into the model, followed by Euro 2. Since the mopeds have a shorter life span than motorcycles, the older models are excluded from the model faster. For example, in 1998, all vehicles were Pre-Euro 1[17], while in 2009 approximately 15% of the vehicles are Pre-Euro 1.

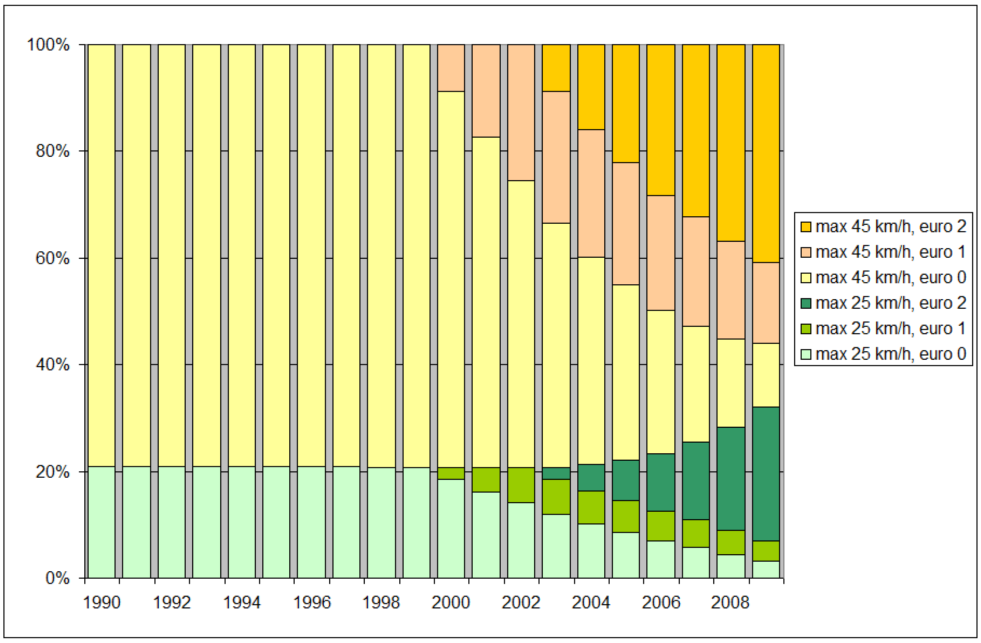

Figure 11: Relative contribution of vehicles to the total moped fleet for the years 1990-2009

4.2.2 Kilometres

Figure 12 shows the total vehicle performance according to CBS (CBS, 2010), split into the two road types (model output, mopeds do not drive on highways).

[17] Pre-Euro 1 vehicles are often referred to as Euro 0 vehicles

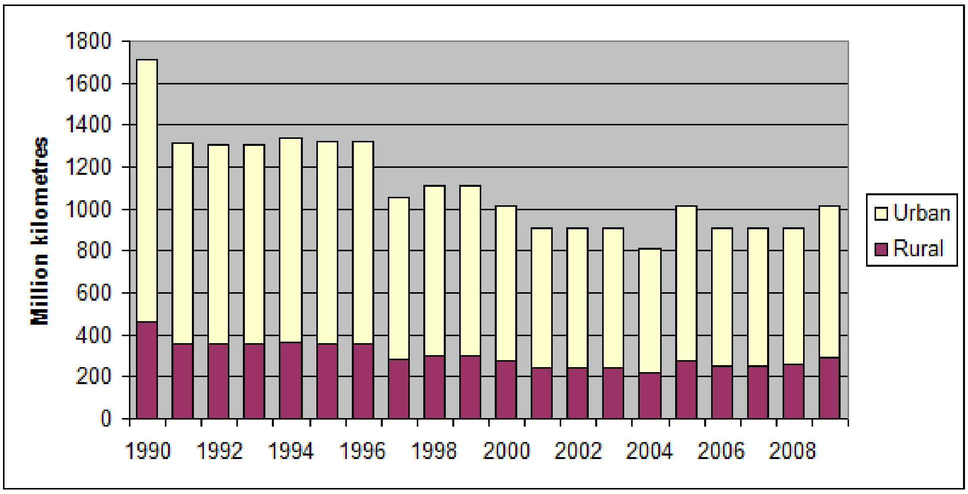

Figure 12: Vehicle performance of mopeds per road type for the years 1990-2009

4.2.3 Fuel use

Fuel use by mopeds has also been recalculated. Chapter 2 shows the fuel use per kilometre, which have been combined with the vehicle kilometres per vehicle category and road type from the model. In equation 6, the calculation of fuel use is shown.

$$FuelUse_{RoadType} = \sum_{VehicleCategory} Kilometre_{VehicleCategory,RoadType} \times FuelFactor_{VehicleCategory,RoadType} \quad (6)$$

Where:

$FuelUse_{RoadType}$	= Total fuel use (kg)
$Kilometre_{VehicleCategory,RoadType}$	= Vehicle performance per vehicle category and road type (km)
$FuelFactor_{VehicleCategory,RoadType}$	= Fuel use per kilometre per vehicle category and road type (kg/km)

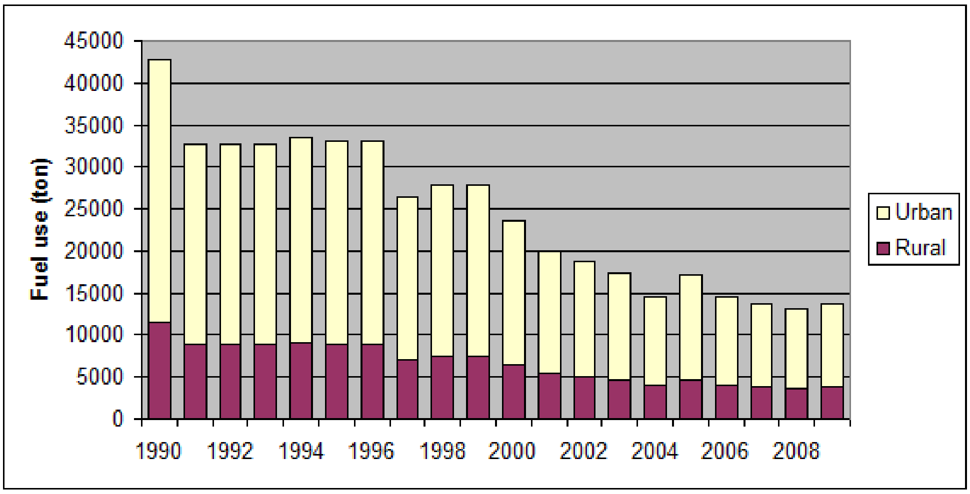

Figure 13: Fuel use (ton) by mopeds per road type for the years 1990-2009, as calculated with the fleet model

As with the motorcycle fuel consumptions, moped fuel consumptions in the emission model are based on the results of the task group.

4.3 Total emissions

Emissions are calculated either using kilometres per vehicle category or using fuel use per vehicle category. Equation 7 and equation 8 show the emission calculation for each pollutant. Equation 7 is used for the pollutants NO_x, PM10, CO, HC, metals (from lubricants), NH_3 and N_2O. Equation 8 is used for the pollutants CO_2, SO_2, Pb and metals (from gasoline).

$$Emission_{RoadType} = \sum_{VehicleCategory} Kilometre_{VehicleCategory,RoadType} \times EF_{VehicleCategory,RoadType} \quad (7)$$

Where:

$Emission_{RoadType}$	= Emission per road type of a pollutant (kg)
$Kilometre_{VehicleCategory,RoadType}$	= Vehicle performance per vehicle category and road type (km)
$EF_{VehicleCategory,RoadType}$	= Emission factor per vehicle category, road type and pollutant (kg/km)

$$Emission_{RoadType} = FuelUse_{RoadType} \times EF_{RoadType} \quad (8)$$

Where:

$Emission_{RoadType}$	= Emission per road type of a pollutant (kg)
$FuelUse_{RoadType}$	= Fuel use per road type (kg)
$EF_{RoadType}$	= Emission factor per road type and pollutant (kg/kg fuel)

Emission factors (and subsequent emissions) for NH_3 and N_2O did not change and are therefore not described in this chapter. Also the emission factors for CO_2, SO_2, lead and metals (from gasoline) did not change although the change in calculated fuel use caused a change in emissions. Therefore, these pollutants are shown in this chapter. A complete list of all calculated emissions is provided in appendix A.

4.3.1 Comparison between results of the new model and the previous methodology

Figures 14-21 show the comparison between the emissions calculated using the new methodology and the previous methodology. For substances SO_2, CO_2 and lead, the emissions have shifted only slightly due to a change in estimation of the fuel use by motorcycles and mopeds. For substances NO_x, PM10, CO and HC the changes were larger, due to a change in emission factor per technology. For example, for motorcycles the Euro 1 NO_x emission factor is higher than the one for Pre-Euro 1. Therefore, the emissions have increased much since the implementation of Euro 1. For some other substances, the Euro implementation caused a decrease in calculated emissions (for example PM10, CO and HC).

For motorcycles the NO_x emissions are higher with the new method (see Figure 14). For mopeds in the older years the emissions decrease, while for more recent years the emissions increase. All these trends can be explained by the fact that new technologies to reduce HC and CO emissions, invoked a rise in the NO_x emissions.

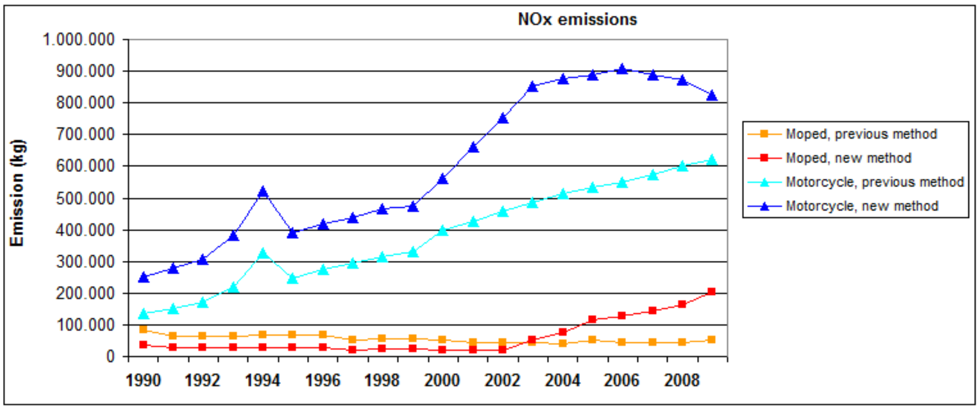

Figure 14: Emissions of nitrogen oxide according to the new and the previous methodology

For motorcycles and mopeds the SO_2 are minimalized due to lowering of legal limits of sulphur content in gasoline (see Figure 15). The differences are caused by the new calculation of the vehicle kilometres driven and the preliminary fuel use factors, since the emission factor didn't change.

