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TNO report

TNO 2013 R10232

Tail-pipe emissions and fuel consumption of standard and tampered mopeds

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Copy no	TNO-060-DTM-2012-01367
Number of pages	56 (incl. appendices)
Number of appendices	2
Sponsor	The Ministry of Infrastructure and the Environment H. Baarbé
Project name	Steekproefprogramma Light Duty
Project number	033.24444

Summary

Recently, a proposal for the renewal of the legislation for the emissions of powered two-wheelers was published by the European Commission. The Dutch Ministry of Infrastructure and Environment wanted to have more understanding of the effects of tampering of mopeds on emissions to be able to estimate whether the measures proposed in this legislation will have the right output. Therefore, a measurement program was set up to evaluate the effects of tampering on emissions and fuel consumption of mopeds.

The emissions and fuel consumption of a standard and a tampered version of a 2-stroke and a 4-stroke moped were measured. The mopeds were tested on the official ECE-R47 test cycle, as well as on other test cycles. Regulated emissions (CO, NO_x and HC) as well as currently unregulated emissions (CO_2, PM and PN) were measured.

The 4-stroke moped was tested on the R47 cycle and did not meet the limits at all. No technical defect or abnormalities were found. After consulting the importer, the main jet and the fuel pump were replaced, but still the moped did not comply. Only after the exhaust (with catalyst) and the carburettor of another moped supplied by the importer were fitted, the moped met the limits. Four mopeds (two 25 km/h versions and two 45 km/h versions) supplied by the importer (which were directly delivered by the OEM) were tested on the R47. Three mopeds complied easily with the limits, one moped exceeded the CO limit slightly.

The 2-stroke moped also did not comply with the limits, because of high HC emissions. The manufacturer of the 2-stroke moped also performed tests with the same moped which showed comparable emissions. The manufacturer is still testing the moped at this moment to look for a cause and possible solutions. Another similar 2-stroke moped was also tested by the manufacturer, this moped did comply with the limits.

The 4-stroke and 2-stroke mopeds were also modified to test the impact of tampering on emissions and fuel consumption. The 4-stroke moped was tested in various configurations: first the speed limiters (variomatic limiter and engine speed limiter) were modified, then the variomatic limiter was removed, then the moped was tuned (with various components). The same adjustments (except for the engine speed limiter) were made at the 2-stroke moped, but also the exhaust was replaced. In all stages fuel consumption and emissions were measured at various speeds.

The results on the effect of tampering on the emissions and fuel consumption of the 4-stroke moped are shown in the following table:

Table 1: Effects of tampering on the emissions and fuel consumption (FC) of a 4-stroke moped on various test cycles

Moped configuration → adjustments	**Max. speed before and after adjustment**	**Test cycle**	**% Change**		
			CO	**HC+NO$_x$**[1]	**FC**
4-stroke 25 km/h version → modified variomatic limiter	25 → 36 km/h	Official R47 test cycle	-18%	-14%	-23%
		Max. allowed speed	-52%	+126%	-71%
		Max. configuration speed	+52%	+304%	-27%
4-stroke 45 km/h version → without variomatic limiter	40 → 56 km/h	Official R47 test cycle	-5%	+21%	-23%
		Max. allowed speed	+32%	+280%	-44%
		Max. configuration speed	+47%	+200%	-29%
4-stroke 45 km/h version → tuned	40 → 58 km/h	Official R47 test cycle	-15%	-7%	-20%
		Max. allowed speed	+39%	+311%	-45%
		Max. configuration speed	+14%	+167%	-34%

If the 4-stroke moped is tampered to increase maximum speed, the emissions decrease in almost all cases on the official R47 test cycle. On the other cycles, in most cases emissions increase. Fuel consumption of the 4-stroke mopeds decrease after removal of the speed limiters and after tuning. This decrease in fuel consumption was investigated further by driving at various speeds with the 4-stroke moped in various configurations. This showed that fuel consumption increases dramatically while increasing speed from 90% to 100% of the maximum configuration speed. This also showed that speed limiters increase fuel consumption.

In almost all cases the emissions of the 2-stroke moped increase after removal of the speed limiter or after tuning. Fuel consumption decreases after removal of the speed limiter but increases if the moped is tuned. Results are shown in the following table:

Table 2: Effects of tampering on the emissions and fuel consumption (FC) of a 2-stroke moped on various test cycles

Moped configuration → adjustments	**Max.speed before and after adjustment**	**Test cycle**	**% Change**		
			CO	**HC+NO$_x$**[2]	**FC**
2-stroke 45 km/h version → without variomatic limiter	48 → 61 km/h	Official R47 test cycle	+19%	+48%	-12%
		Max. allowed speed	-64%	+101%	-42%
		Max. configuration speed	-19%	+25%	-17%
2-stroke 45 km/h version → with replacement exhaust	48 → 57 km/h	Official R47 test cycle	+171%	+250%	-22%
		Max. allowed speed	+130%	+2891%	-39%
		Max. configuration speed	+153%	+4515%	-27%
2-stroke 45 km/h version → tuned	48 → 70 km/h	Official R47 test cycle	+543%	+457%	+8%
		Max. allowed speed	+240%	+3695%	-33%
		Max. configuration speed	+437%	+8019%	+7%

Conclusions:

- The tested mopeds did not comply with current EU emission limits. No technical defects could be found. The 4-stroke mopeds delivered by the importer met the limits. The earlier tested 4-stroke moped only met the limits after the fuel pump, the carburettor and the exhaust (with catalyst) were replaced.
- Tampering has effects on emissions and fuel consumption of mopeds, but not necessarily adverse effects. Removal of the speed limiters lowered the fuel consumption of the mopeds, but with tuning it rose.

[1] The HC+NOx consists mainly of HC.
[2] The HC+NOx consists mainly of HC.

- PM emissions of 2-stroke mopeds are substantially higher than PM emissions of 4-stroke mopeds.
- There is no reason to revise the current moped emission factors based on these measurements.
- The Euro 2 mopeds did not comply with the Euro 3 limits. It will be much harder for a 2-stroke moped to comply with the Euro 3 limits than for the 4-stroke moped.
- The use of speed limiters increases the fuel consumption of mopeds.

Samenvatting

De Europese Commissie heeft kort geleden een voorstel voor de vernieuwing van de wetgeving over de emissies van gemotoriseerde tweewielers gepubliceerd. Het Ministerie van Infrastructuur en Milieu wil meer inzicht in de effecten van het opvoeren van brommers op emissies om te kunnen bepalen of de voorgestelde, nieuwe maatregelen tegen opvoeren het juiste effect hebben. Om dit inzicht te bieden is een testprogramma opgezet waarmee de effecten van opvoeren op emissies en brandstofverbruik bepaald kunnen worden.

De emissies en het brandstofverbruik van een standaard en een opgevoerde versie van een 2-takt en een 4-takt brommer zijn gemeten. De brommers zijn zowel getest op de officiële ECE-R47 testcyclus als op andere testcycli. Zowel de gereguleerde emissies (CO, NO_x en HC) als de tot nu toe ongereguleerde emissies (CO_2, PM en PN) zijn gemeten.

De 4-takt brommer voldeed op de R47 cyclus bij lange na niet aan de normen. Er zijn geen technische defecten of afwijkingen gevonden. Na overleg met de importeur is ervoor gekozen de sproeier en de brandstofpomp te vervangen, maar ook daarmee voldeed de brommer niet aan de normen. Pas toen de uitlaat (met katalysator) en de carburateur waren vervangen door die van de door de importeur geleverde 4-takt brommer, voldeed de brommer aan de normen. Daarnaast zijn er vier door de importeur geleverde brommers (de importeur heeft deze brommers rechtstreeks verkregen van de fabrikant) getest op de R47, zowel twee 25 km/h versies (snorfiets) als twee 45 km/h versies (bromfiets). Drie van de vier brommers voldeden ruimschoots aan de normen, één brommer overschreed de norm voor CO in geringe mate.

De 2-takt brommer voldeed ook niet aan de normen door hoge HC emissies. De fabrikant van de 2-takt brommer heeft de brommer nogmaals getest en kreeg vergelijkbare resultaten. Op dit moment is de fabrikant nog bezig met eigen testen om een oorzaak en mogelijke oplossing voor de hoge emissies te achterhalen. Een andere vergelijkbare 2-takt brommer die is getest door de fabrikant voldeed wel aan de normen.

Vervolgens zijn de 4-takt en 2-takt brommers aangepast om de effecten van opvoeren op emissies en brandstofverbruik te bepalen. De 4-takt brommer is in verschillende uitvoeringen getest: eerst zijn de snelheidsbegrenzers (varioring en ontstekingsmodule) aangepast en daarna is de varioring verwijderd, ten slotte is de brommer opgevoerd (met verschillende componenten). Dezelfde aanpassingen (behalve de ontstekingsmodule) zijn gedaan aan de 2-takt brommer, aanvullend is de uitlaat nog vervangen. In alle verschillende uitvoeringen zijn de emissies en het brandstofverbruik gemeten bij verschillende snelheden.

De resultaten van de effecten van opvoeren op de emissies en het brandstof-verbruik van een 4-takt brommer zijn in de volgende tabel weergegeven:

Table 3: Effecten van opvoeren op de emissies en het brandstofverbruik (FC) van een 4-takt brommer op verschillende testcycli

Brommer uitvoering → aanpassingen	Max.snelheid voor en na aanpassing	Test cyclus	% Verandering		
			CO	HC+NOx[3]	FC
4-takt 25 km/h versie → aangepaste varioring	25 → 36 km/h	Officiële R47 test cyclus	-18%	-14%	-23%
		Max. allowed speed	-52%	+126%	-71%
		Max. configuration speed	+52%	+304%	-27%
4- takt 45 km/h versie → varioring verwijderd	40 → 56 km/h	Officiële R47 test cyclus	-5%	+21%	-23%
		Max. allowed speed	+32%	+280%	-44%
		Max. configuration speed	+47%	+200%	-29%
4- takt 45 km/h versie → sterker opgevoerd	40 → 58 km/h	Officiële R47 test cyclus	-15%	-7%	-20%
		Max. allowed speed	+39%	+311%	-45%
		Max. configuration speed	+14%	+167%	-34%

Na het opvoeren van de 4-takt brommer nemen de emissies tijdens de R47 cyclus af in bijna alle gevallen, bij de andere cycli nemen de emissies toe. Het brandstofverbruik van de 4-takt brommer neemt af na verwijdering van de snelheidsbegrenzers en na het verder opvoeren. Deze afname in brandstofverbruik is verder onderzocht door bij verschillende snelheden met verschillende uitvoeringen van de 4-takt brommer te rijden. Hierbij nam het brandstofverbruik dramatisch toe wanneer de snelheid werd verhoogd van 90% naar 100% van de maximum snelheid van die uitvoering. Dit laat zien dat de gebruikte snelheidsbegrenzers het brandstofverbruik verhogen.

De emissies van de 2-takt brommer nemen toe na opvoeren. Het brandstofverbruik neemt af na het verwijderen van de snelheidsbegrenzer, bij opvoeren neemt het brandstofverbruik toe. De resultaten zijn in de volgende tabel te zien:

Table 4: Effecten van opvoeren op de emissies en het brandstofverbruik (FC) van een 2-takt brommer op verschillende testcycli

Brommer uitvoering → aanpassing	Max.snelheid voor en na aanpassing	Test cyclus	% Verandering		
			CO	HC+NOx[4]	FC
2-takt 45 km/h versie → varioring verwijderd	48 → 61 km/h	Officiële R47 test cyclus	+19%	+48%	-12%
		Max. allowed speed	-64%	+101%	-42%
		Max. configuration speed	-19%	+25%	-17%
2-takt 45 km/h versie → uitlaat vervangen	48 → 57 km/h	Officiële R47 test cyclus	+171%	+250%	-22%
		Max. allowed speed	+130%	+2891%	-39%
		Max. configuration speed	+153%	+4515%	-27%
2-takt 45 km/h versie → sterker opgevoerd	48 → 70 km/h	Officiële R47 test cyclus	+543%	+457%	+8%
		Max. allowed speed	+240%	+3695%	-33%
		Max. configuration speed	+437%	+8019%	+7%

Conclusies:

- De geteste brommers voldeden niet aan de huidige Europese normen. Er zijn geen technische defecten gevonden. De door de importeur geleverde 4-takt brommers voldeden wel aan de normen. De eerder geteste 4-takt brommer voldeed pas aan de normen toen de brandstofpomp, carburateur en de uitlaat (met katalysator) waren vervangen.
- Opvoeren heeft een effect op de emissies en het brandstofverbruik van brommers, maar niet per se een negatief effect. Verwijdering van de snelheidsbegrenzers verlaagt het brandstofverbruik van de brommers, maar met sterker opvoeren neemt het brandstofverbruik toe.