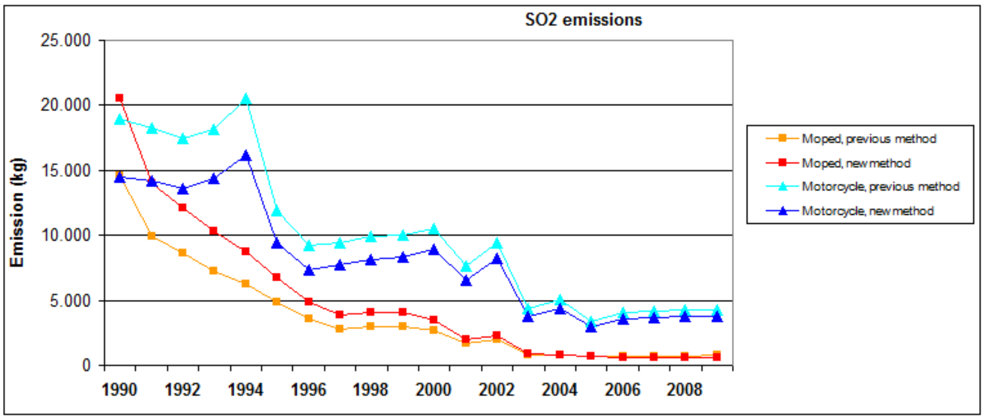

Figure 15: Emissions of sulphur dioxide according to the new and the previous methodology

PM10 emissions for mopeds are much higher with the new calculation method (see Figure 16). Especially older vehicles emit more PM10 than was assumed previously. For motorcycles the emissions are also a bit higher than formerly estimated.

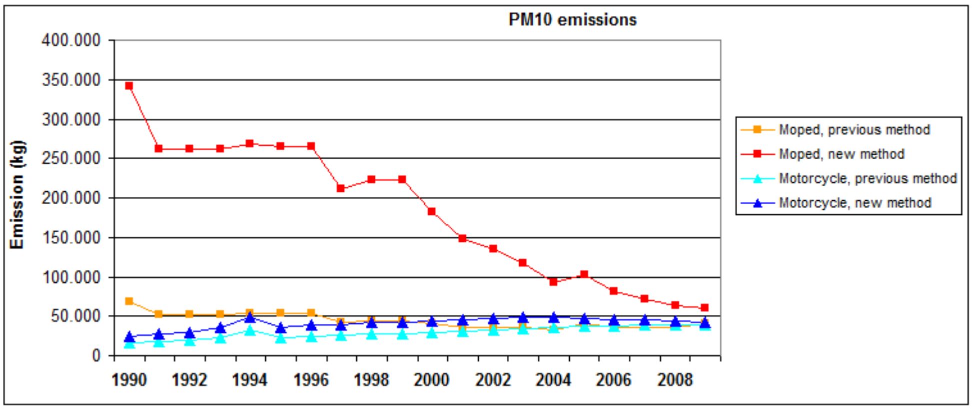

Figure 16: Emissions of PM10 according to the new and the previous methodology

Total CO emissions of all motorcycles decrease due to the new method, but especially new motorcycles seem to emit less CO than was assumed in the previous method (see Figure 16). For mopeds the trend is steeper with the new method, indicating that the previous emission factor was an average for all moped types.

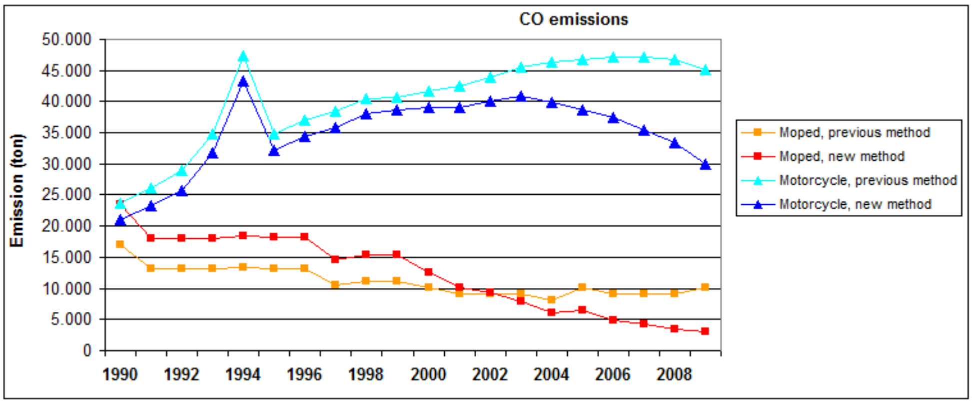

Figure 17: Emissions of carbon monoxide according to the new and the previous methodology

The total CO_2 emissions are calculated with preliminary CO_2 emission factors (see Figure 17). Overall motorcycle emissions are lower with the new method. Older mopeds seem to emit more CO_2 than was assumed with the previous method.

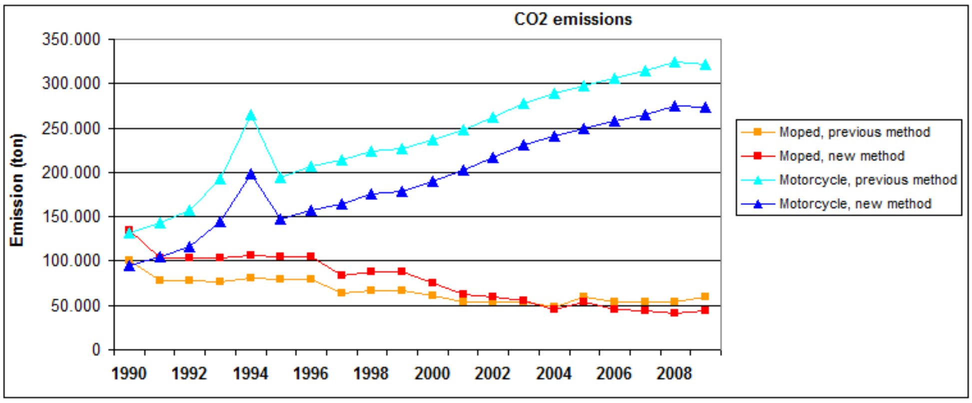

Figure 18: Emissions of carbon dioxide according to the new and the previous methodology

The new method calculated lower HC emissions for motorcycles (see Figure 19). For mopeds, the trend is similar to the CO trend: steeper with the new method, indicating that the previous emission factor was an average for all moped types.

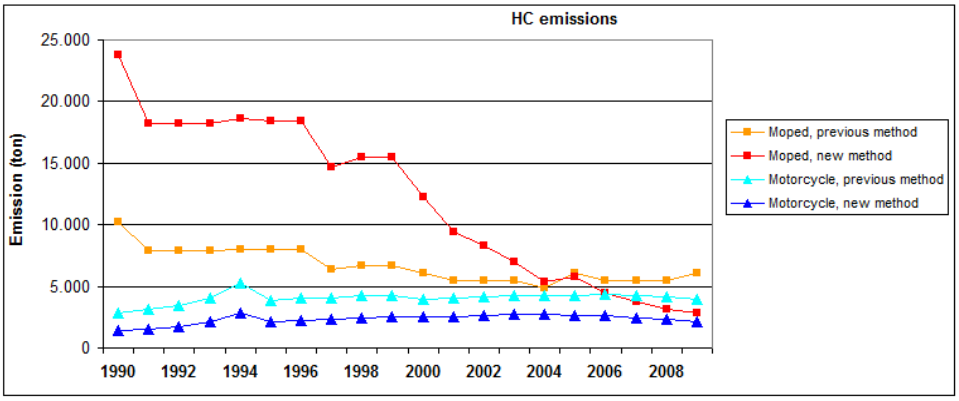

Figure 19: Emissions of hydrocarbon according to the new and the previous methodology

Since lead addition to fuel is prohibited, the emissions are virtual zero (see Figure 20). The differences between the old and the new method are caused by the new calculation of the vehicle kilometres driven and the preliminary fuel use factors, since the emission factor didn't change.

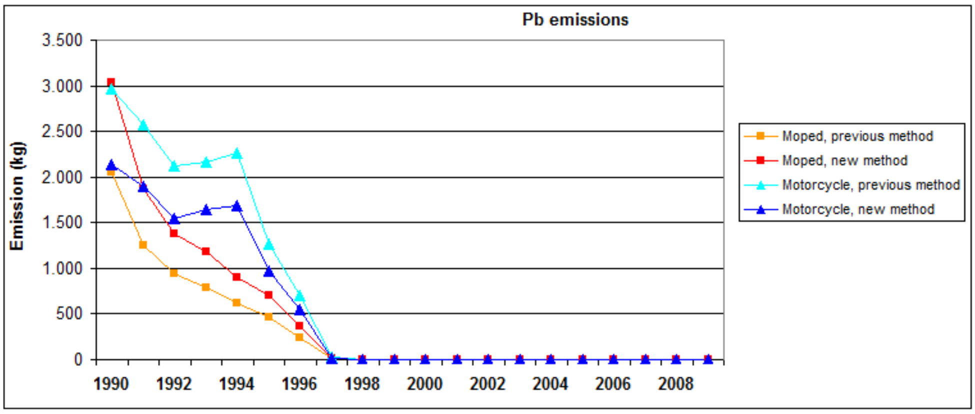

Figure 20: Emissions of lead according to the new and the previous methodology

The difference in emissions of metals (other than lead) between the previous and the new methodology is very small. The main part of the emissions (metal emissions from lubricants) is calculated based on vehicle performance. Since the emission factor has not changed, the emissions remained the same. A small part (metal emissions from gasoline) is calculated based on the fuel use. Since the preliminary fuel use factors have changed, the emissions also changed (see Figure 21).

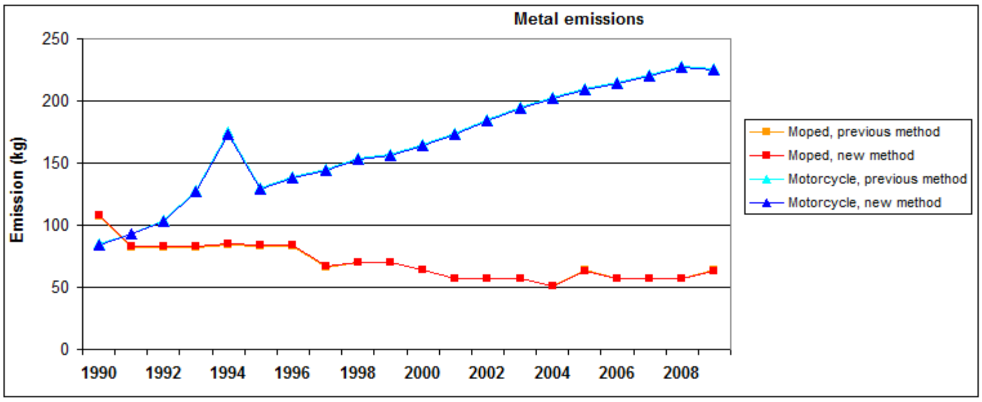

Figure 21: Emissions of metals (excluding lead) from both gasoline and lubricants according to the new and the previous methodology

5 VOC profiles and PAH emission factors

In this chapter, the derivation of volatile organic compounds (VOC) profiles and polycyclic aromatic hydrocarbons (PAH) emission factors from literature in mopeds and motorcycles exhaust gases is explained in detail.

5.1 Method of determination of profiles and emission factors

The definition of a profile used in this regard is the distribution of emissions of different types of VOC for which the summed fractions is equal to 1. As basis for the derivation of profiles a literature search was conducted. Searching was done especially for emission factors of VOC- and PAH-substances in the exhaust gases of mopeds and motorcycles. All emission factors that were found were collected in a database and subsequently used as foundation for the calculation of the profiles. It is important to notice that for the calculation of VOC emissions a *profile* is assembled, but that for PAH emissions *emission factors* are to be employed. This difference in calculation method is explained further in the results section of this chapter (paragraph 5.3). A more detailed method for calculating the profiles and emission factors is given in paragraph 5.2.

5.1.1 Literature selection

Each obtained literature reference was subjected to certain parameters, to determine affiliation with the project. Affiliation with the project is defined, here, as overall quality of the reference. The parameters to which the references were tested are shown in Table 17.

Only direct measurements with clearly mentioned driving cycles, done on vehicles sufficiently described (and manufactured after 1990) and with an extensive list of detected VOCs or PAHs are used in this research to calculate VOC and PAH profiles. References with testing conducted in the Netherlands were not available. In the references that were found though, all tested vehicles are or were available at the Dutch market.

Table 17: Parameters for determining the quality of obtained references

Parameter	Description
experimental setup	direct measurements of emissions on vehicles driven on dynamometers or on board when driven outside
engine type	vehicles have 2- or 4-stroke combustion engines.
emissions control	vehicles were equipped with catalyst or not and if yes, what kind
date of manufacture	vehicles manufactured in or after 1990[18]
number of measured VOCs[19]	available list of measured (analysed) and detected VOCs in exhaust gases as well as sum of VOC
driving cycles	vehicles tested on several driving cycles with result for each
other variables	mentioning of variables as weather or season, vehicle maintenance state, etc.

[18] It is not always mentioned when the vehicle was manufactured. In that case, an assumption was made on the basis of brand and model.
[19] Or measured number of PAHs.

5.1.2 Vehicle types

In this research, a distinction was made between two types of two-wheeled vehicles: motorcycles and mopeds. The emission calculating model which is explained in chapters 2 and 3 discerns between the following vehicle/engine type combinations: 2-stroke motorcycles, 4-stroke motorcycles and mopeds.

No distinction is made between 2-stroke and 4-stroke mopeds in the emission model. Since data was only found on 2-stroke mopeds, this means that the VOC and PAH profiles calculated here are directly based on these vehicles. The implication of this is that, indirectly, the same profile is used for both 2- and 4-stroke mopeds.

Only VOC emission factors for mopeds and 4-stroke motorcycles were found in literature, so a profile for 2-stroke motorcycles could not be compiled. PAH emission factors were found for mopeds as well as motorcycles, but no motorcycle PAH profile (neither 2-stroke nor 4-stroke) could be calculated because the collected data proved to be too few to support profiles. This point will be elaborated on later.

5.1.3 Emissions control

Two-wheeled vehicles can be - at least nowadays - equipped with catalysts as a means to control hazardous substances in exhaust gases. In this research, this is taken into account by allowing tested vehicles both with and without catalysts. The types of converters used in the quoted references are oxidation catalysts, two-way and three-way catalysts. The distribution of two-wheeled vehicles with catalysts in the Netherlands was not taken into account in this research.

5.1.4 Driving cycles

Daily traffic is not limited to a steady movement but, instead, is made up of a complex mixture of starting, acceleration, braking and moving at different speeds. As a consequence the amount of emissions and the VOCs and PAHs fractions in the emissions - and, as such, the profiles - can be quite different. In order to approach the reality of daily traffic as good as possible, vehicles are tested during standardized driving cycles. These driving cycles consist of fixed, documented routines such as acceleration, braking and driving at constant speed during a certain amount of time. All driving cycles that were used in the literature references are shown in the appendix B.

In the EMPA study, in which exclusively NMVOCs (Non-Methane Volatile Organic Compounds) were measured, the CADC and SC driving cycles were used. In the other references both PAHs and VOCs were measured. The driving cycles used were the ECE and WMTC.

5.1.5 Compounds

A limited amount of chemical compounds is presented in this study. As a basis, the list as in Veldt *et al.* (1993) was used. After reviewing the list, it was specified which compounds were measured and detected in the reference studies. It was found that there are many discrepancies between the number of measured and detected compounds per reference. Therefore it was decided to aggregate certain compounds into categories (for example ‘alkenes < C8 N.S’ - in which N.S. means not specified). The reason for this aggregation is that, for the aggregated compounds, no extensive health- and/or environmental problems are to be expected, the compounds are only found in one literature reference and because the list would become too comprehensive. Furthermore, an adequate balance is required between compounds with priority in environmental policy and the emission of these compounds. A complete list with all compounds encountered in literature reference can be found in Hulskotte *et al.* (2009).

Two-wheeled vehicle methane emission factors were not found in the literature. The presented profiles here thus actually contain NMVOCs (non methane volatile organic compounds). A value for methane was copied from Veldt *et al.* (1993), expressed as (weight-) percentage of the NMVOC profile. This will be explained in detail further on in this chapter.

The PAH compounds regarded in this research were the PAK10 (PAH10) as well as benzo(b)fluoranthene. The 'PAK10' is a collection of 10 PAHs that were of interest to the former Dutch ministry of Housing, Spatial planning and Environment (VROM - Volkshuisvesting, Ruimtelijke Ordening en Milieu) because of their toxic effects and the amount that was (and still is) emitted. Belonging to the PAK10 group are anthracene, phenanthrene, fluoranthene, naphthalene, benzo(a)anthracene, benzo(a)pyrene, benzo(ghi)perylene, benzo(k)fluoranthene, chrysene and indeno(123-cd)pyrene. A profile value for benzo(b)fluoranthene also was calculated, because of reporting obligations of benzo(b)fluoranthene to EMEP within the framework of heavy metals and POP (persistent organic pollutants) protocols.

5.2 Determination of profiles and emission factors

After preparing the basic data, VOC profiles were calculated for 4-stroke motorcycles and mopeds, compiled from 'fresh' data found in the literature study. The main strategy used was to calculate the profile per measurement, calculate the average accordingly and, as final step, combine all individual profiles into one profile. The formula shown hereafter explains the calculations steps in more detail.

$$NMVOC_{compound\_profile\_i} = \frac{EF_{NMVOC\_compound\_i}}{EF_{NMVOC\_total}} \qquad (9)$$

The abbreviation 'EF' means emission factor. In case the literature source did not report a value for total NMVOC, the sum of the individual NMVOCs was used instead.

It is inevitable that among the references not the same list of compounds was used in the measurements, since each author chooses a different set. As a result, the values, when averaged, were too high and did not add up to 100%. In an extra calculation step this was corrected for by dividing the fraction of each compound in the profile by the sum of the fractions:

$$NMVOC_{compound\_profile\_fitting} = \frac{NMVOC_{compound\_profile\_i}}{\sum_{n=1}^{i} NMVOC_{compound\_profile}} \qquad (10)$$

The result from this calculation step was a general profile based on all available data in the literature. It was assumed that the profile was valid for all emission limits

(Pre-Euro 1, 1, 2 and 3). To obtain a value for methane in the profile, the value in Veldt *et al.* (1993) was copied, which will be explained in the next section. PAH emission factors were calculated by averaging emission factors, per measurement, found in the literature.

5.3 VOC profiles and PAH emission factors

This section covers the profiles and emission factors that were calculated in this research. Before the tables with profiles are shown, a complete overview of the newly calculated profiles and the profiles which could not be calculated from new data (because of a lack of data) is displayed.

Table 18: Overview of profiles that were calculated and profiles for which data was lacking

Vehicle type	**Compound group**	**Profile/emission factors basis**	
Moped	(NM)VOC	Calculated from new data (profile, see paragraph 5.3.1)	
	PAH	Calculated from new data (emission factors per Euro class, see paragraph 5.3.2)	
		2-stroke engines	4-stroke engines
Motorcycle	(NM)VOC	*Not calculated due to lack of data (see paragraph 5.3.3)*	Calculated from new data (profile, see paragraph 5.3.1)
	PAH	*Not calculated due to lack of data (see paragraph 5.3.3)*	*Not calculated due to lack of data (see paragraph 5.3.3)*

As can be concluded from Table 18, for mopeds VOC profiles and PAH emission factors are calculated from (new) data found in literature whereas for 2-stroke motorcycles no data was found, nor for 4-stroke motorcycle PAH emission factors. In the following sections (paragraphs 5.3.1 and 5.3.2) the new VOC profiles and PAH emission factors are explained. In paragraph 5.3.3 suggestions are given for filling up the missing data.

5.3.1 VOC profiles

The calculated NMVOC profile valid for 4-stroke motorcycles is shown below.

Table 19: Motorcycle (4-stroke) VOC-profile

Compound	**Profile value**	**n**[20]	**SD**[21]	**Lower interval limit**[22]	**Upper interval limit**[23]
			Aldehydes		
Aceetaldehyde	0.24%	9	0.09%	0.18%	0.30%
Acrolein	0.11%	9	0.06%	0.07%	0.15%
Aldehydes C >4	0.35%	9	0.15%	0.25%	0.45%
Benzaldehyde	0.35%	9	0.17%	0.24%	0.46%
Crotonaldehyde	0.02%	9	0.03%	0.01%	0.04%
Formaldehyde	0.82%	9	0.66%	0.39%	1.25%
Methacrolein	0.05%	9	0.04%	0.02%	0.07%

[20] The total number of measurements that the profile value was made up of
[21] Standard deviation
[22] Lower limit of the 95%-reliability interval
[23] Upper limit of the 95%-reliability interval