[3] De HC+NOx bestaat voornamelijk uit HC.
[4] De HC+NOx bestaat voornamelijk uit HC.

- In vergelijking tot de 4-takt brommers zijn de fijn stof emissies van 2-takt brommers flink hoger.
- De resultaten uit deze studie geven geen aanleiding de emissiefactoren voor brommers te herzien.
- De Euro 2 brommers voldeden niet aan de voorgestelde Euro 3 normen. Het zal moeilijker zijn voor een 2-takt brommer om te voldoen aan de normen dan voor een 4-takt brommer.
- Het brandstofverbruik van brommers neemt toe door het gebruik van snelheids-begrenzers.

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B Current emission factors for mopeds used by the Emissieregistratie (Pollutant Release and Transfer Register, PRTR)

1 Introduction

Recently, a proposal for the renewal of the legislation for the emissions of powered two-wheelers was published and will come into force from 2014 onwards if the legislation is approved by European Council and Parliament. One of the aims of the proposal is to reduce the possibilities of tampering of mopeds.

The Dutch Ministry of Infrastructure and Environment needs more information on the effects of tampering on emissions of powered two-wheelers, to influence the European Commission in order to establish good legislation that reduces emissions in the real world. To evaluate the effects of tampering on emissions of mopeds, a measurement program was set up. In this program emission tests were performed on standard and tampered mopeds and the effects of tampering on the emissions and the fuel consumption were analysed.

By European law, mopeds have an engine capacity smaller than 50cc which distinguishes them from motorcycles. In the Dutch law the moped has two configurations: the 25 km/h version and 45 km/h version. For these two categories manufacturers of mopeds produce the same vehicle with the same technical specifications. The only differences are the speed limiters limiting the maximum speed of the vehicle to 25 km/h or 45 km/h.

Tampering is the modification of mopeds (or other vehicles), usually to increase maximum speed. A mild form of tampering mostly consist of the removal of the speed limiters. A more extreme form of tampering is applied if additionally several components are replaced/modified to increase the maximum speed even more, this is called tuning. In an earlier TNO study (Dröge 2011) no literature was found on the effects of tampering on emissions and fuel consumption. No measurements were found to compare regular emissions of a moped to those of a tampered moped.

According to Rijkeboer (Rijkeboer, 2002) and Spezzano (Spezzano et al, 2008) readjustments and change of the exhaust are very easy and this obviously influences the emissions. Removal or adjustment of the parts that limit the maximum speed are the most common tampering measures and make the moped run 10-15 km/h faster. Adjustments that make the mopeds run even faster, up to 80 km/h, are less common. The possible tampering methods are various and depend on the type of engine (2-stroke versus 4-stroke).

The contribution of moped emissions to total traffic emissions is considered almost negligible, especially because NO_x emissions are low. This contribution, however, is calculated with emission factors that are based on a low number of measurements compared to other vehicles and these emission factors don’t include the effects of tampering. Also, little is known about the number of vehicle kilometres driven by mopeds in general, let alone tampered mopeds, so calculation of the total contribution of mopeds to traffic emissions is undermined.

Compared to passenger cars and trucks little (scientific) attention is paid to the emissions of mopeds. Comprehensive surveys on powered two-wheelers, particularly on mopeds, are scarce. PM emissions could be high and may have a significant impact on health because of their composition (mainly hydrocarbons).

A measurement program was set up to increase the knowledge on moped emissions, especially on the effects of tampering on emissions. Two representative mopeds, a 2-stroke and a 4-stroke, in various configurations, were measured on their fuel consumption and the emission of HC (hydrocarbons), CO (carbon monoxide), NO_x (nitrogen oxides), PM (particulate matter) and PN (particle number).

The first test program aimed to find answers to the following questions:

1. Do the standard mopeds in-service perform conform the current standards of the type-approval for gaseous emissions (European Directive 97/24/EC)?
2. What are the effects on emissions and fuel consumption of different stages of tampering?
3. What are the emissions and fuel consumption at maximum configuration speed and at maximum allowed speed and how do these emissions compare to the emissions over the standard driving cycle?
4. How do mopeds perform compared to Euro 5 passenger cars? This will be investigated to be able to compare the absolute emissions from mopeds to those of currently sold passenger cars.
5. How do mopeds perform compared to current moped emission factors? This will be investigated to be able to judge the emission factors which are based on literature research (Dröge, 2011).
6. How do the results for the Euro 2 test cycle compare to the results for the proposed Euro 3 test cycle? The future test procedure will include a cold start, therefore in this test program the currently sold mopeds will also be tested on the new test procedure.

The results following from the research questions above led to new research questions that were answered in a second test program.

7. Do other mopeds comply with the limits and can the emissions of the tested mopeds be improved by replacing components?
8. What is the fuel consumption at various speeds and what is the influence of speed limiters on fuel consumption?

In the second chapter the method used to collect data on emissions and fuel consumption is explained. In chapter 3 a summary of the results is shown. After that, a discussion of the results follows in chapter 4. Finally, conclusions are drawn in Chapter 5.

2 Method

Two test programs were executed in this research. In this chapter the tested vehicles and tampering measures, the test procedure, the test cycles, the test programs and the measuring methods are illustrated.

2.1 Test vehicles

Most newly sold mopeds in The Netherlands are 4-stroke mopeds, but still the current fleet of vehicles consists mainly of 2-stroke mopeds. Of both engine types one vehicle was tested in an emission test laboratory on a chassis dynamometer. Each type was tested in different configurations with different stages of tampering.

Two new vehicles were purchased in their original, standard configuration. In this way influences of defects and possible changes of components on the emissions were prevented. The purchased mopeds were amongst the best sold makes of 2011 (Table 5). Both vehicles were type-approved according to Euro 2 limits (European Directive 97/24/EC).

Table 5: Number of mopeds sold in The Netherlands in 2011 (BOVAG-RAI 2012)

	45 km/h version	25 km/h version
Total	32648	61841
Make A	3818 (12%)	5624 (9%)
Make B	4201 (13%)	8235 (13%)

Table 6 shows an overview of the technical details of the mopeds tested. The only difference between the 25 km/h and 45 km/h version of the 4-stroke moped is the type of speed limiter (as far as shown in these specifications). This results in a difference in minimum transmission ratio and maximum engine speed. The difference in maximum engine speed causes a different maximum power and torque, and thus maximum speed.

A remarkable difference between the 2- and 4-stroke is the catalyst type according to the type-approval documents (obtained by the Dutch importer). The 2-stroke has an oxidation catalyst (reduces only CO and HC) and the 4-stroke has an 3-way catalyst (reduces NO_x, CO and HC). Both catalyst types use Secondary Air Injection (SAI) to improve oxidation within the catalyst.

That the 4-stroke has a 3-way catalyst does not seem plausible, because it was combined with SAI, according to the type approval documents in this case a pulse air system. The pulse air system adds air in the exhaust before the catalyst so that CO and HC can be reduced over the catalyst with the provided oxygen. This device is normally not combined with a 3-way catalyst. Additionally a 3-way catalyst is normally combined with a lambda sensor, which was not installed in this case.

Table 6: Technical specifications mopeds

Make **Max Speed**	A 25 km/h	A 45 km/h	B 45 km/h
Engine	4-stroke, spark ignition	4-stroke, spark ignition	2-stroke, spark ignition
Cylinder capacity	49,5 cm3	49,5 cm3	49 cm3
Max power	1,8 kW at 6500 rpm	2,3 kW at 7500 rpm	3,3 kW at 6700 rpm
Max torque	2,6 Nm at 6500 rpm	3,1 Nm at 6500 rpm	4,3 Nm at 6500 rpm
Fuel supply	Carburettor	Carburettor	Carburettor
Transmission	Automatic	Automatic	Automatic
Type	Variomatic	Variomatic	Variomatic
Transmission ratio min	1,55	0,99	0,79
Transmission ratio max	3,05	3,05	3,07
Anti-pollution devices	1 catalytic converter with SAI	1 catalytic converter with SAI	1 catalytic converter with SAI
Type of catalyst	3-way with pulse air	3-way with pulse air	Oxidation with pulse air
Speed limiter; transmission	Variomatic ring (7,7mm)	Variomatic ring (4mm)	Variomatic ring (n.a.)
Speed limiter; ignition unit	Change of ignition timing from 6900rpm	Change of ignition timing from 8400rpm	Not applicable
Mass	92 kg	92 kg	95 kg
Mass with driver	167 kg	167 kg	170 kg
Date type approval	19-11-2010	19-11-2010	13-9-2009
Date registration	02-2012	02-2012	02-2012
Condition	new	new	new
Total driving distance before test	approx. 400km	approx. 400km	approx. 400km

For the second test program the importer of the make A mopeds supplied four 4-stroke mopeds, two of similar type as the one mentioned in Table 6 (25 and 45 km/h version) and two of an another type (25 and 45km/h version). The 4-stroke moped of the first test program was adjusted with a smaller main jet and a new fuel pump.

The 2-stroke moped used in the first test program was transported to the manufacturers testing facilities. No results are available yet of the measurements made there.

2.2 Methods to tamper a moped

Tampering can be divided into two categories: removal of the speed limiters and tuning. To increase the maximum speed of a moped, first the speed limiters can be removed and further adjustments (tuning) can increase maximum speed even more.

2.2.1 Removal or adjustment of the speed limiter

In The Netherlands the category mopeds sold with a maximum speed of 25 km/h are usually speed limited versions of the 45 km/h version of the same type of moped. Also the 45 km/h versions have to be limited in maximum speed, because of the relatively high power of the engine.

- For both the 2-stroke and the 4-stroke moped the variomatic ring limits minimum transmission ratio, thus reducing maximum speed. The replacement of the variomatic ring by a thinner variomatic ring or removal of the variomatic ring increases the maximum speed.
- In 4-stroke mopeds, the ignition unit regulates the ignition timing. By replacing the ignition unit, the ignition timing can be altered and a higher

engine speed is possible. This increases the maximum speed of the moped.

- For the 2-stroke moped usually also the air flow engine in and/or engine out is restricted with a flow limiter. This reduces the oxygen and fuel supply to the engine and in some cases also the flow of exhaust gas engine out and results in a lower maximum speed. If the restriction is removed, the maximum speed will increase.

2.2.2 *Tuning*

Mopeds can be tuned to reach even higher speeds than can be achieved by the removal of the speed limiter alone. For 2-stroke and 4-stroke mopeds different options are possible:

- For both the 2-stroke and the 4-stroke moped the size of the main jet in the carburettor can be adjusted. A smaller main jet reduces the fuel flow to the engine, so the maximum speed of the vehicle is reduced. If a larger main jet is installed, fuel flow to the engine is increased. This result in a higher engine speed and thus the maximum speed will increase (air flow needs also to be increased).
- In 2-stroke mopeds the replacement of an exhaust with an optimised air flow also increases the maximum engine- and vehicle speed.
- In 2-stroke mopeds the air filter and spark plug can be optimised. This increases the air flow to the engine, increasing the engine speed and thus maximum speed.
- Additional measures to increase speed even further are optional, but less common, since more knowledge of tampering is needed.

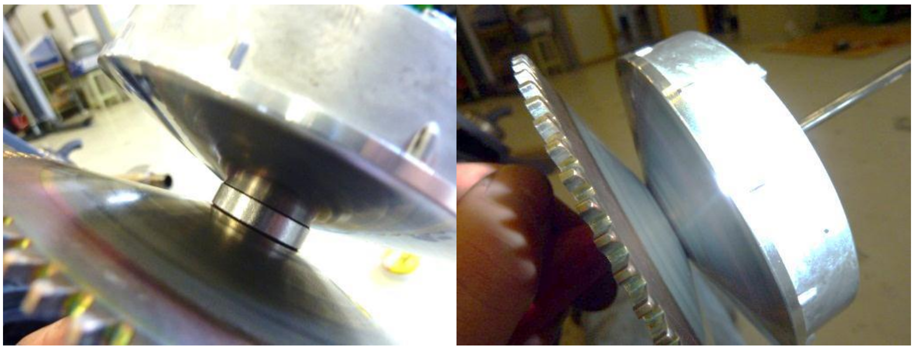

Figure 1: Variomatic with (left) and without (right) ring

2.2.3 *Methods of tampering in this research*

After consulting different experts, the components necessary to modify the mopeds to the different stages of tampering were selected and purchased. All configurations with different stages of tampering were tested before the emission measurements began. This was done to make sure that all configurations were feasible and to obtain a measurement of the maximum speed per configuration. The 2-stroke moped could be tuned to higher speeds than the 4-stroke moped.