Compound	**Profile value**	**n**	**SD**	**Lower interval limit**	**Upper interval limit**
Alkanes					
Alkanes C <10 N.S.	10.62%	13	5.88%	7.42%	13.81%
Alkanes C >10 N.S.	0.00%	9	0.00%	0.00%	0.00%
Ethane	1.44%	9	0.49%	1.12%	1.76%
Isobutane	0.57%	11	0.36%	0.36%	0.79%
Isopentane	11.15%	13	5.78%	8.01%	14.30%
n-Butane	1.57%	11	0.97%	1.00%	2.14%
n-Decane	0.00%	9	0.00%	0.00%	0.00%
n-Heptane	0.77%	11	0.46%	0.50%	1.04%
n-Hexane	4.41%	9	1.33%	3.54%	5.28%
n-Nonane	0.05%	11	0.04%	0.03%	0.08%
n-Octane	0.23%	11	0.09%	0.18%	0.29%
n-Pentane	3.64%	13	2.99%	2.01%	5.26%
Propane	0.16%	9	0.05%	0.13%	0.19%
Methane	5% of NMVOC				
Alkenes					
1,3-Butadiene	0.31%	9	0.17%	0.20%	0.42%
1-Butene	0.32%	11	0.13%	0.24%	0.39%
1-Heptene	0.00%	9	0.00%	0.00%	0.00%
1-Hexene	0.04%	9	0.03%	0.02%	0.06%
1-Nonene	0.00%	9	0.00%	0.00%	0.00%
1-Octene	0.00%	9	0.00%	0.00%	0.00%
1-Pentene	0.09%	11	0.06%	0.05%	0.12%
Alkenes C <8 N.S	2.60%	11	1.53%	1.70%	3.51%
Ethene	8.09%	9	3.53%	5.78%	10.40%
Propadiene	0.11%	9	0.13%	0.03%	0.19%
Propene	3.00%	13	1.72%	2.06%	3.93%
Alkynes					
Ethyne	5.01%	9	6.27%	0.91%	9.10%
Propyne	0.21%	9	0.22%	0.07%	0.36%
Aromatic compounds					
1,2,3-Trimethylbenzene	0.45%	9	0.15%	0.35%	0.55%
1,2,4-Trimethylbenzene	2.45%	12	1.39%	1.66%	3.24%
Arom. C >=8	4.89%	13	2.69%	3.43%	6.35%
Benzene	7.71%	13	4.90%	5.04%	10.37%
Ethylbenzene	2.12%	12	1.18%	1.45%	2.78%
M/P-Xylene	7.68%	13	4.15%	5.43%	9.93%
O-Xylene	3.02%	12	1.72%	2.05%	3.99%
Styrene	0.24%	11	0.14%	0.15%	0.32%
Toluene	14.94%	13	7.59%	10.81%	19.06%
Ketones					
Acetone	0.20%	9	0.15%	0.10%	0.29%
Ketones C <15	0.00%	9	0.00%	0.00%	0.00%

The profile shows many similarities with the 'old' profile of four-wheeled gasoline vehicles without catalyst in Veldt *et al.* (1993). For example, the values of several priority compounds (compounds with a prioritized status in the Dutch PRTR) are similar: acrolein is 0.2% (four-wheeled vehicle) vs. 0.06% (this study), benzene 4.5% vs. 7.7%, ethane 7.2% vs. 8.1% and formaldehyde 1.7% vs. 0.82%.

Furthermore, it is notable that the amount of alkanes, alkenes and aromatic compounds together take up more than 90% of the profile. Especially toluene and ethene are highly represented within these groups (15% respectively 8%). This can be explained by the fact that most two-wheeled vehicles are not equipped with catalysts or any other form of exhaust gas treatment, leaving the original fuel mix more or less in tact.

Since the NMVOC profile calculated in this research compares well to the four-wheeled vehicle profile of gasoline-powered vehicles without catalyst (Veldt *et al*, 1993), it was decided to obtain the methane profile value from that study. As the table shows, the value is 5% (in weight% with regard to NMVOC).

Table 20: Moped VOC-profile

Compound	**Profile value**	**n**[24]	**SD**[25]	**Lower interval limit**[26]	**Upper interval limit**[27]
			Aldehydes		
Aceetaldehyde	0.46%	17	0.54%	0.21%	0.72%
Acrolein	0.04%	17	0.05%	0.02%	0.07%
Aldehydes C >4	0.31%	17	0.24%	0.20%	0.42%
Benzaldehyde	0.13%	17	0.13%	0.07%	0.19%
Crotonaldehyde	0.07%	17	0.08%	0.03%	0.10%
Formaldehyde	1.33%	17	1.35%	0.69%	1.97%
Methacrolein	0.08%	17	0.09%	0.04%	0.13%
p-Tolualdehyde	0.08%	8	0.04%	0.05%	0.10%
			Alkanes		
Alkanes C <10 N.S	18.89%	21	9.40%	14.87%	22.91%
Alkanes C >10	0.04%	9	0.05%	0.00%	0.07%
Ethane	1.67%	17	1.39%	1.01%	2.32%
Isobutane	0.72%	19	0.34%	0.56%	0.87%
Isopentane	10.82%	13	4.19%	8.54%	13.10%
n-Butane	2.02%	19	0.79%	1.67%	2.37%
n-Decane	0.01%	9	0.02%	0.00%	0.02%
n-Heptane	1.05%	19	0.36%	0.89%	1.22%
n-Hexane	2.94%	17	1.61%	2.18%	3.71%
n-Nonane	0.07%	11	0.03%	0.05%	0.09%
n-Octane	0.27%	11	0.11%	0.20%	0.33%
n-Pentane	3.94%	21	2.04%	3.07%	4.81%
Propane	0.16%	17	0.07%	0.12%	0.19%
Methane	5% of NMVOC				

[24] The total number of measurements that the profile value was made up of

[25] Standard deviation

[26] Lower limit of the 95%-reliability interval

[27] Upper limit of the 95%-reliability interval

Compound	**Profile value**	**n**	**SD**	**Lower interval limit**	**Upper interval limit**
Alkenes					
1,3-Butadiene	0.85%	17	0.68%	0.53%	1.18%
1-Butene	0.79%	20	0.67%	0.49%	1.08%
1-Heptene	0.00%	9	0.00%	0.00%	0.00%
1-Hexene	0.06%	9	0.04%	0.03%	0.09%
1-Nonene	0.00%	9	0.00%	0.00%	0.00%
1-Octene	0.00%	9	0.00%	0.00%	0.00%
1-Pentene	0.12%	11	0.05%	0.09%	0.15%
Alkenes C <8 N.S	5.44%	19	3.86%	3.71%	7.18%
Ethene	6.11%	17	3.51%	4.44%	7.78%
Propadiene	0.04%	9	0.06%	0.00%	0.08%
Propene	3.55%	19	2.73%	2.32%	4.78%
Alkynes					
Ethyne	4.47%	17	2.78%	3.14%	5.79%
Propyne	0.28%	17	0.25%	0.16%	0.40%
Aromats					
1,2,3-Trimethylbenzene	0.55%	9	0.16%	0.45%	0.65%
1,2,4-Trimethylbenzene	1.67%	19	1.46%	1.01%	2.33%
Arom. C >=8	3.94%	19	3.82%	2.22%	5.66%
Benzene	3.05%	21	2.02%	2.19%	3.92%
Ethylbenzene	1.90%	19	0.78%	1.55%	2.25%
M/P-Xylene	6.53%	13	3.46%	4.65%	8.41%
M-Xylene	4.10%	8	0.69%	3.62%	4.58%
O-Xylene	2.37%	19	1.01%	1.91%	2.82%
Styrene	0.21%	11	0.18%	0.10%	0.31%
Toluene	8.71%	21	4.74%	6.68%	10.74%
Ketones					
Acetone	0.04%	17	0.04%	0.02%	0.05%
Ketones C <15	0.09%	17	0.12%	0.03%	0.15%

As with the 4-stroke motorcycle NMVOC profile, the moped NMVOC profile is remarkably similar to the Veldt *et al.* (1993) profile (gasoline-powered four-wheeled vehicles without catalyst). Another similarity is that the aggregated groups of alkanes, alkenes and aromatic hydrocarbons make up more than 90% of the profile. The difference with the motorcycle profile is the absence of peak values within the profile. Instead, there appears to be a more equal distribution of the values within the aggregated compound groups. Furthermore, the high values of the following compounds are notable: isopentane (11%), xylenes (13%), toluene (9%) and the aggregated compounds alkanes C<10 (19%).

This can be explained by the principle of how most conventional 2-stroke engines operate. Contrarily to 4-stroke engines, power is provided for during every down stroke of the piston. Thus, at the same engine speed (RPM), a 2-stroke engine delivers twice as much power strokes as a 4-stroke engine. The downside of this operation principle is that there is less time for mixing fuel and air and for the exchange of fresh air-/fuel mixture to and from the combustion chamber. This leads to a suboptimal combustion. Also, un- and partially burned hydrocarbons are expelled by ‘flush losses’ in the exhaust: a small part of the fresh air-fuel mixture is forced through the exhaust port before combustion even has occurred. Plus, in 2-stroke engines, lubrication oil must be added to the fuel in order to achieve lubrication. The partially burned fuel and oil lead to a high number of emitted NMVOCs (and, consequently, PAHs) and as such to high profile values (and different profiles).

Methane emission factors of mopeds (as well as motorcycles) were not found either. Though, as mentioned in the paragraph above, the moped NMVOC profile was similar to the Veldt *et al.* (1993) four-wheeled vehicle gasoline profile. It was therefore decided to, again, obtain the methane profile value from this reference and apply it to the moped NMVOC profile, as can be seen in the table.

5.3.2 PAH emission factors

Initially, profiles were calculated for mopeds and 4-stroke motorcycles using the same method as during the LDV/HDV research (Hulskotte *et al.*, 2009). The results showed unexpected differences in the outcome of the calculations, especially the ratio between mopeds/motorcycles profile values. It was then decided to use absolute emission factors instead of profile values. This was possible since, in the literature, emission factors were produced per emission limit (the Euro classes Pre-Euro 1, 1 and 2). The emission factors were calculated by averaging the emission factors per vehicle/engine type and per emission limit. The resulting (rounded) averaged emission factors are shown in the tables below.

Table 21: Average PAH emission factors (rounded, in μg/km) of mopeds

PAH-compound	**Emission factor per Euro class (μg/km)**		
	Pre-Euro 1	**Euro 1**	**Euro 2**
Anthracene	75	25	25
Fenanthrene	300	100	100
Fluoranthene	100	35	35
Naphtalene	8000	4000	3000
Benzo(a)anthracene	30	15	5
Benzo(a)pyrene	20	8	3
Benzo(b)fluoranthene	15	6	2
Benzo(ghi)perylene	45	15	3
Benzo(k)fluoranthene	15	6	2
Chrysene	25	10	3
Indeno(123-cd)pyrene	13	5	2

The calculated emission factors are deviating from emission factors presented in Veldt *et al.* (1993). Naphtalene is increased by a factor 8, while the other PAH compounds are decreased by a factor of around 2. While the naphthalene emission factor is high compared to the emission factor in Veldt *et al.* (1993), it shows a plausible decrease within the Euro classes without any discrepancies. The other PAH compounds also show an expected decrease by each following Euro class.

5.3.3 Suggestions for missing VOC profiles and PAH emission factors

In this section, an attempt is made to make estimations for the missing profiles and emission factors. The section is divided in VOC and PAH, respectively.

VOC profiles
A NMVOC profile based on recent literature data was calculated for mopeds and 4-stroke motorcycles. There was not enough data on 2-stroke motorcycles, so no profiles were calculated for these vehicles. Thus, within the motorcycle vehicle group, only a 4-stroke VOC profile could be calculated. For the missing 2-stroke profile, it is suggested to use the same profile as the moped NMVOC profile.