All the mopeds in Table 6 were tampered to analyse the effects on emissions and fuel consumption. Table 7 gives an overview of the modifications performed for tampering.

Table 7: Modifications (tampering)

Moped version	Modification	Effect	Maximum configuration speed*
25km/h version 4-stroke	Variomatic ring of moped installed	Smaller transmission ratio (this results in a higher speed at the same engine speed)	36km/h
45km/h version 4-stroke	Variomatic ring removed	Smaller transmission ratio	56km/h
	a. Variomatic ring remove b. Lighter variomatic rolls** c. Unlimited ignition unit d. Larger main jet***	a. Smaller transmission ratio b. Faster acceleration c. Higher engine speed d. Higher fuel supply (higher engine speed possible)	63km/h***
45km/h version 2-stroke	Without variomatic limiter	Smaller transmission ratio	65km/h
	a. Without variomatic limiter b. Replacement exhaust	a. Smaller transmission ratio b. No catalytic converter	60km/h
	a. Without variomatic limiter b. Complete adjusted variomatic and clutch** c. Replacement exhaust without flow limiter d. Larger main jet e. Different spark plug	a. Smaller transmission ratio b. Faster acceleration c. Optimal exhaust gas flow (higher engine speed) d. More fuel supply e. Better combustion at high engine speeds	77km/h

* Measured on a flat road with GPS, top speeds on the test bench did not match these speeds.
** These adjustments were made to improve acceleration and drivability, measures that are regularly applied with tuning
*** During the emission tests, this modification was cancelled because it resulted in a too rich mixture and poor drivability.

2.3 Test procedure

The mopeds were tested according to the official test procedure of the type approval (European Directive 97/24/EC). The following regulated emissions were measured: CO (carbon monoxide) and HC+NO_x (hydrocarbons + nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number) were measured. Before the test program the mopeds were driven 250 km on a simple chassis dynamometer as prescribed by the European test procedure.

2.4 Test cycles

The test cycles used were the ECE-R47 cycle (both the Euro 2 and the Euro 3 sequence). Additionally, a steady speed cycle at maximum allowed speed and at maximum configuration speed were used. In the second test program the mopeds were also tested at different constant speeds to analyse fuel consumption.

2.4.1 ECE-R47 cycle

The R47 cycle was used to determine whether the tested vehicle conformed to the Euro 2 and 3 limits. The test cycle consists of eight times the same elementary cycle (Figure 2), each of which consists of seven parts (Table 8). This cycle is fairly representative for urban driving of mopeds because full throttle is used to achieve maximum speed. For the Euro 2 test procedure, only the emissions of the last four cycles are sampled. For the Euro 3 test procedure the emissions of all the eight cycles are sampled, so cold start emissions are included. The R47 cycle could be used for all configurations, since accelerations and constant speed are performed with full throttle.

The R47 cycle was used to check the emission performance of the vehicles. In this way a possible emission related defect could be detected. Two times the R47 test was carried out in duplicate, to check the stability of the emissions.

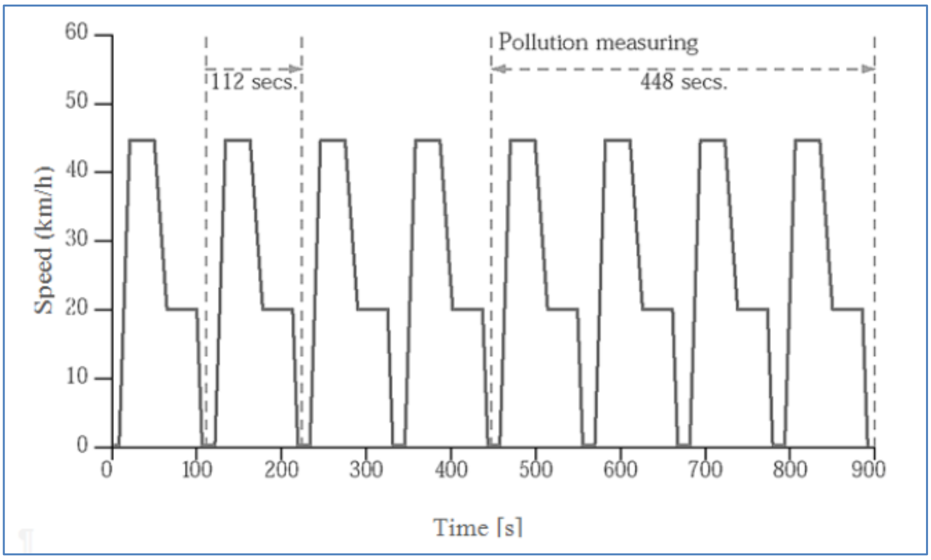

Figure 2: R47 cycle

Table 8: Phases and characteristics of the R47 test cycle

Phase number	Operation	Acceleration (m/s2)	Speed (km/h)	Duration (s)	Cumulative time (s)
1	Idling	-	-	8	8
2	Acceleration	Full throttle	0-max		-
3	Steady speed	Full throttle	Max	57	-
4	Deceleration	-0,56	Max-20		65
5	Steady speed	-	20	36	101
6	Deceleration	-0,93	20-0	6	107
7	Idling	-	-	5	112

2.4.2 *Constant speed cycles at maximum allowed speed*

In the R47 cycle the maximum speed is not the same for all moped configurations. Mopeds without variomatic limiter drive at lower engine speeds at maximum allowed speed. So, a speed cycle was developed to simulate the situation at *maximum allowed speed* for the given type of moped (25 km/h or 45 km/h) for different configurations. In this way the tampered vehicles could be compared to the standard vehicles on their emissions at the same speed. Mopeds were driven at maximum allowed speed (25 km/h or 45 km/h) for ten minutes.

2.4.3 *Constant speed cycles at maximum configuration speed*

To compare the emissions at maximum possible speed for each configuration, a speed cycle was developed to simulate the situation at maximum configuration speed (full throttle) for that configuration. Mopeds were driven at maximum configuration speed for ten minutes. See Table 7 for maximum configuration speeds.

Both cycles are shown in Figure 3. Before the start of both cycles mopeds were warmed up for five minutes on test speed (this is not shown in Figure 3).

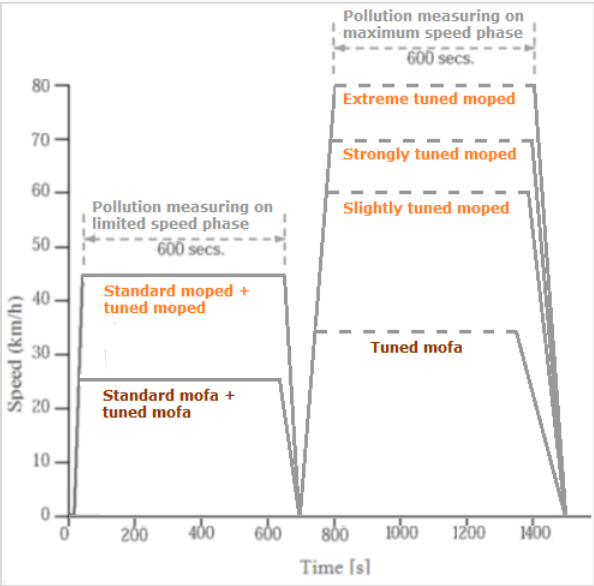

Figure 3: Steady cycle at maximum allowed speed and at maximum configuration speed (mofa = '25km/h version' and moped = '45km/h version')

2.4.4 *Constant speed at various speeds*

In the second test program, next to the regular R47 cycle, the 4-stroke moped tested in the first test program was also submitted to driving at various constant speeds to investigate the effect of the speed limiters on fuel consumption. For each configuration a different set of speeds was used, depending on maximum configure-tion speed for that configuration, and emissions were measured for three minutes per speed.

Table 9: Speeds used for the investigation of the effect of speed limiters on fuel consumption

Maximum configuration speed	Constant speeds between
27 km/u	15 and 27 km/h
33 km/u	21 and 33 km/h
39 km/u	24 and 39 km/h
47 km/u	25 and 47 km/h

2.5 Two test programs

First a test program was set up to analyse the effects of tampering on emissions and fuel consumption, see first test program in Table 10. The 2-stroke standard 25 km/h version was not tested, since this variant is rare in the Dutch vehicle fleet.

After completion of the first test program described the results gave reason to investigate the moped emissions further. Therefore, a second test program was set up in constructive collaboration with the importer and manufacturers of the mopeds. In this second test program the 25 km/h version of the 4-stroke moped of the first test program was measured again, with some adjustments made after deliberation with the importer.

The main jet was replaced with a smaller one and the fuel pump was replaced with a new one. Also, four 4-stroke mopeds provided by the importer were tested. The 2-stroke moped was also tested again and compared to similar models provided by the manufacturer, but results were not available yet upon releasing this report.

The importer or manufacturer was responsible for the right preparation of the mopeds they provided.

See Table 10 and Table 11 for the vehicle configurations and test cycles used in the first and the second test program.

Table 10: Test program

Type of moped	Configuration	Test cycle[5]
TNO 4-stroke	Standard 25 km/h version	R47, MAS
	Standard 45 km/h version	R47, MAS
	25 km/h version with adjusted variomatic limiter	R47, MAS and MCS
	45 km/h version without variomatic limiter	R47, MAS and MCS
	Tuned 45 km/h version	R47, MAS and MCS
	25 km/h version with smaller main jet and new fuel pump	R47 (twice), R47 HS, MCS, CVS
	25 km/h version with smaller main jet, new fuel pump and 45km/h engine speed limiter	CVS
	25 km/h version with smaller main jet, new fuel pump and 45km/h variomatic limiter	CVS
	25 km/h version with smaller main jet, new fuel pump and 45 km/h engine speed limiter and variomatic limiter (standard 45 km/h version)	CVS
	25 km/h version with smaller main jet, new fuel pump and carburettor replaced with the carburettor of importers 4-stroke type 1 of the 25 km/h version	R47
	25 km/h version with smaller main jet, new fuel pump and exhaust replaced with the exhaust of importers 4-stroke type 1 of the 25 km/h version	R47
	25 km/h version with smaller main jet, new fuel pump and carburettor and exhaust replaced with carburettor and exhaust of importers 4-stroke type 1 of the 25 km/h version	R47
Importers 4-stroke type 1	Standard 25 km/h version	R47
	Standard 45 km/h version	R47
Importers 4-stroke type 2	Standard 25 km/h version	R47
	Standard 45 km/h version	R47
TNO 2-stroke	Standard 45 km/h version	R47 (twice), MAS
	45 km/h version without variomatic limiter	R47, MAS and MCS
	45 km/h version with replacement exhaust	R47, MAS and MCS
	Tuned 45 km/h version	R47, MAS and MCS
First test program		
Second test program		

[5] See Table 11 for explanation of the abbreviations

Table 11: Explanation of the cycle abbreviations used in Table 10, Table 14 and Table 15

Abbreviation	**Cycle**
R47	ECE-R47 cycle
MAS	maximum allowed speed
MCS	maximum configuration speed
R47 HS	ECE-R47 cycle with hot start
CVS	Constant speed at various speeds

Table 12: Summary of the first and second test program

	Version and adjustments made											Test cycle					
	25km/h version	45km/h version	adjusted variomatic limiter	without variomatic limiter	tuned	smaller main jet and new fuel pump	45km/h engine speed limiter	45km/h variomatic limiter	carburettor of importers 4-stroke type 1 of the 25km/h version	exhaust of importers 4-stroke type 1 of the 25km/h version	replacement exhaust	ECE-R47 cycle	ECE-R47 cycle with hot start	maximum allowed speed	maximum configuration speed	constant speed at various speeds	
TNO 4-stroke	x											x		x			First test program
		x										x		x			
	x		x									x		x	x		
		x		x								x		x	x		
		x			x							x		x	x		
	x					x						2x	x		x	x	Second test program
	x					x	x									x	
	x		x			x		x								x	
	x		x			x	x	x								x	
	x					x			x			x					
	x					x				x		x					
	x					x			x	x		x					
Importers 4-stroke type 1	x											x					
		x										x					
Importers 4-stroke type 2	x											x					
		x										x					
TNO 2-stroke		x										2x		x			First test pr.
		x		x								x		x	x		
		x									x	x		x	x		
		x			x							x		x	x		

2.6 Emission measuring methods

Almost all emission tests were performed at the University of Applied Sciences in Biel/Bienne (Switzerland) because of their experience with emission measurements on powered two-wheelers. Table 13 gives an overview of the measuring methods used in Biel/Bienne.