The advantage of using a profile to calculate emissions is that a profile is only dependent on the total emission of the aggregated compound group (e.g. VOC) it belongs to, instead of relying on emission factors of each individual compound. It provides information about the ratio of compounds within an emitted aggregated group rather than treating each compound individually.

Since a certain engine type operates according to the same combustion principle regardless (at least to some degree) if operated in mopeds or motorcycles, it is therefore reasonable to assume that the ratio of VOC compounds within a profile will not significantly change per engine type, although the *absolute* emission of VOCs is likely to be different. For this reason it is suggested to base the 2-stroke motorcycle VOC profile upon the VOC profile of 2-stroke mopeds.

PAH emission factors
No PAH emission factors nor profiles could be compiled for motorcycles (neither 2-, nor 4-stroke). In this section suggestions are given to fill up the missing motorcycle emission factor sets.

Unlike mopeds, there is no good indicator to base the actual PAH emissions of motorcycles upon. The best approximation for 2-stroke motorcycles is the set of 2-stroke moped PAH emission factors, since (as explained before) both vehicles are equipped with the same type of engine and emission profiles are expected to be similar. It is however likely that actual emission factors are different, since motorcycles typically have larger engines with higher cylinder volumes. Furthermore, motorcycles are built for higher speeds and loads. But since there is no research data to base the assumptions on, it is suggested here to apply the 2-stroke moped PAH emission factors directly to the 2-stroke motorcycle PAH emission factors.

A different approach was chosen for the 4-stroke motorcycles. Four-wheeled passenger cars were chosen to compare the 4-stroke motorcycles with, again because these vehicles share the same engine technology. Plus, it is shown that the two VOC profiles show a high similarity (see paragraph 5.3.1). Therefore it is reasonable to assume that PAH emission factors of both vehicles will be similar as well. Or, at least, more similar than any other two vehicles compared.

In the motorcycle emission model, distinction was made between several Euro emission limits. It was decided to use emission factors from Veldt *et al.* (1993) and apply them to different Euro standards:

- Pre-Euro 1: identical to four-wheeled gasoline passenger car (without catalyst) PAH profile as in Veldt et al. (1993).
- Euro 1: identical to Pre-Euro 1.
- Euro 2 and higher: identical to four-wheeled gasoline passenger car (with catalyst) PAH profile as in Veldt et al. (1993).

Table 22: Overview of origin of profiles and emission factors

Vehicle type	**Compound group**	**Profile/emission factors basis**	
Moped	(NM)VOC	Calculated from new data	
	PAH	Calculated from new data	
		2-stroke engines	4-stroke engines
Motorcycle	(NM)VOC	Identical to moped NMVOC profile	Calculated from new data
	PAH	Identical to moped PAH emission factors	Euro 0 and 1: identical to gasoline passenger car (without catalyst) Euro 2 and higher: identical to gasoline passenger car (with catalyst

6 Conclusions and discussion

6.1 Conclusions

In this research, the following goals were achieved:
- development of emission factors for major air pollutants from motorcycles and mopeds,
- development of a model to calculate the composition of the two-wheeled vehicle fleet in the Netherlands,
- calculation of total emissions, and
- development of VOC profiles and PAH emission factors.

Development of emission factors of motorcycles and mopeds
New emission factors of two-wheeled vehicles were developed in this research. The emission factors are valid for 2- and 4-stroke motorcycles, Euro classes up to 3, urban, rural and highway roads and all engine volumes. Emission factors were derived for the pollutants CO_2, HC, CO, NO_x and PM10 in g/km. Moped emission factors were developed for engine volumes less than 50 cc and Euro classes up to 2, but regardless of engine type (2- or 4-stroke) and road type because of lack of information.

Results show that for motorcycles and mopeds, all emissions decrease as new Euro stages are introduced, except for the component NO_x which increases. Apart from CO_2, CO emission factors are highest for motorcycles and HC emission factors are highest for mopeds. NO_x increases per Euro class, because of applied leaner combustion techniques to meet the Euro limits. The new emission factors represent the state of technology found in the two-wheeled vehicle fleet nowadays and as such are an improvement for the emission calculations.

Development of a model to calculate the composition of the two-wheeled vehicle fleet
The two-wheeled vehicle model that is developed is a major improvement in comparison to the old two-wheeled vehicle model, because the technological developments in the vehicle fleet have been modelled and based on administrative data as far as possible. This enables the usage of a set of more differentiated emission factors that represent the different technologies that emerge in practice.

Despite this improvement in the model, major uncertainties remain because of the uncertainties in total traffic volume of recent years, especially for mopeds. In addition, current emission factors of mopeds do not discriminate between 2-stroke and 4-stroke engines. The emission factors are a weighed value for both 2-stroke and 4-stroke mopeds. In the development of the vehicle fleet of mopeds recently a tendency towards more 4-stroke engines is observed, but this observation cannot yet be proofed by accurate statistics.

An increase of 4-stroke mopeds could lead to less emissions in practice. Possible consequences for practical emissions cannot be modelled however, since not enough results of emission measurements in real world situations are available and there are no statistics available to discriminate between the 2-stroke and the 4-stroke mopeds in the fleet. It is recommended to improve the model and the emission factors for discriminating between the 2-stroke and the 4 stroke mopeds as soon as relevant data become available.

Total emissions
Total National emissions were calculated for the regulated pollutants and the pollutants depending on fuel consumption and compared to total emissions using the old emission factors and fleet model. For the regulated pollutants the following trend were observed.

HC emissions, for 90% produced by mopeds, decrease from 25 kiloton to around 5 kiloton from 1990 to 2009. Stricter emission regulations resulting in improved technology cause the HC emissions to decrease. The new method calculated lower HC emissions for motorcycles. The new and old method calculated similar emissions for mopeds, only the distribution over the years was different in the new method, indicating that the previous emission factor was an average for all moped types.

The total CO emissions remain relatively constant from 1990 to 2005, even though emission factors have decreased over time. New motorcycles seem to emit less CO than was assumed with the previous method. For mopeds the same trend as for HC is found.

PM10 emissions, for 90% produced by mopeds, decrease for mopeds over time, for motorcycles they remain constant. PM10 emissions for mopeds are much higher with the new calculation method. Especially older vehicles seem to emit more PM10 than was assumed with the previous method.

The increase in NO_x emissions, caused by both vehicle types, is due to the technological adjustments to improve HC and CO emissions. The NO_x emissions have increased (250 ton in 1990 to >1000 ton in 2009). For motorcycles the NO_x emissions are higher with the new method. For mopeds in the older years the emissions decrease, while for more recent years the emissions increase.

Based on preliminary CO_2 emission factors, emissions of CO_2 continue to rise, from 100 kiloton in 1990 to more than 250 kiloton in 2009, mainly caused by the expansion of the motorcycle vehicle fleet and increased travelled kilometres by the motorcycles. Overall motorcycle CO_2 emissions are lower with the new method. Older mopeds seem to emit more CO_2 than was assumed with the previous method.

For SO_2, Pb and metals, the differences between the old and the new method are caused by the calculation of the new vehicle kilometres driven and the preliminary fuel use factors, since the emission factor didn't change. SO_2 emissions were and are low, which is caused by a lowering in sulphur content of fuels on the market. Since Pb is abolished from fuel, the emissions are zero. No comparison between the old and the new method can be made for metals, since with the previous method these emissions were not calculated.

Development of VOC profiles and PAH emission factors
New VOC profiles and PAH emission factors of two-wheeled vehicles were presented. New VOC profiles were calculated for mopeds and 4-stroke

motorcycles. These new profiles show high similarity with the passenger car - without catalyst - VOC profile. Not enough data was found to calculate a profile for 2-stroke motorcycles. To calculate emissions of VOC however, it is suggested to use the moped VOC profile.

PAH emission factors, separated per Euro class, were updated for mopeds, but no data on motorcycles was found. Therefore, emission factors for all motorcycles had to be linked to other sources, like gasoline passenger cars.

6.2 Recommendations

Until this day, there has been no usage of recent investigations in order to calculate specific two-wheeled vehicle emissions. The model, emission factors and profiles presented here are an improvement in the accuracy of two-wheeled vehicle emission calculations. Therefore it is recommended to incorporate the results of this method into the Dutch PRTR.

6.3 Reliability

To indicate the reliability of the new emission factors and the results of the vehicle fleet model, the method used in Emission Inventory publications has been followed as far as possible in classifying the quality of information (Van der Most *et al.*, 1998). It is based on the CORINAIR (CORe emission INventories AIR) methodology, which is also used within the EMEP/EEA Guidebook (2009). It applies the following quality classifications:

Table 23: Quality classifications used by CORINAIR

classification	a value based on a
A	large number of measurements from representative sources
B	number of measurements from some of the sources that are representative of the sector
C	limited number of measurements, together with estimates based on technical knowledge of the process
D	small number of measurements, together with estimates based on assumptions
E	technical calculation on the basis of a number of assumptions

1. *Reliability of emission factors of motorcycles and mopeds*

A number of relevant studies were used to develop the new emission factors. Almost all of these studies described several measurements performed on powered two-wheeled vehicles. Although moped emission factors couldn't be established as detailed as preferred, the number of underlying studies per emission factor remains relatively high. Because of this the emission factors can be qualified with a reliability of level B.

2. *Reliability of the vehicle fleet model*

The composition of the vehicle fleet is based upon sales, combined with assumptions. These assumptions are made regarding to the road type that the vehicles travelled on and the average age of the fleet. Furthermore, calibrations are made using official statistics. Therefore, classification B is appropriate. This classification is valid for both mopeds and motorcycles.

3. *Reliability of the travelled distance*

For the compilation of travelled distances official statistics from Statistics Netherlands are used, which, in turn, are based upon actual kilometres travelled as observed in the vehicle fleet. For motorcycles a classification B is applied, while for mopeds a classification E is applied.

4. *Reliability of the emissions*

The emissions are calculated from the numbers in the vehicle fleet, multiplied by the emission factors and travelled distances. The uncertainty in emissions is mainly caused by the uncertainty in estimation of vehicle kilometres. For motorcycles a classification B is applied, while for mopeds a classification E is applied.

5. *Reliability of VOC profiles*

For the calculation of moped and motorcycles VOC profiles, several studies were used. Although limited in number, the researches were representative and the results show consistency. Therefore classification B is applied. No data was found on 2-stroke motorcycles, so an assumption had to be made. It was assumed that the 2-stroke moped VOC profile would fit best for 2-stroke motorcycles. Since for both two-wheeled vehicles a 2-stroke engine is used, it is expected that the reliability of the VOC profile is good. A classification C is applied.

6. *Reliability of PAH emission factors*

Moped PAH emission factors were derived from several representative studies, so classification B is applied. No motorcycle PAH profile, nor PAH emission factors could be calculated due to insufficient data. Therefore assumptions were made to be able to use emission factors and so classification E is applied.