Table 13: Measuring methods

Component	**Analysis**
CO	NDIR, Non Dispersive Infrared
HC	Heated Flame Ionization Detection HFID
NO_x	Chemo Luminescence (CLD)
CO_2	NDIR
PM	Gravimetric
PN	Condensation Particle Counter (CPC) with Volatile Particle Remover(VPR)

The second test program for the 2-stroke mopeds was performed at the manufacturers facilities. For the 2-stroke moped these results were not available yet whit the release of this report.

3 Results

Table 14 provides an overview of the results for the 4-stroke moped.

Table 14: Overall 4-stroke results for the 4-stroke moped

Type of moped	**Cycle**[6]	**CO** [g/km]	**HC** [g/km]	**NO_x** [g/km]	**HC+NO_x** [g/km]	**PM** [g/km]	**PN** [#/km]	**CO_2** [g/km]	**FC** [l/100km]	**Avg. speed** [km/h]	**Max. speed** [km/h]
TNO 4-stroke 25 km/h version	R47 E2	26,00	1,68	0,04	1,72	0,005	9,03E+12	54	4,23	20,0	27
	R47 E3	27,05	2,10	0,04	2,14	0,007	9,12E+12	50	4,20	20,0	27
	MAS*	16,37	0,25	0,02	0,27	0,004	1,11E+13	95	5,15	26,8	27
TNO 4-stroke 45 km/h version	R47 E2	18,33	1,07	0,04	1,11	0,002	5,249E+12	39	3,02	25,1	40
	R47 E3	19,28	1,27	0,04	1,31	0,005	6,06E+12	38	3,07	25,1	40
	MAS*	11,59	0,22	0,02	0,24	0,001	4,52E+12	67	3,56	40,2	40
TNO 4-stroke 25 km/h version with adjusted variomatic limiter	R47 E2	21,22	1,44	0,04	1,48	0,005	6,22E+12	39	3,26	23,7	36
	R47 E3	21,36	1,61	0,04	1,65	0,006	6,49E+12	38	3,24	23,6	36
	MAS	7,79	0,54	0,07	0,61	0,002	3,12E+11	22	1,51	26,7	36
	MCS	24,94	1,07	0,02	1,09	0,005	1,08E+13	46	3,74	36,4	36
TNO 4-stroke 45km/h version without variomatic limiter	R47 E2	17,36	1,30	0,04	1,34	0,009	5,62E+12	23	2,32	29,1	56
	R47 E3	17,31	1,38	0,04	1,42	0,011	5,98E+12	23	2,33	28,8	56
	MAS	15,31	0,88	0,03	0,91	0,004	1,66E+12	20	1,98	40,0	56
	MCS	17,07	0,69	0,03	0,72	0,004	5,81E+12	31	2,52	56,6	56
TNO 4-stroke 45 km/h version tuned	R47 E2	15,58	1,00	0,03	1,03	0,008	5,41E+12	30	2,43	29,8	58
	R47 E3	16,43	1,23	0,04	1,27	0,008	5,6E+12	27	2,39	29,5	58
	MAS	16,15	0,96	0,03	0,99	0,004	2,69E+12	18	1,96	40,0	58
	MCS	13,24	0,57	0,07	0,64	0,012	3,65E+12	33	2,34	58,6	58
Importers 4-stroke type 1 25 km/h version	R47 E2	0,11	0,05	0,17	0,22	0,003	n.a.	64	2,70	20,2	27
Importers 4-stroke type 1 45 km/h version	R47 E2	1,02	0,08	0,03	0,11	0,005	n.a.	46	2,02	20,8	33
Importers 4-stroke type 2 25 km/h version	R47 E2	0,16	0,21	0,11	0,32	0,001	n.a.	44	1,88	20,0	27
Importers 4-stroke type 2 45 km/h version	R47 E2	0,27	0,40	0,34	0,74	0,006	n.a.	46	2,03	27,0	46
TNO 4-stroke 25 km/h version with smaller main jet and new fuel pump	R47 E2	11,88	0,62	0,11	0,73	0,008	n.a.	63	3,56	20,2	27
	R47 E2	12,77	0,60	0,10	0,71	0,006	n.a.	63	3,58	20,0	27
	R47 HS E2	7,34	0,33	0,12	0,45	0,084	n.a.	66	3,33	20,1	27
	MAS*	2,56	0,22	0,10	0,32	0,044	n.a.	95	4,20	26,9	27
	MAS*	0,33	0,30	0,11	0,41	0,120	n.a.	96	4,12	26,9	27

[6] See Table 11 for explanation of the cycle abbreviations used

Continuation of Table 14:

Type of moped	Cycle[7]	CO [g/km]	HC [g/km]	NOx [g/km]	HC+NOx [g/km]	PM [g/km]	PN [#/km]	CO_2 [g/km]	FC [l/100km]	Avg. speed [km/h]	Max. speed [km/h]
Importers 4-stroke type 1 25 km/h version	R47 E3	0,24	0,76	0,16	0,92	0,004	n.a.	62	2,71	17,9	27
Importers 4-stroke type 1 45 km/h version	R47 E3	0,85	0,22	0,07	0,29	0,014	n.a.	47	2,05	19,7	33
Importe rs 4-stroke type 2 25km/h version	R47 E3	0,35	0,92	0,11	1,03	0,002	n.a.	44	1,93	19,0	27
Importers 4-stroke type 2 45 km/h version	R47 E3	0,35	0,50	0,29	0,79	0,005	n.a.	46	2,04	26,0	46
TNO 4-stroke 25 km/h version with smaller main jet and new fuel pump	R47 E3	13,25	0,97	0,11	1,08	0,007	n.a.	59	3,54	20,0	27
	R47 E3	13,90	0,89	0,11	1,00	0,009	n.a.	59	3,56	20,0	27
	R47 HS E3	4,55	0,33	0,12	0,45	0,169	n.a.	70	3,31	20,0	27

*The maximum configuration speed (MCS) of the standard versions do not match the maximum allowed speeds (MAS) of 25km/h and 45km/h, hence the MAS is assimilated to the MCS of the standard version in order to enable comparison.

Table 15: Overall 2-stroke results

Type of moped	Cycle[8]	CO [g/km]	HC [g/km]	NOx [g/km]	THC+NOx [g/km]	PM [g/km]	PN [#/km]	CO_2 [g/km]	FC [l/100km]	Avg. speed [km/h]	Max speed [km/h]
TNO 2-stroke	R47 E2	2,46	1,92	0,09	2,01	0,040	1,014E+13	77	3,67	27,1	48
45 km/h version	R47 E3	5,56	6,55	0,07	6,62	0,122	1,77E+13	58	3,72	26,7	48
	MAS*	3,39	0,20	0,05	0,25	0,045	3,26E+13	84	3,82	48,7	49
	R47 E2	2,51	1,95	0,09	2,04	0,017	4,35E+12	75	3,62	27,3	48
	R47 E3	5,19	6,60	0,07	6,67	0,065	1,25E+13	60	3,76	26,8	48
	MAS*	3,36	0,01	0,05	0,05	0,016	2,41E+13	85	3,81	48,6	49
TNO 2-stroke	R47 E2	2,95	2,81	0,18	2,99	0,020	5,27E+12	62	3,20	30,8	61
45 km/h version	R47 E3	5,11	6,53	0,15	6,68	0,063	1,27E+13	51	3,36	30,0	61
Without variomatic limiter	MAS	1,20	0,20	0,10	0,30	0,004	1,06E+12	49	2,20	48,7	64
	MCS	2,73	0,02	0,16	0,19	0,007	1,4E+13	70	3,16	63,5	64
TNO 2-stroke	R47 E2	6,73	7,02	0,07	7,09	0,067	9,87E+12	34	2,84	28,7	57
45 km/h version	R47 E3	8,34	7,51	0,06	7,57	0,072	1,16E+13	36	3,07	28,6	57
With replacement exhaust	MAS	7,77	4,41	0,05	4,46	0,001	7,17E+12	28	2,31	48,8	58
	MCS	8,54	6,77	0,11	6,88	0,103	1,37E+13	31	2,77	57,3	58
TNO 2-stroke	R47 E2	15,99	11,22	0,05	11,27	0,094	1,59E+13	32	3,93	33,3	70
45 km/h version	R47 E3	17,14	11,51	0,04	11,55	0,109	1,87E+13	31	3,99	33,4	70
Tuned	MAS	11,46	5,63	0,03	5,66	0,029	6,82E+12	25	2,56	48,6	71
	MCS	18,12	12,02	0,08	12,10	0,175	2,71E+13	30	4,08	70,2	71

*The maximum configuration speed (MCS) of the standard version did not match the maximum allowed speed (MAS) of 45km/h, hence the MAS is assimilated to the MCS of the standard version in order to enable comparison.

No results for the 2-stroke mopeds measured in the second test program were available upon releasing this report. The results of the test performed to investigate the influence of speed limiters on fuel consumption are given in paragraph 4.8.

[7] See Table 11 for explanation of the cycle abbreviations used
[8] See Table 11 for explanation of the cycle abbreviations used

4 Discussion of the results

In the next paragraphs the results are discussed for each research questions appointed in Chapter 1 (page 11).

4.1 Do the standard mopeds in-use perform conform the current standards of the type-approval for gaseous emissions (European Directive 97/24/EC)?

In Figure 4 the measurements of the standard vehicles are compared to the Euro 2 limits. The measurements were performed exactly like the official type approval test for new vehicles.

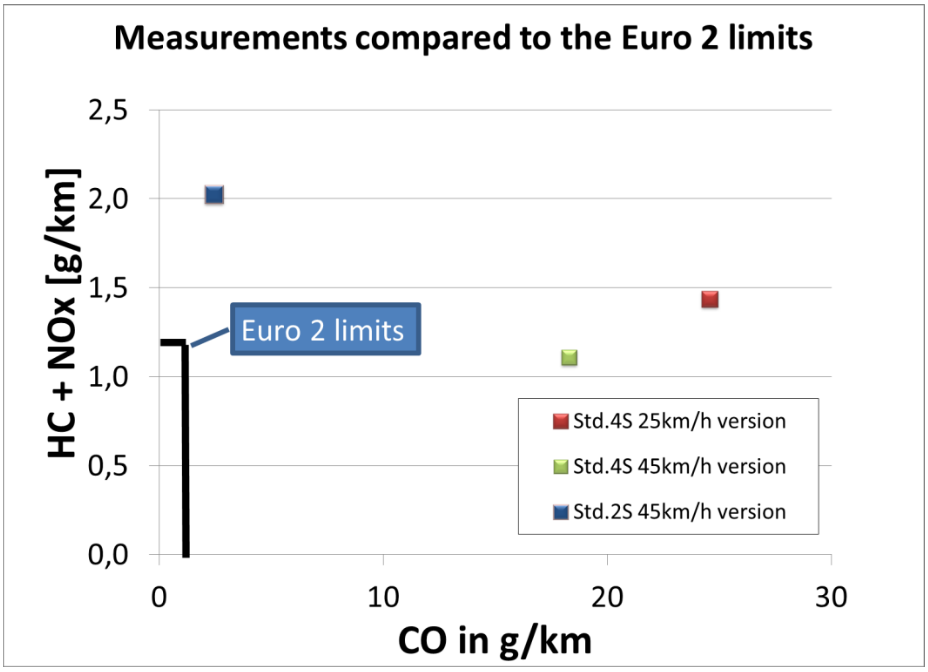

Figure 4: Emissions of the two vehicles in standard configuration compared to Euro 2 limits. The 4 stroke was measured as standard 25km/h and as standard 45km/h version.

All three standard moped configurations do not comply with the Euro 2 limit. This is remarkable, since the measurements were done on the standard configuration and the vehicles were new. As will be shown in the next paragraphs, the HC + NO_x emissions consist mainly of HC emissions.

The standard configuration 2-stroke moped has especially high HC emissions, exceeding the limit by 1,7 times. It's CO emission almost complies with the limit. Both standard configurations of the 4-stroke moped have lower HC emissions than the 2-stroke. The standard 4-stroke 45 km/h version even complies with the HC limit. The 4-strokes, however, have a very high CO emission, exceeding the limit more than 18 times.

The Euro 2 mopeds also did not comply with the Euro 3 limits. These limits are the same as the Euro 2 limits, but the test procedure is different. In the Euro 3 test

procedure a cold start is included in the measurements, because emission measurements start at the beginning of the R47 cycle.
For Euro 2 the emission measurements start after the first half of the R47 cycle, when the moped engine and catalyst are already heated.

During the official type approval the mopeds complied easily with the Euro 2 limits, this is shown in Table 16.