Table 24: Reliability index of methods used in this research

	Element of emission calculation	**classification**
1	Moped emission factors	B
	Motorcycle emission factors	B
2	Moped vehicle fleet	B
	Motorcycle vehicle fleet	B
3	Travelled distance, mopeds	E
	Travelled distance, motorcycles	B
4	Emissions, mopeds	E
	Emissions, motorcycles	B
5	VOC profiles, mopeds and 4-stroke motorcycles	B
	VOC profiles, 2-stroke motorcycles	C
6	PAH emission factors, mopeds	B
	PAH emission factors, motorcycles	E

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A Total emissions in kilograms per road type, pollutant and year

Table A.1 Total emissions from motorcycles in kilograms per road type, pollutant and year, given for the new and the previous method

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**	**New method**	**Previous method**
PM10	1990	4 225	9 681	11 557	3 965	9 342	2 260
	1991	4 591	10 744	12 575	3 921	10 201	2 648
	1992	5 012	11 802	13 751	4 307	11 212	2 909
	1993	6 083	12 910	16 714	6 627	13 709	3 765
	1994	8 180	16 200	22 513	9 072	18 583	6 509
	1995	5 985	11 418	16 489	7 033	13 679	5 047
	1996	6 337	11 556	17 482	7 910	14 574	5 675
	1997	6 530	11 340	18 035	8 732	15 123	6 266
	1998	6 841	11 539	18 904	9 477	15 935	6 800
	1999	6 916	11 285	19 118	9 931	16 191	7 126
	2000	7 117	9 832	19 703	9 832	16 836	9 832
	2001	7 311	10 297	20 278	10 297	17 484	10 297
	2002	7 601	10 874	21 113	10 874	18 350	10 874
	2003	7 896	11 465	21 962	11 465	19 239	11 465
	2004	7 749	11 875	21 566	11 875	18 959	11 875
	2005	7 520	12 221	20 944	12 221	18 469	12 221
	2006	7 349	12 524	20 485	12 524	18 123	12 524
	2007	7 186	12 821	20 051	12 821	17 805	12 821
	2008	7 065	13 141	19 732	13 141	17 598	13 141
	2009	6 633	13 250	18 550	13 250	16 610	13 250
PM2,5	1990	4 225	9 681	11 557	3 965	9 342	2 260
	1991	4 591	10 744	12 575	3 921	10 201	2 648
	1992	5 012	11 802	13 751	4 307	11 212	2 909
	1993	6 083	12 910	16 714	6 627	13 709	3 765
	1994	8 180	16 200	22 513	9 072	18 583	6 509
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	1996	6 337	11 556	17 482	7 910	14 574	5 675
	1997	6 530	11 340	18 035	8 732	15 123	6 266
	1998	6 841	11 539	18 904	9 477	15 935	6 800
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	2001	7 311	10 297	20 278	10 297	17 484	10 297
	2002	7 601	10 874	21 113	10 874	18 350	10 874
	2003	7 896	11 465	21 962	11 465	19 239	11 465
	2004	7 749	11 875	21 566	11 875	18 959	11 875
	2005	7 520	12 221	20 944	12 221	18 469	12 221
	2006	7 349	12 524	20 485	12 524	18 123	12 524
	2007	7 186	12 821	20 051	12 821	17 805	12 821
	2008	7 065	13 141	19 732	13 141	17 598	13 141
	2009	6 633	13 250	18 550	13 250	16 610	13 250

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	Year	New method	Previous method	New method	Previous method	New method	Previous method
NO_x	1990	14 792	50 102	96 159	35 251	140 933	51 575
	1991	16 285	56 433	105 907	35 517	155 296	61 312
	1992	18 084	62 845	117 649	39 698	172 716	68 253
	1993	22 348	69 434	145 377	61 860	213 845	89 223
	1994	30 616	87 531	199 156	85 175	293 608	154 936
	1995	22 714	61 893	147 704	66 306	218 188	120 500
	1996	24 390	62 883	158 603	74 926	234 673	136 018
	1997	25 521	61 527	165 908	82 410	246 084	149 731
	1998	27 073	62 982	175 833	90 020	261 475	163 267
	1999	27 675	62 263	179 562	95 136	267 649	171 971
	2000	32 072	56 796	206 800	98 005	324 649	243 496
	2001	36 900	61 367	236 629	105 165	387 322	258 810
	2002	41 496	66 448	265 599	113 259	447 160	276 626
	2003	46 221	71 612	295 751	121 502	510 614	294 819
	2004	49 225	75 791	301 451	128 089	524 654	308 817
	2005	51 889	79 277	304 136	133 437	533 087	320 141
	2006	54 434	82 535	308 442	138 455	543 596	330 626
	2007	54 923	86 396	298 951	144 286	533 260	342 298
	2008	55 508	91 650	290 535	152 049	525 898	357 121
	2009	54 234	96 109	271 623	158 477	498 483	368 110
SO_2	1990	2 486	11 533	5 645	4 724	6 355	2 692
	1991	2 427	11 331	5 510	4 135	6 210	2 792
	1992	2 339	10 839	5 308	3 956	5 992	2 671
	1993	2 461	10 039	5 577	5 153	6 310	2 928
	1994	2 772	10 478	6 274	5 867	7 117	4 210
	1995	1 620	5 767	3 663	3 552	4 164	2 549
	1996	1 262	4 218	2 851	2 887	3 247	2 072
	1997	1 322	4 078	2 980	3 140	3 402	2 253
	1998	1 404	4 122	3 158	3 386	3 614	2 429
	1999	1 436	4 005	3 225	3 524	3 699	2 529
	2000	1 509	3 500	3 412	3 500	3 973	3 500
	2001	1 091	2 533	2 485	2 533	2 937	2 533
	2002	1 359	3 141	3 110	3 141	3 717	3 141
	2003	623	1 445	1 431	1 445	1 728	1 445
	2004	722	1 677	1 664	1 677	2 026	1 677
	2005	486	1 133	1 127	1 133	1 382	1 133
	2006	577	1 348	1 343	1 348	1 658	1 348
	2007	592	1 385	1 382	1 385	1 716	1 385
	2008	610	1 429	1 427	1 429	1 782	1 429
	2009	602	1 417	1 417	1 417	1 779	1 417

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	Year	New method	Previous method	New method	Previous method	New method	Previous method
CO	1990	3 118 675	16 015 708	8 373 637	3 972 049	9 630 549	3 641 262
	1991	3 427 940	17 921 955	9 204 520	3 951 593	10 598 350	4 294 013
	1992	3 796 027	19 838 834	10 194 533	4 365 686	11 763 384	4 744 884
	1993	4 671 554	21 824 045	12 548 768	6 745 973	14 528 727	6 169 532
	1994	6 371 291	27 456 664	17 119 829	9 252 467	19 893 912	10 686 789
	1995	4 708 218	19 387 258	12 653 953	7 183 188	14 752 972	8 297 102
	1996	5 039 028	19 665 080	13 546 264	8 091 278	15 835 907	9 346 506
	1997	5 248 496	19 265 403	14 114 131	8 921 449	16 563 934	10 305 042
	1998	5 540 000	19 604 625	14 901 620	9 676 486	17 562 840	11 191 569
	1999	5 636 897	19 010 422	15 165 157	10 042 508	17 944 810	11 678 893
	2000	5 579 126	16 098 140	15 195 357	9 612 954	18 239 730	15 915 441
	2001	5 487 830	16 361 985	15 162 045	9 734 201	18 485 851	16 430 108
	2002	5 521 910	16 845 727	15 420 158	9 989 448	19 048 032	17 143 884
	2003	5 549 707	17 357 846	15 654 854	10 261 644	19 591 446	17 883 912
	2004	5 429 218	17 588 309	15 261 802	10 363 797	19 218 575	18 340 819
	2005	5 249 237	17 716 152	14 698 415	10 412 397	18 623 722	18 686 588
	2006	5 097 115	17 802 846	14 253 637	10 435 331	18 184 103	18 980 075
	2007	4 874 500	17 721 216	13 455 459	10 345 361	17 151 823	19 189 297
	2008	4 660 216	17 353 506	12 673 408	10 060 281	16 134 441	19 282 185
	2009	4 245 131	16 631 953	11 353 450	9 554 115	14 447 212	19 040 878
NH_3	1990	275	1 081	787	443	713	252
	1991	303	1 213	866	443	785	299
	1992	335	1 345	960	491	872	332
	1993	413	1 483	1 184	761	1 079	432
	1994	565	1 867	1 619	1 045	1 479	750
	1995	418	1 319	1 198	812	1 098	583
	1996	448	1 339	1 285	916	1 179	657
	1997	468	1 311	1 341	1 009	1 235	724
	1998	495	1 338	1 419	1 099	1 311	788
	1999	506	1 311	1 447	1 154	1 340	828
	2000	532	1 156	1 522	1 156	1 415	1 156
	2001	560	1 217	1 600	1 217	1 492	1 217
	2002	593	1 291	1 694	1 291	1 585	1 291
	2003	627	1 366	1 790	1 366	1 680	1 366
	2004	652	1 421	1 861	1 421	1 750	1 421
	2005	673	1 465	1 918	1 465	1 806	1 465
	2006	691	1 506	1 970	1 506	1 856	1 506
	2007	710	1 548	2 024	1 548	1 909	1 548
	2008	733	1 597	2 087	1 597	1 970	1 597
	2009	727	1 583	2 069	1 583	1 953	1 583

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	Year	New method	Previous method	New method	Previous method	New method	Previous method
N_2O	1990	275	1 081	787	443	713	252
	1991	303	1 213	866	443	785	299
	1992	335	1 345	960	491	872	332
	1993	413	1 483	1 184	761	1 079	432
	1994	565	1 867	1 619	1 045	1 479	750
	1995	418	1 319	1 198	812	1 098	583
	1996	448	1 339	1 285	916	1 179	657
	1997	468	1 311	1 341	1 009	1 235	724
	1998	495	1 338	1 419	1 099	1 311	788
	1999	506	1 311	1 447	1 154	1 340	828
	2000	532	1 156	1 522	1 156	1 415	1 156
	2001	560	1 217	1 600	1 217	1 492	1 217
	2002	593	1 291	1 694	1 291	1 585	1 291
	2003	627	1 366	1 790	1 366	1 680	1 366
	2004	652	1 421	1 861	1 421	1 750	1 421
	2005	673	1 465	1 918	1 465	1 806	1 465
	2006	691	1 506	1 970	1 506	1 856	1 506
	2007	710	1 548	2 024	1 548	1 909	1 548
	2008	733	1 597	2 087	1 597	1 970	1 597
	2009	727	1 583	2 069	1 583	1 953	1 583
CO_2	1990	16 407 386	79 909 944	37 253 804	32 731 991	41 943 031	18 651 749
	1991	18 047 764	88 754 046	40 973 253	32 388 917	46 177 893	21 873 035
	1992	20 027 387	97 642 832	45 444 531	35 632 692	51 304 104	24 063 636
	1993	24 746 530	106 399 722	56 085 056	54 618 524	63 463 344	31 033 252
	1994	33 905 455	134 854 536	76 740 601	75 518 540	87 055 495	54 187 005
	1995	25 163 626	94 481 854	56 877 192	58 200 822	64 657 409	41 760 980
	1996	27 022 591	95 048 864	61 020 558	65 055 667	69 496 033	46 679 553
	1997	28 294 003	91 889 183	63 790 755	70 754 671	72 831 535	50 768 774
	1998	30 044 934	92 884 619	67 601 462	76 289 234	77 368 549	54 740 002
	1999	30 742 483	90 235 532	69 037 025	79 407 268	79 183 834	56 977 293
	2000	32 297 937	78 869 158	73 037 171	78 869 158	85 044 546	78 869 158
	2001	33 878 886	82 817 187	77 187 758	82 817 187	91 233 839	82 817 187
	2002	35 878 598	87 295 474	82 103 234	87 295 474	98 132 761	87 295 474
	2003	37 956 106	92 672 873	87 161 463	92 672 873	105 245 622	92 672 873
	2004	39 425 697	96 431 515	90 894 852	96 431 515	110 662 545	96 431 515
	2005	40 540 342	99 399 561	93 918 511	99 399 561	115 226 383	99 399 561
	2006	41 549 261	102 173 522	96 661 138	102 173 522	119 375 415	102 173 522
	2007	42 619 317	104 998 212	99 480 934	104 998 212	123 562 398	104 998 212
	2008	43 895 100	108 174 244	102 779 032	108 174 244	128 315 893	108 174 244
	2009	43 357 089	107 147 675	102 035 364	107 147 675	128 064 318	107 147 675

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**	**New method**	**Previous method**
HC	1990	377 822	2 266 145	579 956	396 323	470 986	202 493
	1991	412 621	2 525 376	632 249	390 952	514 974	234 374
	1992	453 805	2 784 746	693 596	428 507	566 968	254 454
	1993	556 124	3 054 837	847 145	658 300	694 705	326 568
	1994	755 569	3 838 246	1 147 032	900 437	943 652	562 212
	1995	557 723	2 707 722	844 142	697 722	695 887	434 613
	1996	595 178	2 743 570	898 552	784 158	742 542	487 089
	1997	619 466	2 690 048	932 184	866 123	772 012	539 170
	1998	655 751	2 734 072	983 240	937 591	815 143	581 868
	1999	669 424	2 648 623	1 000 317	973 701	829 928	603 034
	2000	669 773	2 229 827	1 012 889	930 472	856 316	792 324
	2001	666 434	2 259 314	1 021 654	945 254	881 648	799 684
	2002	676 330	2 319 799	1 046 805	972 810	919 420	818 326
	2003	685 309	2 384 160	1 070 849	1 001 905	958 090	838 216
	2004	677 794	2 408 598	1 058 061	1 013 684	953 766	842 479
	2005	663 240	2 421 706	1 034 720	1 022 177	939 445	846 606
	2006	651 942	2 428 301	1 017 560	1 027 172	929 729	846 925
	2007	623 170	2 409 033	965 997	1 022 022	884 209	836 664
	2008	594 241	2 345 317	913 988	999 838	838 931	808 289
	2009	541 146	2 229 038	825 567	954 044	760 661	756 554
Pb	1990	367.72	1 806.35	834.92	739.90	940.01	421.62
	1991	324.72	1 599.32	737.21	583.64	830.85	394.15
	1992	265.51	1 313.66	602.48	479.39	680.17	323.74
	1993	281.21	1 199.78	637.33	615.89	721.17	349.94
	1994	288.97	1 155.82	654.04	647.26	741.95	464.43
	1995	166.80	616.59	377.03	379.82	428.60	272.53
	1996	93.83	321.03	211.88	219.73	241.31	157.66
	1997	3.57	12.70	8.05	9.78	9.20	7.02
	1998	0.09	0.29	0.21	0.24	0.24	0.17
	1999	0.10	0.28	0.22	0.25	0.25	0.18
	2000	0.10	0.25	0.23	0.25	0.27	0.25
	2001	0.11	0.26	0.24	0.26	0.29	0.26
	2002	0.11	0.28	0.26	0.28	0.31	0.28
	2003	0.12	0.29	0.28	0.29	0.33	0.29
	2004	0.12	0.30	0.29	0.30	0.35	0.30
	2005	0.13	0.31	0.30	0.31	0.36	0.31
	2006	0.13	0.32	0.31	0.32	0.38	0.32
	2007	0.13	0.33	0.31	0.33	0.39	0.33
	2008	0.14	0.34	0.32	0.34	0.41	0.34
	2009	0.14	0.34	0.32	0.34	0.40	0.34

		Motorcycles, urban		Motorcycles, rural		Motorcycles, highway	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**	**New method**	**Previous method**
Metals (lubricants)	1990	12.72	49.96	36.40	20.46	32.97	11.66
	1991	13.99	56.05	40.03	20.45	36.30	13.81
	1992	15.50	62.19	44.39	22.69	40.32	15.33
	1993	19.11	68.52	54.73	35.18	49.85	19.99
	1994	26.11	86.28	74.81	48.32	68.34	34.67
	1995	19.33	60.95	55.38	37.55	50.73	26.94
	1996	20.72	61.87	59.37	42.34	54.50	30.38
	1997	21.63	60.58	61.99	46.65	57.08	33.47
	1998	22.90	61.83	65.58	50.78	60.57	36.44
	1999	23.37	60.59	66.86	53.32	61.93	38.26
	2000	24.60	53.44	70.34	53.44	65.38	53.44
	2001	25.88	56.25	73.94	56.25	68.94	56.25
	2002	27.42	59.65	78.30	59.65	73.24	59.65
	2003	28.99	63.14	82.75	63.14	77.67	63.14
	2004	30.15	65.69	86.02	65.69	80.89	65.69
	2005	31.09	67.73	88.65	67.73	83.46	67.73
	2006	31.93	69.59	91.04	69.59	85.80	69.59
	2007	32.82	71.53	93.53	71.53	88.24	71.53
	2008	33.87	73.79	96.45	73.79	91.06	73.79
	2009	33.59	73.15	95.62	73.15	90.25	73.15
Metals (gasoline)	1990	0.35	1.71	0.80	0.70	0.90	0.40
	1991	0.39	1.90	0.88	0.69	0.99	0.47
	1992	0.43	2.09	0.97	0.76	1.10	0.52
	1993	0.53	2.28	1.20	1.17	1.36	0.67
	1994	0.73	2.89	1.64	1.62	1.87	1.16
	1995	0.54	2.03	1.22	1.25	1.39	0.90
	1996	0.58	2.04	1.31	1.39	1.49	1.00
	1997	0.61	1.97	1.37	1.52	1.56	1.09
	1998	0.64	1.99	1.45	1.64	1.66	1.17
	1999	0.66	1.93	1.48	1.70	1.70	1.22
	2000	0.69	1.69	1.57	1.69	1.82	1.69
	2001	0.73	1.78	1.65	1.78	1.96	1.78
	2002	0.77	1.87	1.76	1.87	2.10	1.87
	2003	0.81	1.99	1.87	1.99	2.26	1.99
	2004	0.85	2.07	1.95	2.07	2.37	2.07
	2005	0.87	2.13	2.01	2.13	2.47	2.13
	2006	0.89	2.19	2.07	2.19	2.56	2.19
	2007	0.91	2.25	2.13	2.25	2.65	2.25
	2008	0.94	2.32	2.20	2.32	2.75	2.32
	2009	0.93	2.30	2.19	2.30	2.74	2.30

Table A.2 Total emissions from mopeds in kilograms per road type, pollutant and year, given for the new and the previous method

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
PM10	1990	249 071	61 497	92 577	6 833
	1991	191 119	47 186	71 026	5 243
	1992	190 729	47 088	70 871	5 232
	1993	190 736	47 088	70 864	5 232
	1994	195 520	48 268	72 633	5 363
	1995	193 308	47 720	71 803	5 302
	1996	193 314	47 720	71 797	5 302
	1997	154 117	38 043	57 233	4 227
	1998	161 934	39 972	60 130	4 441
	1999	162 183	40 032	60 217	4 448
	2000	133 186	36 360	49 448	4 040
	2001	107 664	32 760	39 970	3 640
	2002	98 484	32 760	36 560	3 640
	2003	85 508	32 760	31 742	3 640
	2004	67 027	29 160	24 913	3 240
	2005	74 198	36 360	27 663	4 040
	2006	58 841	32 760	22 028	3 640
	2007	52 368	32 760	19 771	3 640
	2008	45 486	32 760	17 399	3 640
	2009	43 300	36 518	16 891	4 058
PM2,5	1990	249 071	61 497	92 577	6 833
	1991	191 119	47 186	71 026	5 243
	1992	190 729	47 088	70 871	5 232
	1993	190 736	47 088	70 864	5 232
	1994	195 520	48 268	72 633	5 363
	1995	193 308	47 720	71 803	5 302
	1996	193 314	47 720	71 797	5 302
	1997	154 117	38 043	57 233	4 227
	1998	161 934	39 972	60 130	4 441
	1999	162 183	40 032	60 217	4 448
	2000	133 186	36 360	49 448	4 040
	2001	107 664	32 760	39 970	3 640
	2002	98 484	32 760	36 560	3 640
	2003	85 508	32 760	31 742	3 640
	2004	67 027	29 160	24 913	3 240
	2005	74 198	36 360	27 663	4 040
	2006	58 841	32 760	22 028	3 640
	2007	52 368	32 760	19 771	3 640
	2008	45 486	32 760	17 399	3 640
	2009	43 300	36 518	16 891	4 058

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
NO_x	1990	24 907	76 871	9 258	8 541
	1991	19 112	58 983	7 103	6 554
	1992	19 073	58 860	7 087	6 540
	1993	19 074	58 860	7 086	6 540
	1994	19 552	60 335	7 263	6 704
	1995	19 331	59 650	7 180	6 628
	1996	19 331	59 650	7 180	6 628
	1997	15 412	47 554	5 723	5 284
	1998	16 193	49 964	6 013	5 552
	1999	16 218	50 040	6 022	5 560
	2000	14 731	45 450	5 469	5 050
	2001	13 273	40 950	4 927	4 550
	2002	13 273	40 950	4 927	4 550
	2003	38 547	40 950	14 304	4 550
	2004	54 333	36 450	20 379	4 050
	2005	84 813	45 450	32 267	5 050
	2006	92 796	40 950	35 656	4 550
	2007	103 981	40 950	40 756	4 550
	2008	117 866	40 950	47 102	4 550
	2009	145 472	45 647	59 319	5 072
SO_2	1990	14 944	13 123	5 555	1 458
	1991	10 177	8 901	3 782	989
	1992	8 821	7 729	3 278	859
	1993	7 510	6 557	2 790	729
	1994	6 330	5 622	2 351	625
	1995	4 929	4 369	1 831	485
	1996	3 576	3 177	1 328	353
	1997	2 851	2 523	1 059	280
	1998	2 996	2 648	1 112	294
	1999	3 000	2 653	1 114	295
	2000	2 551	2 408	947	268
	2001	1 479	1 492	549	166
	2002	1 648	1 744	612	194
	2003	660	758	245	84
	2004	613	753	228	84
	2005	472	615	177	68
	2006	464	642	175	71
	2007	440	642	168	71
	2008	415	642	161	71
	2009	433	712	172	79