Table 16: Type approval results of the tested mopeds

Moped version	Cycle	CO [g/km] limit is 1,0 g/km	$HC+NO_x$ [g/km] limit is 1,2 g/km
25 km/h 4-stroke	R47 Euro 2	0.641	0.175
45 km/h 4-stroke	R47 Euro 2	0.589	0.081
45 km/h 2-stroke	R47 Euro 2	0.281	0.222

4.1.1 Discussion of the results for the 4-stroke moped

The moped was tested in standard configuration with the original components, which were checked for defects. The choke which provides a richer mixture during cold start worked automatically. All wiring for this system was in good condition. All further components and connections at the carburettor also were in good condition. The main jet was the same size as the one documented in the type approval documents.

Another possible cause for the high CO emission could be a malfunctioning catalyst. CO was measured before and after catalyst to check the efficiency of the catalyst. CO emissions after the catalyst were low compared to the emissions before the catalyst, which indicates that the catalyst was functioning.

The proper reduction of emissions in the catalyst is also dependent on the functioning of the secondary air system. The so-called pulse air system adds air in the exhaust before the catalyst. The provided oxygen reduces CO and HC in the catalyst. It is not sure if the pulse air system provides enough oxygen under all circumstances. The functioning of this pulse air system was checked by blocking the air flow to the exhaust. This clearly lead to an increase of the CO and HC emissions.

In paragraph 4.7 the results of tests with replaced (suspicious) components are shown.

4.1.2 Discussion of the results for the 2-stroke moped

The high HC emission of the 2-stroke could be the result of a rich mixture. In 2-stroke mopeds, HC's consist mainly of products of incomplete combustion of fuel and lubrication oil. For 2-stroke additional HC emissions are caused by scavenging losses of the air fuel mixture.
The 2-stroke moped was tested in standard configuration with the original components. All components were in good condition. Also the main jet was standard, however the main jet used during the official type approval wasn't noted in the type approval documents. The catalyst was working properly as well; there was a significant reduction of CO and HC emissions during and after the warming-up phase. A 2-stroke moped needs a certain amount of oil within the fuel for lubrication, there-

fore an automatic oil pump is installed. It is possible to adjust the supplied amount of oil. The setting for the oil pump was standard and did not need to be adjusted.

Studying the instantaneous measurement data made clear that, like in the 4-stroke moped, CO and HC emissions were lower during idling and high during periods with full throttle.

4.2 What are the effects on emissions and fuel consumption of different stages of tampering?

4.2.1 Results for the 4-stroke moped on the R47 cycle

In Figure 5 and Figure 6 the measurements on the Euro 2 test (R47 cycle) of the standard and modified versions of the 4-stroke moped are compared.

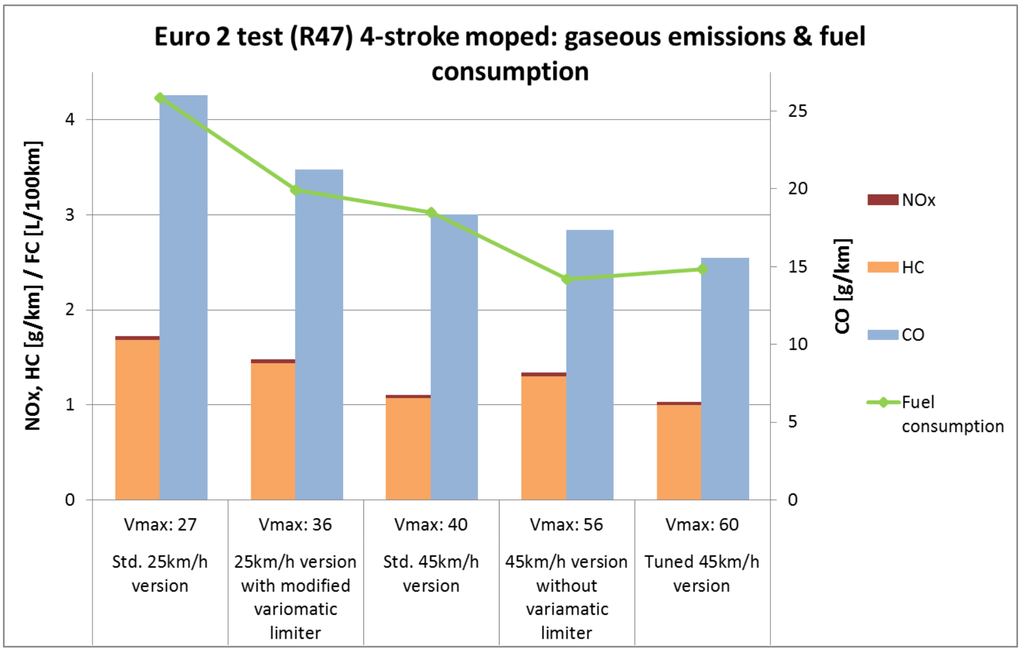

Figure 5: Euro 2 test (R47) 4-stroke moped: gaseous emissions and fuel consumption

The gaseous emissions decrease at faster moped configurations, except for a slight increase in HC+NO_x emissions in the 45km/h version without variomatic limiter. The fuel consumption also decreases at faster moped configurations, only the fuel consumption of the tuned 45km/h version increases slightly. Both emissions and fuel consumption of the tested standard 4-stroke 45km/h version are lower than the standard 4-stroke 25km/h version. In all configurations the 45km/h version has lower emissions and fuel consumption than the 25km/h version.

Especially CO decreases at faster moped configurations. The same trend is observed for HC+NO_x, with the 45km/h version without variomatic limiter as an exception. A possible cause for the higher HC emissions for this 45km/h version without variomatic limiter is the lower exhaust gas temperature. The exhaust gas temperature is about 200ºC in the first three configurations, 107ºC in the 45km/h version without variomatic limiter and the tuned version has an exhaust gas temperature of 150ºC. This lower exhaust gas temperature is possibly a result of a lower engine speed, caused by the smaller transmission ratio. In contrast, the tuned

45km/h version can accelerate faster and is able to reach slightly higher engine speeds.

Another possible cause of the higher exhaust gas temperature at the standard versions is the engine speed limiter. In order to limit the engine speed, the ignition timing is delayed significantly. This minimizes the engine efficiency and causes high exhaust gas temperatures.

The fuel consumption decreases significantly at faster configurations. The use of the variomatic limiter leads to relatively high engine speeds at a low vehicle speed, hence the engine is operating inefficiently and this leads to an increase of the fuel consumption.

Another cause of the increasing fuel consumption is the engine speed limiter, which caused lower engine efficiency and thus higher fuel consumption. The fuel consumption of the tuned 45km/h version increases somewhat compared to the version without limiter because it has a somewhat higher engine speed.

In the following graph the PM emissions and PN are shown for the 4-stroke moped. Also displayed are the limits for Euro 5 diesel passenger cars for comparison. No limits for PM and PN are applicable for mopeds yet.

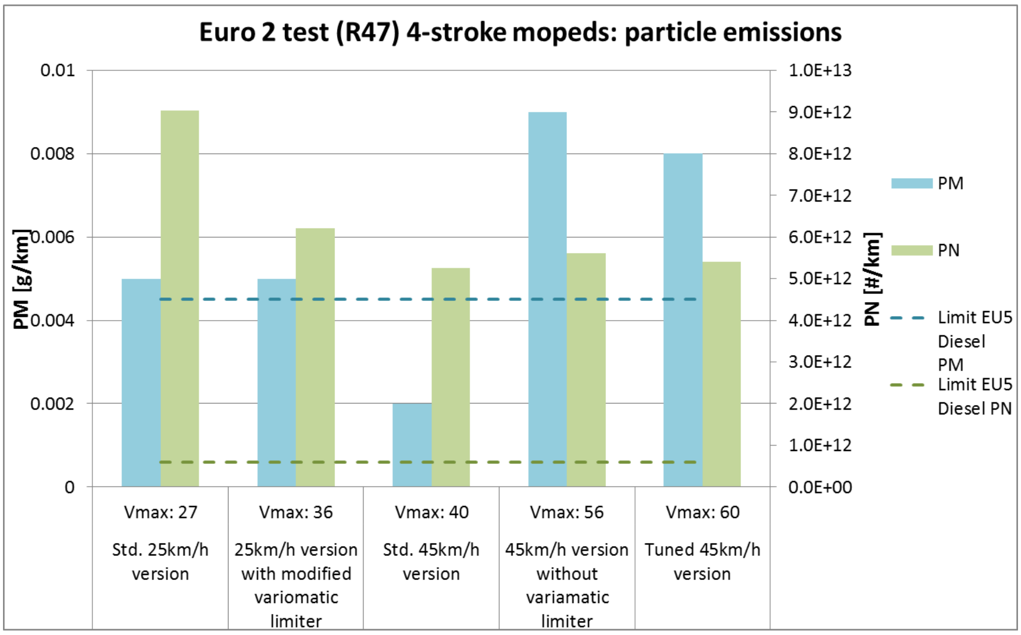

Figure 6: Euro 2 test (R47) 4-stroke mopeds: PM and PN emissions

The measured PM emissions of mopeds are of the same order of magnitude as the PM emission limit of Euro 5 diesel passenger cars, normally with particle traps (Figure 6). There doesn't seem to be a correlation between PM and PN. PN decreases at faster configurations. PM emissions occur mainly during the acceleration phase which corresponds to a very rich combustion mixture (Prati et al, 2009). Both PM and PN emissions of the tested standard 4-stroke 45km/h version are lower than the standard 4-stroke 25km/h version.

4.2.2 Results for the 2-stroke moped over the R47 cycle

In Figure 7 and Figure 8 the measurements of the standard and modified configurations of the 2-stroke moped are compared for the Euro 2 test (R47 cycle).

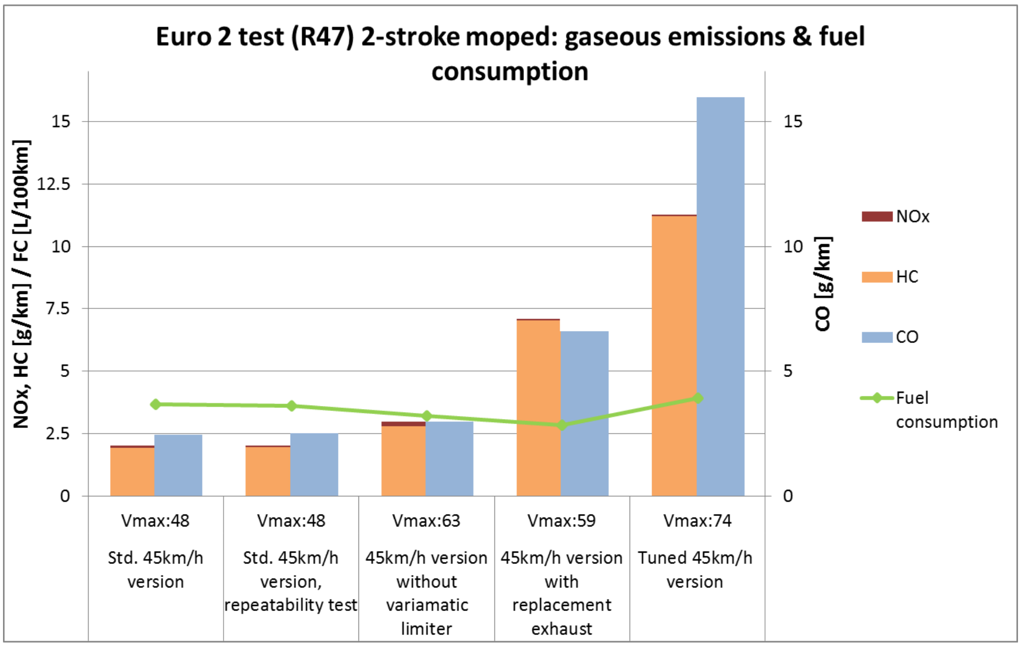

Figure 7: Euro 2 test (R47) 2-stroke moped: gaseous emissions and fuel consumption

The test results from 2-stroke mopeds on the R47 cycle show that gaseous emissions increase at faster configurations (Figure 7). Fuel consumption decreases if the variomatic limiter is removed, only for the tuned version fuel consumption increases. The repeatability test shows that repeatability is very good for both gaseous emissions and fuel consumption.

The emissions of the 2-stroke without the variomatic limiter are slightly higher compared to the standard 45km/h version. The version with the replacement exhaust and the tuned version clearly have higher emissions. The installed replacement exhaust had no catalyst, which probably caused the very high emissions of HC and CO. The tuned version has, among other things, a larger main jet to provide a higher fuel supply. With this larger main jet the vehicle is able to reach high engine speeds.