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
CO	1990	17 185 920	15 374 160	6 387 792	1 708 240
	1991	13 187 210	11 796 506	4 900 765	1 310 723
	1992	13 160 299	11 772 000	4 890 101	1 308 000
	1993	13 160 750	11 772 000	4 889 650	1 308 000
	1994	13 490 897	12 066 900	5 011 683	1 340 767
	1995	13 338 262	11 930 000	4 954 404	1 325 556
	1996	13 338 661	11 930 000	4 954 006	1 325 556
	1997	10 634 053	9 510 750	3 949 097	1 056 750
	1998	11 173 422	9 992 880	4 148 994	1 110 320
	1999	11 190 607	10 008 000	4 154 993	1 112 000
	2000	9 199 248	9 090 000	3 415 425	1 010 000
	2001	7 445 504	8 190 000	2 764 160	910 000
	2002	6 818 208	8 190 000	2 531 124	910 000
	2003	5 766 529	8 190 000	2 140 635	910 000
	2004	4 381 231	7 290 000	1 627 413	810 000
	2005	4 710 340	9 090 000	1 752 422	1 010 000
	2006	3 589 277	8 190 000	1 338 382	910 000
	2007	3 073 245	8 190 000	1 151 553	910 000
	2008	2 511 447	8 190 000	948 958	910 000
	2009	2 199 676	9 129 397	843 076	1 014 377
NH_3	1990	1 245	1 537	463	171
	1991	956	1 180	355	131
	1992	954	1 177	354	131
	1993	954	1 177	354	131
	1994	978	1 207	363	134
	1995	967	1 193	359	133
	1996	967	1 193	359	133
	1997	771	951	286	106
	1998	810	999	301	111
	1999	811	1 001	301	111
	2000	737	909	273	101
	2001	664	819	246	91
	2002	664	819	246	91
	2003	664	819	246	91
	2004	590	729	220	81
	2005	734	909	276	101
	2006	660	819	250	91
	2007	658	819	252	91
	2008	654	819	256	91
	2009	722	909	288	101

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
N_2O	1990	1 245	1 537	463	171
	1991	956	1 180	355	131
	1992	954	1 177	354	131
	1993	954	1 177	354	131
	1994	978	1 207	363	134
	1995	967	1 193	359	133
	1996	967	1 193	359	133
	1997	771	951	286	106
	1998	810	999	301	111
	1999	811	1 001	301	111
	2000	737	909	273	101
	2001	664	819	246	91
	2002	664	819	246	91
	2003	664	819	246	91
	2004	590	729	220	81
	2005	734	909	276	101
	2006	660	819	250	91
	2007	658	819	252	91
	2008	654	819	256	91
	2009	722	909	288	101
CO_2	1990	98 632 234	90 924 779	36 660 374	10 102 753
	1991	75 683 118	69 719 774	28 126 131	7 746 642
	1992	75 528 671	69 628 239	28 064 929	7 736 471
	1993	75 531 263	69 489 270	28 062 337	7 721 030
	1994	77 426 020	72 356 872	28 762 700	8 039 652
	1995	76 550 028	71 582 884	28 433 972	7 953 654
	1996	76 552 313	71 585 142	28 431 687	7 953 905
	1997	61 030 219	56 843 998	22 664 381	6 316 000
	1998	64 125 726	59 672 723	23 811 618	6 630 303
	1999	64 224 353	59 766 162	23 846 047	6 640 685
	2000	54 605 998	54 255 094	20 273 440	6 028 344
	2001	45 943 275	48 765 046	17 056 130	5 418 338
	2002	43 520 135	48 471 661	16 155 449	5 385 740
	2003	40 232 715	48 617 395	14 934 108	5 401 933
	2004	33 506 833	43 281 831	12 468 685	4 809 092
	2005	39 358 641	53 949 980	14 725 264	5 994 442
	2006	33 399 232	48 629 905	12 575 633	5 403 323
	2007	31 681 476	48 621 608	12 077 500	5 402 401
	2008	29 852 471	48 556 406	11 573 909	5 395 156
	2009	31 198 168	53 846 281	12 363 371	5 982 920

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
HC	1990	17 322 909	9 224 496	6 438 710	1 024 944
	1991	13 292 325	7 077 903	4 939 829	786 434
	1992	13 265 200	7 063 200	4 929 080	784 800
	1993	13 265 655	7 063 200	4 928 625	784 800
	1994	13 598 433	7 240 140	5 051 631	804 460
	1995	13 444 582	7 158 000	4 993 896	795 333
	1996	13 444 983	7 158 000	4 993 495	795 333
	1997	10 718 817	5 706 450	3 980 575	634 050
	1998	11 262 485	5 995 728	4 182 066	666 192
	1999	11 279 807	6 004 800	4 188 113	667 200
	2000	8 929 525	5 454 000	3 315 331	606 000
	2001	6 896 081	4 914 000	2 560 263	546 000
	2002	6 040 746	4 914 000	2 242 608	546 000
	2003	5 100 963	4 914 000	1 893 642	546 000
	2004	3 910 326	4 374 000	1 452 873	486 000
	2005	4 191 035	5 454 000	1 560 499	606 000
	2006	3 211 219	4 914 000	1 199 302	546 000
	2007	2 740 436	4 914 000	1 030 214	546 000
	2008	2 263 659	4 914 000	860 364	546 000
	2009	2 021 381	5 477 638	782 243	608 626
Pb	1990	2 210.51	2 055.33	821.62	
	1991	1 361.72	1 256.33	506.06	
	1992	1 001.33	936.76	372.07	
	1993	858.31	783.57	318.89	
	1994	659.88	620.16	245.14	
	1995	507.43	467.15	188.48	
	1996	265.81	241.78	98.72	
	1997	7.71	7.86	2.86	
	1998	0.20	0.19	0.08	
	1999	0.20	0.19	0.08	
	2000	0.17	0.17	0.06	
	2001	0.15	0.15	0.05	
	2002	0.14	0.15	0.05	
	2003	0.13	0.15	0.05	
	2004	0.11	0.14	0.04	
	2005	0.12	0.17	0.05	
	2006	0.11	0.15	0.04	
	2007	0.10	0.15	0.04	
	2008	0.09	0.15	0.04	
	2009	0.10	0.17	0.04	

		Mopeds, urban		Mopeds, rural	
Pollutant	**Year**	**New method**	**Previous method**	**New method**	**Previous method**
Metals (lubricants)	1990	76.75	94.75	28.53	10.53
	1991	58.89	72.70	21.89	8.08
	1992	58.77	72.55	21.84	8.06
	1993	58.77	72.55	21.84	8.06
	1994	60.25	74.37	22.38	8.26
	1995	59.57	73.52	22.13	8.17
	1996	59.57	73.52	22.12	8.17
	1997	47.49	58.61	17.64	6.51
	1998	49.90	61.58	18.53	6.84
	1999	49.97	61.68	18.56	6.85
	2000	45.39	56.02	16.85	6.22
	2001	40.90	50.47	15.18	5.61
	2002	40.90	50.47	15.18	5.61
	2003	40.90	50.47	15.18	5.61
	2004	36.37	44.93	13.55	4.99
	2005	45.26	56.02	16.99	6.22
	2006	40.69	50.47	15.39	5.61
	2007	40.53	50.47	15.55	5.61
	2008	40.32	50.47	15.76	5.61
	2009	44.47	56.02	17.77	6.22
Metals (gasoline)	1990	2.11	1.95	0.79	0.22
	1991	1.62	1.49	0.60	0.17
	1992	1.62	1.49	0.60	0.17
	1993	1.62	1.49	0.60	0.17
	1994	1.66	1.55	0.62	0.17
	1995	1.64	1.53	0.61	0.17
	1996	1.64	1.53	0.61	0.17
	1997	1.31	1.22	0.49	0.14
	1998	1.37	1.28	0.51	0.14
	1999	1.38	1.28	0.51	0.14
	2000	1.17	1.16	0.43	0.13
	2001	0.98	1.05	0.37	0.12
	2002	0.93	1.04	0.35	0.12
	2003	0.86	1.04	0.32	0.12
	2004	0.72	0.93	0.27	0.10
	2005	0.84	1.16	0.32	0.13
	2006	0.72	1.04	0.27	0.12
	2007	0.68	1.04	0.26	0.12
	2008	0.64	1.04	0.25	0.12
	2009	0.67	1.15	0.26	0.13

B Driving cycles used in the reference studies

<table>
<tr><th>Driving cycle</th><th>Full name</th><th>Description</th><th>Used in …</th></tr>
<tr><td>CADC urban</td><td>Common Artemis Driving Cycle urban</td><td>European orientated driving cycle with several sub-cycles differing in dynamics. Used to simulate driving in the city (with hot start).</td><td rowspan="4">EMPA (2004)</td></tr>
<tr><td>CADC motorway</td><td>Common Artemis Driving Cycle motorway</td><td>European orientated driving cycle with several sub-cycles differing in dynamics. Used to simulate driving on the high- or motorway (with hot start). The motorway cycle comes in two types; one with a speed limit of 130 km/h and one with a speed limit of 160 km/h. In the laboratory used in the reference, the speed limit was 130 km/h.</td></tr>
<tr><td>CADC rural/road</td><td>Common Artemis Driving Cycle rural</td><td>European orientated driving cycle with several sub-cycles differing in dynamics. Used to simulate driving on rural roads (with hot start).</td></tr>
<tr><td>SC</td><td>Scooter Cold Start</td><td>This test consists of a ‘centre’-part of the FHB cycle (FachHochschule Biel cycle; a three-part cycle for two-wheeled vehicles: in the city centre, periphery and regional. Designated to the city of Biel, Switzerland).</td></tr>
<tr><td>UDC/ECE[28]</td><td>Urban Driving Cycle</td><td>A test to simulate driving behaviour in cities. It consists of cycles (each lasting 780 s) in which successively speed limits of 15, 30 and 50 km/h are applied. A cold start is also incorporated.</td><td>Spezzano et al. (2008), Tsai et al. (2000 and 2003) and Yang et al. (2005)</td></tr>
<tr><td>ECE 47</td><td>European Driving Cycle 47</td><td>European driving cycle specifically designed for mopeds. It consists of 8 identical cycles, of which the first 4 cycles are commenced with a cold start.</td><td rowspan="2">Adam et al. (2010)</td></tr>
<tr><td>WMTC</td><td>Worldwide motorcycle test cycle</td><td>The WMTC is a driving cycle proposed by the JRC (Joint Research Centre in Ispra, Italy) with the goal of harmonizing driving cycles for motorcycles. The cycle consists of 3 parts, of which parts 2 and 3 are designed for extra-urban driving (with speeds exceeding 50 km/h). In Adam et al. (2010) only part 1 is tested.</td></tr>
</table>

[28] ECE is the European name, the test is identical