The fuel consumption without the variomatic limiter is 10% lower than the fuel consumption of the standard versions. The use of the variomatic limiter leads to relatively high engine speeds at a low vehicle speed. The engine is than operated inefficiently and this leads to an increase of the fuel consumption.

The fuel consumption of the tuned version increased due to higher fuel need for the higher engine speeds.

In the following graph the PM emissions and PN are shown for the 2-stroke moped. Also displayed are the limits for Euro 5 diesel passenger cars for comparison. No limits for PM and PN are applicable for mopeds yet.

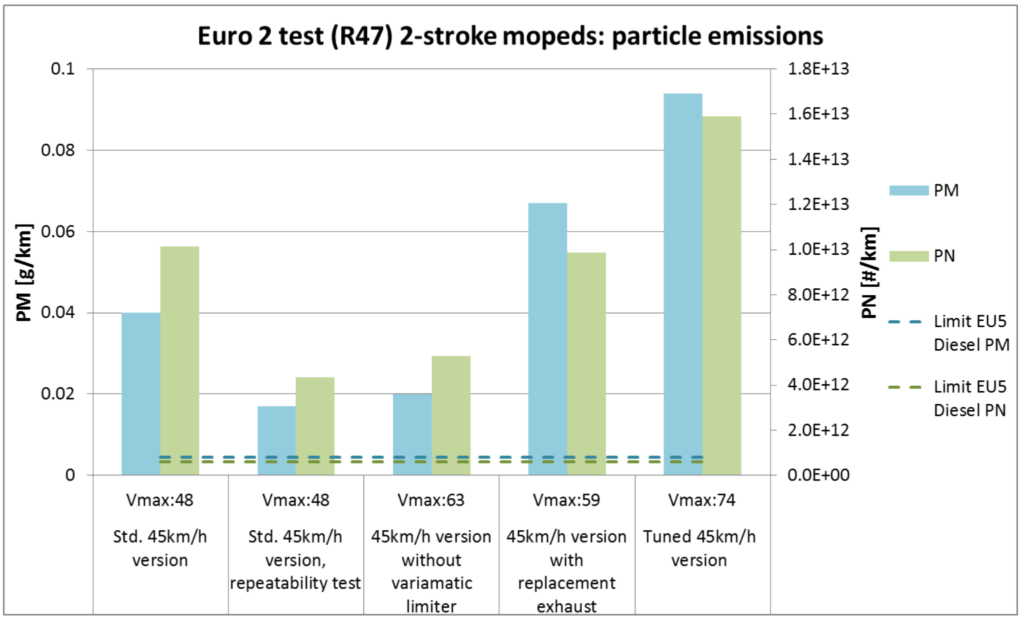

Figure 8: Euro 2 test (R47) 2-stroke moped: PM and PN emissions

The 2-stroke PM and PN are high compared to the limits for Euro 5 diesel passenger cars and increase for the faster moped configurations (Figure 8). The repeatability test shows that the 2-stroke moped cannot reproduce the PM and PN emissions well.

The produced PM and PN emissions are higher than the Euro 5 limit for diesel light duty vehicles. Both PM and PN increase for the faster configurations. After installation of the replacement exhaust there is a significantly increase for both PM and PN, most likely caused by the absence of the oxidation catalyst. The PM probably consist of a large share of organic compounds which can be oxidized by the catalyst.

In 2-stroke mopeds the oil consumption is high because the lubrication of this type of engine depends on oil which is mixed in with the fuel and which is partially burned during combustion. A lot of the PM emission appears to be related to the lubrication oil. The organic fraction of 2-stroke PM can be up to 90% (Adam et al, 2010). Czerwinski showed that lowering of the oil dosing rate and improving the oil quality could lower the PM emission level by 20-40% (Czerwinski et al, 2008).

4.3 What are the emissions and fuel consumption at maximum configuration speed and at maximum allowed speed?

4.3.1 Results for the 4-stroke moped at maximum configuration speed

In Figure 9 the measurements of the standard and modified configurations of the 4-stroke moped are compared for the maximum configuration speed cycle.

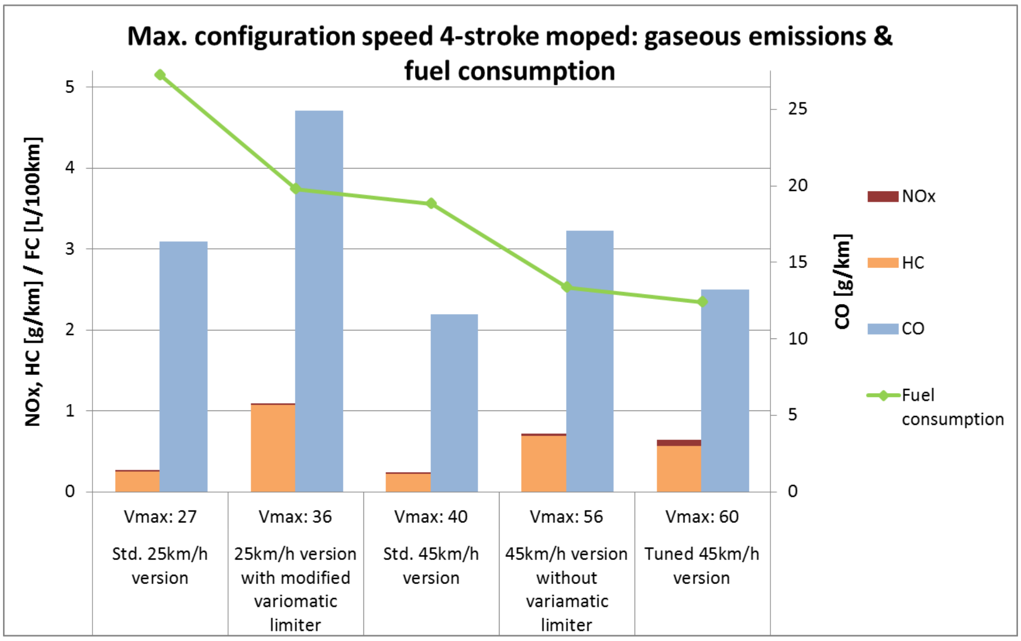

Figure 9: Maximum configuration speed 4-stroke moped: gaseous emissions and fuel consumption

The gaseous emissions of the 4 stroke moped at maximum configuration speed (Figure 9) are lower compared to the emissions measured on the R47 cycle. The standard versions (both 25km/h and 45km/h version) performed better compared to the faster configurations and this is contrary to the results from the R47 cycle. The standard 45km/h version has lower emissions compared to the standard 25km/h version, except for equal NO_x emissions. The fuel consumption decreases at higher speeds.

Most likely the lower emissions of the standard versions are the result of the very high exhaust gas temperature obtained at driving at maximum configuration speed (± 400ºC versus ± 200ºC during the R47).

As mentioned in paragraph 4.2.1 the fuel consumption decreases significantly at faster configurations than standard due to the absence of the variomatic limiter and the different engine speed limiter.

In the following graph the PM emissions and PN are shown for the 4-stroke moped. Also displayed are the limits for Euro 5 diesel passenger cars for comparison. No limits for PM and PN are applicable for mopeds yet.

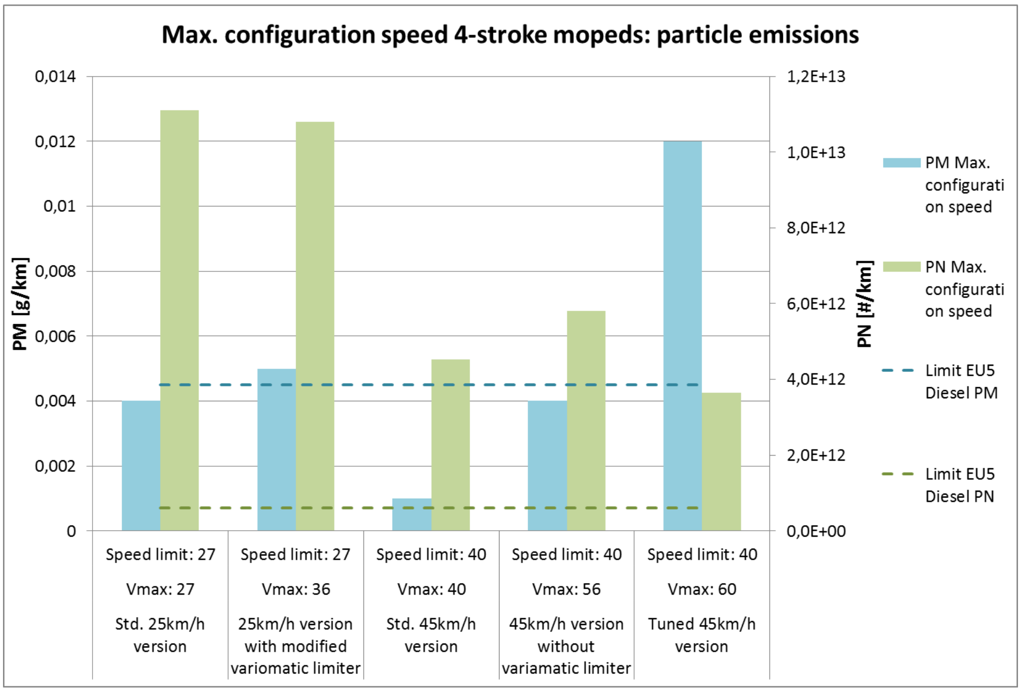

Figure 10: Maximum configuration speed 4-stroke moped: PM and PN emissions

The emission of PM is in most cases lower at maximum configuration speeds than at the R47 cycle (Figure 10). The PN emission is lower for the 45km/h configurations. The 25km/h versions have relatively high PN, also compared to the R47 cycle. Both Pm and PN emissions of the tested standard 4-stroke 45km/h version are lower than the standard 4-stroke 25km/h version.

4.3.2 *Results for the 2-stroke moped at maximum configuration speed*

In Figure 11 and Figure 12 the measurements of the standard and modified versions of the 2-stroke moped are compared for the maximum configuration speed cycle.

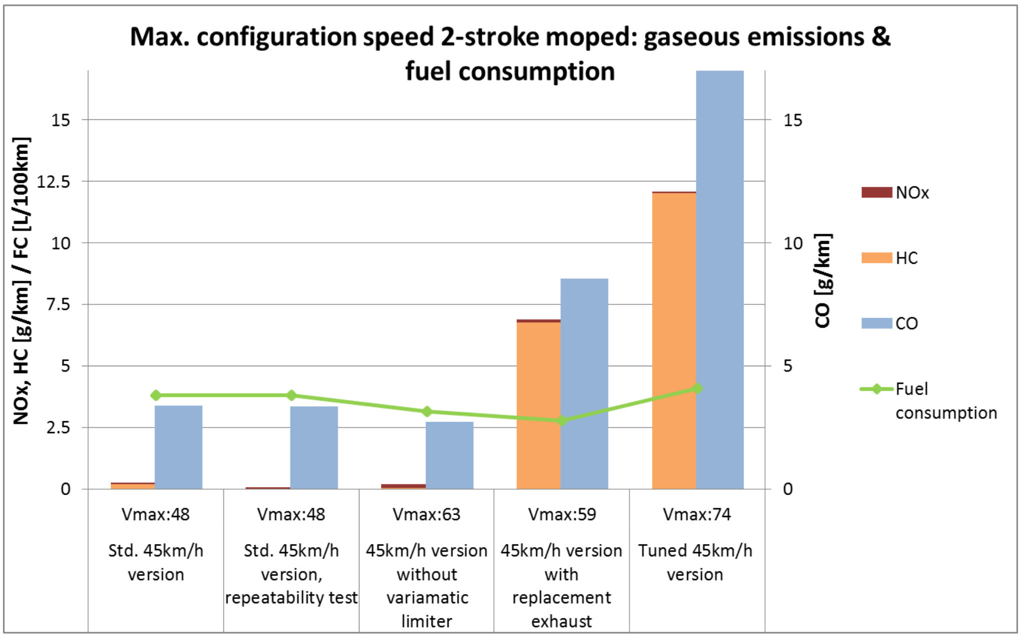

Figure 11: Maximum configuration speed 2-stroke moped: gaseous emissions and fuel consumption

The results for the gaseous emissions and fuel consumption of the 2-stroke at maximum configuration speed (Figure 11) are approximately the same compared to the R47 cycle. However, a remarkable difference is the low HC emission during the first three tests. The HC emissions are probably very low due to the very high exhaust gas temperatures (ranging from 548 ºC to 565ºC). This causes the catalyst to function with a high efficiency. The CO emissions for the version without variomatic limiter are lower than the standard version. During the R47 this was reversed. The version with the replacement exhaust and the tuned version have higher emissions because of the absence of the catalyst.

In the following graph the PM emissions and PN are shown for the 2-stroke moped. Also displayed are the limits for Euro 5 diesel passenger cars for comparison. No limits for PM and PN are applicable for mopeds yet.

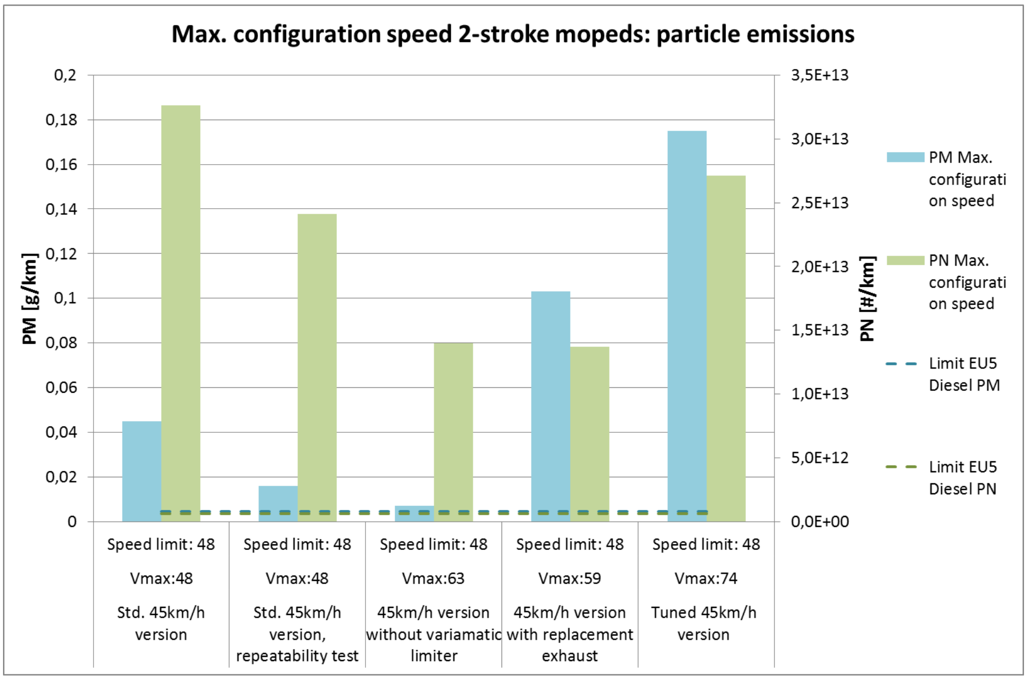

Figure 12: Maximum configuration speed 2-stroke moped: PM and PN emissions

The PM emission is very high after the replacement exhaust is installed (Figure 12). PM emissions are higher than the limits set for the diesel passenger cars, especially for the faster configurations. The PN emission is higher than over the R47 cycle and also much higher than the limit set for diesel passenger cars. PN shows a minimum at intermediate speeds. The repeatability is not good for PM nor PN.

As mentioned in 4.2.2. there is a significantly increase of PM after the installation of the replacement exhaust (during the R47 cycle also PN increases), most likely caused by the absence of the oxidation catalyst in the replacement exhaust. The PM probably consist of a large share of organic compounds which can be oxidized by the catalyst.

4.3.3 Results for the 4-stroke moped at maximum allowed speed

In Figure 13 the measurements of the standard and modified versions of the 4-stroke moped are compared over the maximum allowed speed cycle (25 or 45km/h).

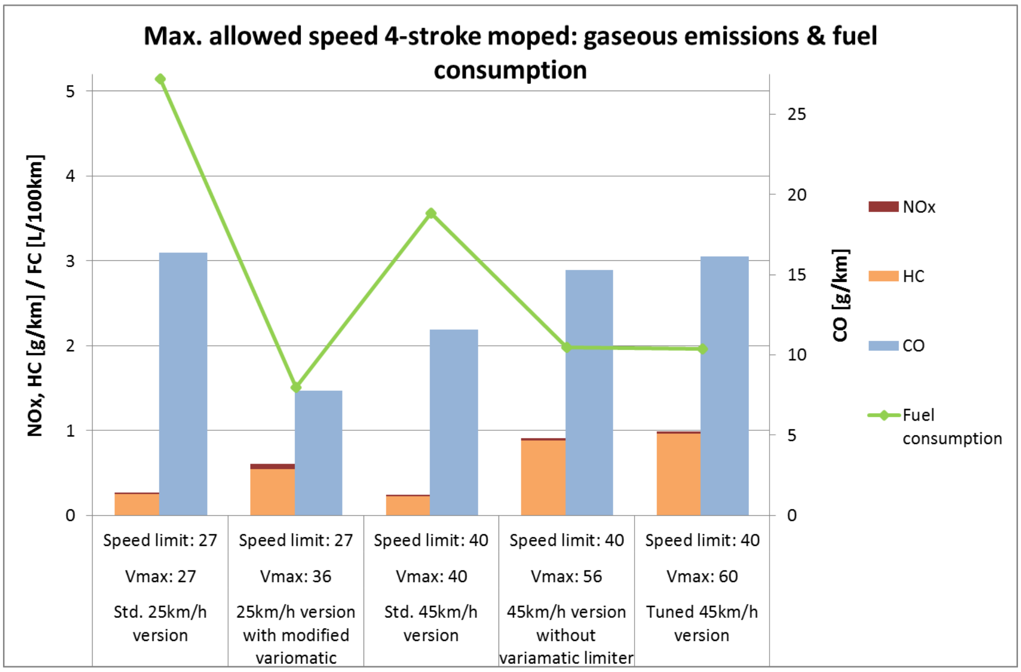

Figure 13: Maximum allowed speed 4-stroke moped: gaseous emissions and fuel consumption

The results for the gaseous emissions of the 4 stroke at maximum allowed speed (Figure 13) are almost the same compared to the maximum configuration speed. However, the 25km/h version with modified variomatic limiter is an exception with significantly lower CO emissions, most likely due to very low engine speed. Both emissions and fuel consumption of the tested standard 4-stroke 45km/h version are lower than the standard 4-stroke 25km/h version.

The largest difference occurs in fuel consumption: the faster 25km/h configuration is 3,5 times more fuel efficient than the standard version. The 45km/h configurations are 1,8 times more fuel efficient compared to the standard version. As mentioned in paragraph 4.2.1 the fuel consumption decreases significantly at faster configurations than standard due to the absence of the variomatic limiter.

Since the measurements of PM and PN on the maximum allowed speed cycle did not provide new insight, results are not shown here.

4.3.4 *Results for the 2-stroke moped at maximum allowed speed*

In Figure 14 the measurements of the standard and modified versions of the 2-stroke moped are compared over the maximum allowed speed cycle (45km/h).

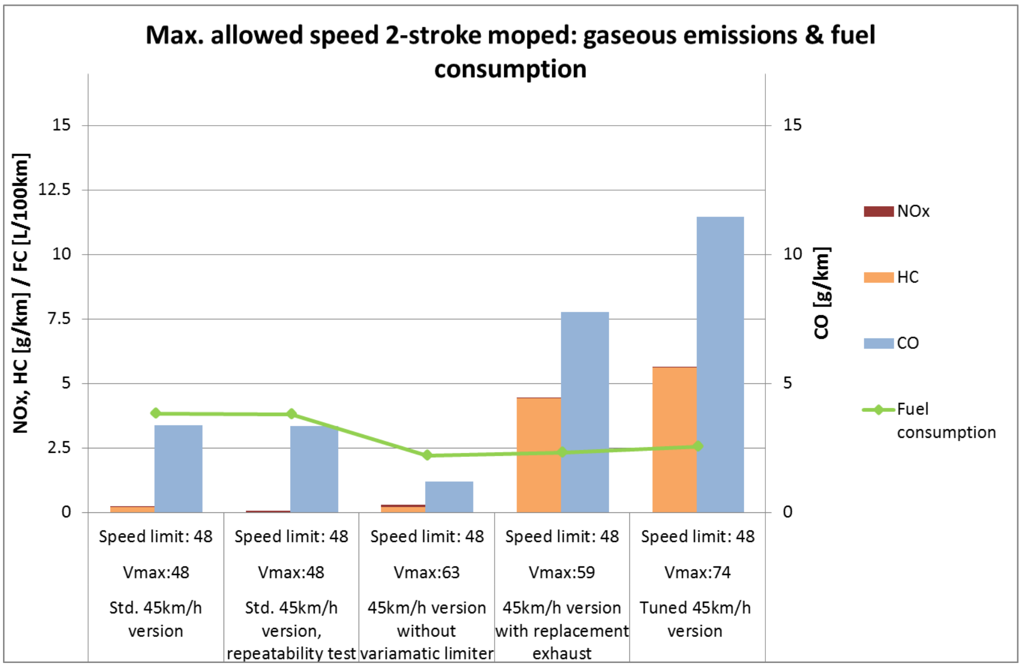

Figure 14: Maximum allowed speed 2-stroke moped: gaseous emissions and fuel consumption

The gaseous emissions of the 2-stroke at maximum allowed speed (Figure 14) are lower in every aspect compared to the maximum configuration speed. Also fuel consumption is 1,6 times lower at the configuration without variomatic limiter.

As mentioned in 4.2.2. the fuel consumption decreases significantly at faster configurations than standard due to the absence of the variomatic limiter. Probably the lower emissions are also a result of the lower engine speed at the same vehicle speed (due to the absence of the variomatic limiter).

Since the measurements of PM and PN on the maximum allowed speed cycle did not provide new insights, results are not shown here.

4.4 How do moped emissions compare to the emissions of Euro 5 passenger cars?

In Figure 15 and Figure 16 the emission measurements of emissions on the Euro 2 test cycle for the standard configurations of the three variants of mopeds are displayed. For the mopeds the emissions during the Euro 2 R47 cycle are shown. Also the emission factor of Euro 5 passenger cars on both petrol and diesel are shown. This emission factor represents the emissions during real-world driving and not the emissions as measured on the type approval test of passenger cars. The emission factors of Euro 5 passenger cars are used for comparison because Euro 5 is the current limit for new passenger cars. The emission factors used are the official emission factors for air quality calculations and calculations of effects of policy measures in The Netherlands (Meet- en rekenvoorschrift 2007).

First the comparison for HC and CO is shown in Figure 15:

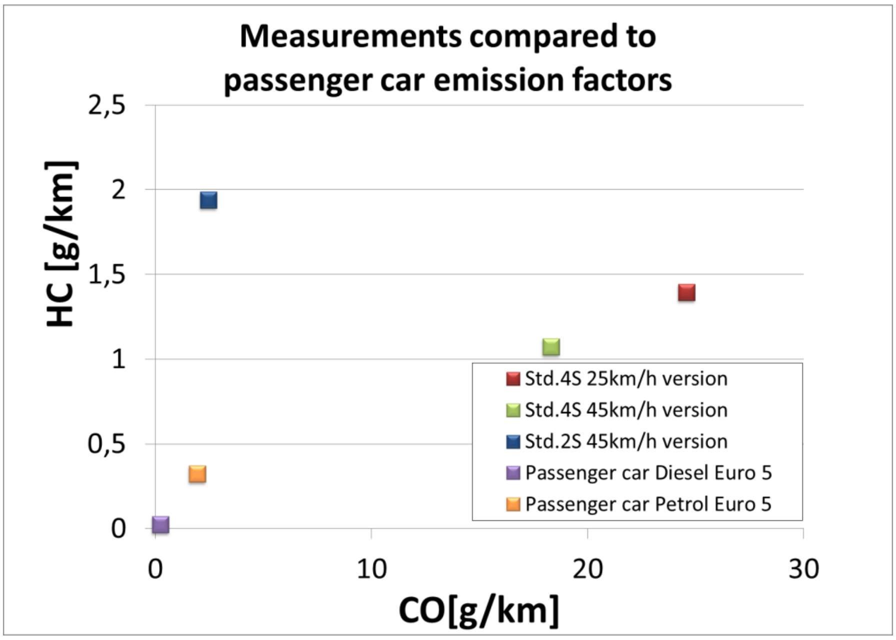

Figure 15: HC and CO emission measurements on the Euro 2 R47 cycle compared to passenger car emission factors

Both the diesel and the petrol passenger car perform better on CO and HC emissions than the mopeds. The 2-stroke moped has especially high HC emissions and the 4-stroke mopeds have especially high CO emissions. A standard 25km/h version of a 4-stroke moped emits 12,5 times as much CO as an Euro 5 petrol passenger car. The 2-stroke moped emits almost 100 times more HC than the diesel passenger car.

It should be noted that emission factors are based on many measurements and various driving conditions, hence a comparison with individual measurements is not entirely fair.

In Figure 16 the comparison between passenger car and moped PM and NO_x emissions is made.

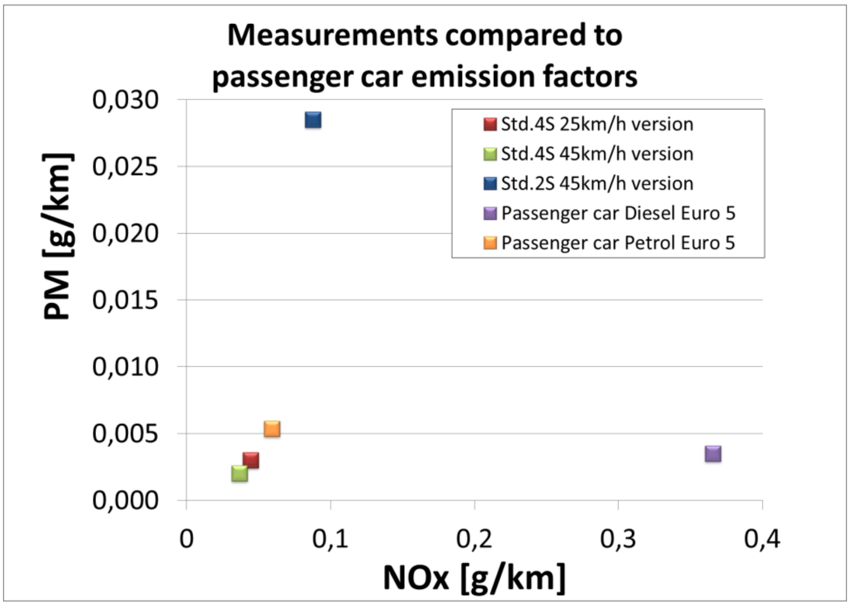

Figure 16: PM and NO_x emission measurements on the Euro 2 R47 cycle compared to passenger car emission factors

All vehicles with 4-stroke petrol engines (4-stroke mopeds and petrol passenger car) have low NO_x and PM emissions compared to the two other vehicles. The diesel passenger car has relatively high NO_x emissions, as is expected for a diesel vehicle compared to petrol vehicles. All mopeds emit 4 times less NO_x than diesel passenger cars. The 2-stroke moped has especially high PM emissions compared to the other vehicles. The 2-stroke moped emits more than 4 times the amount of PM the diesel passenger car produces, which probably consist mainly of HC (see Figure 15).

Although HC and CO emissions of mopeds are high, these vehicles are not as common as passenger cars. The relative contribution to the total HC and CO concentrations in for example urban areas is therefore considered low, but not negligible. The 2-stroke mopeds has high PM concentrations. NO_x emissions are low, so the contribution of mopeds to the NO_2 concentrations is small.

It should be noted that emission factors are based on many measurements and various driving conditions, hence a comparison with individual measurements is not entirely fair.

4.5 How do mopeds perform compared to current emission factors?

To validate the currently used and in 2011 updated emission factors which are based on literature reviews (Dröge 2011), the emission factor for the Euro 2 moped is compared to the three standard mopeds tested (Figure 17 and Figure 18). The emission factors are presented in Appendix 2.

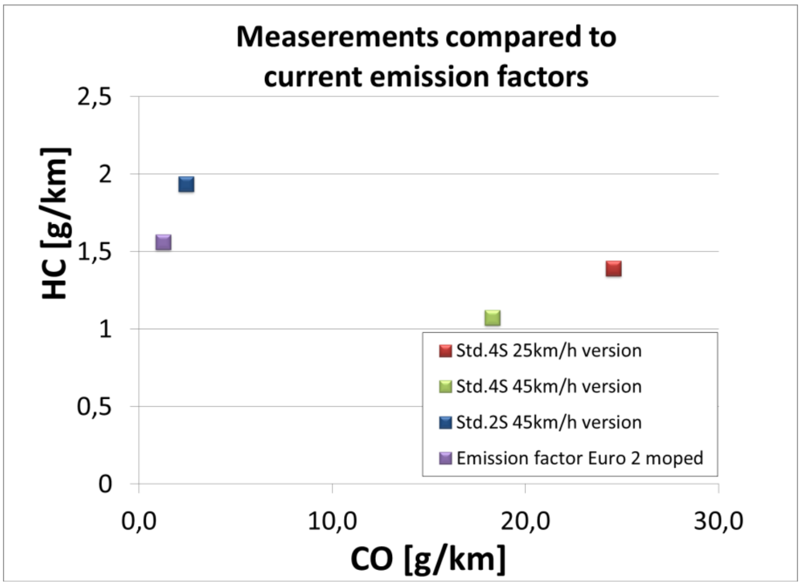

Figure 17: HC and CO emission measurements compared to moped emission factors

The tested 4-stroke mopeds have higher CO emissions than the emission factor indicates, although measured HC is lower. The 2-stroke measurements correlate pretty good with the emission factor. This was expected, since the Dutch fleet consist of mainly 2-stroke mopeds.

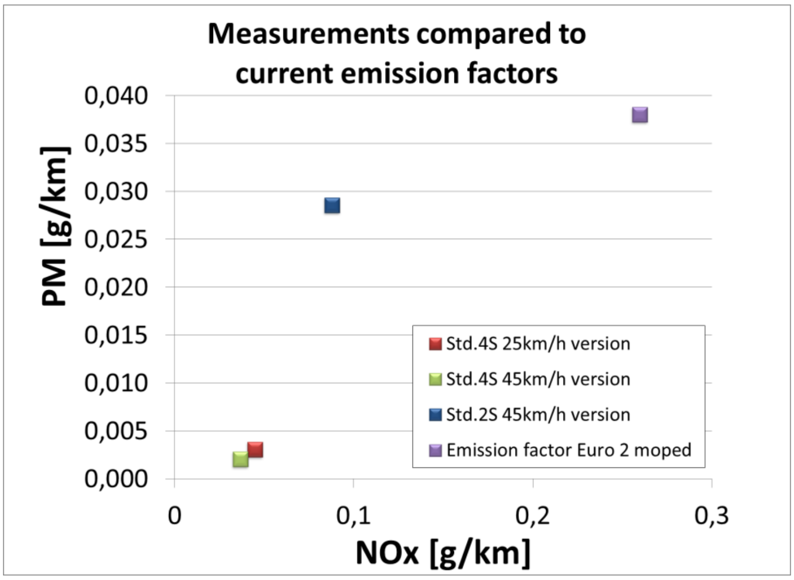

Figure 18: PM and NO_x emission measurements compared to moped emission factors

The 4-stroke mopeds emit less NO_x and PM than the emission factor indicates. The measurements for the 2-stroke mopeds are more similar, but still less NO_x is emitted than presumed by the emission factor. The amount of PM measured is a bit lower.

It should be noted that emission factors are based on many measurements and various driving conditions, hence a comparison with individual measurements is not entirely fair.

4.6 How do the results of the Euro 2 test cycle compare to the results of the proposed Euro 3 test cycle?

4.6.1 Results of the 4-stroke moped over the R47 cycle with and without cold start

In Figure 19 and Figure 20 the measurements of the standard and modified configurations of the 4-stroke moped are compared for the Euro 2 and Euro 3 test (both follow the R47 cycle). The emissions are measured for the Euro 2 test on the part where the moped engine and exhaust are already heated, so only the second half of the R47 cycle, so without cold start effect included. For the Euro 3 test the emissions measurements begin at the beginning of the R47 cycle, so they include the cold start effects. Further test procedures are identical. Figure 21 shows the gaseous emissions for the cycle compared to the Euro limits.

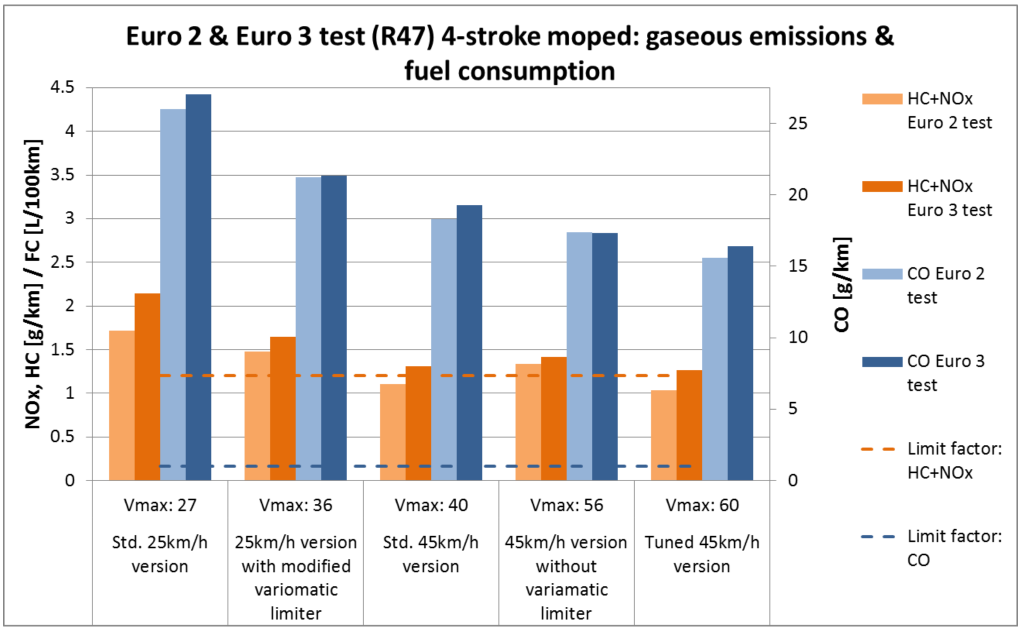

Figure 19: Euro 2 and Euro 3 test for the 4-stroke moped: gaseous emissions and fuel consumption

In all configurations the emissions for the Euro 2 test cycle were a little lower than for the Euro 3 test cycle. This difference is a result of the cold start effect. Only the 45km/h version without variomatic limiter has slightly higher CO emissions on the Euro 2 test cycle. The fuel consumption is comparable for both tests.

Figure 20 shows the PM and PN emissions for the R47 cycle.

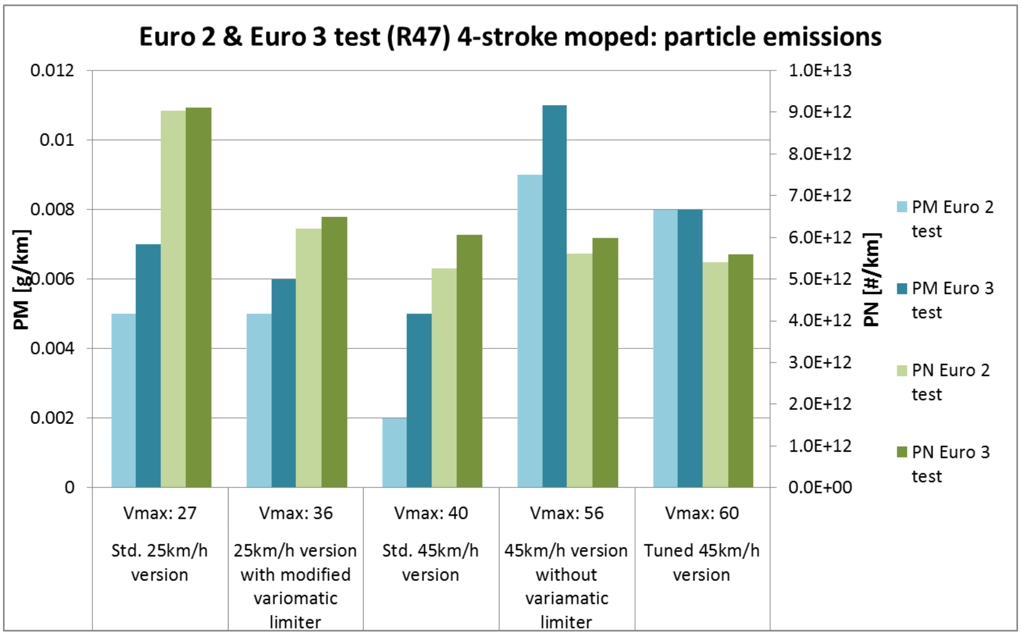

Figure 20: Euro 2 and Euro 3 test for the 4-stroke moped: PM and PN emissions

In all configurations the PM and PN emissions over the Euro 2 test cycle were lower than over the Euro 3 test cycle. This id due to the cold start effect. Only the tuned 45km/h version has comparable PM emissions over both test cycles.

To make clear in what phase of the R47 cycle the cold effect occurs, the following graph is presented. It includes emissions of CO, HC and NO_x during the R47 cycle, also showing speed and exhaust gas temperature.

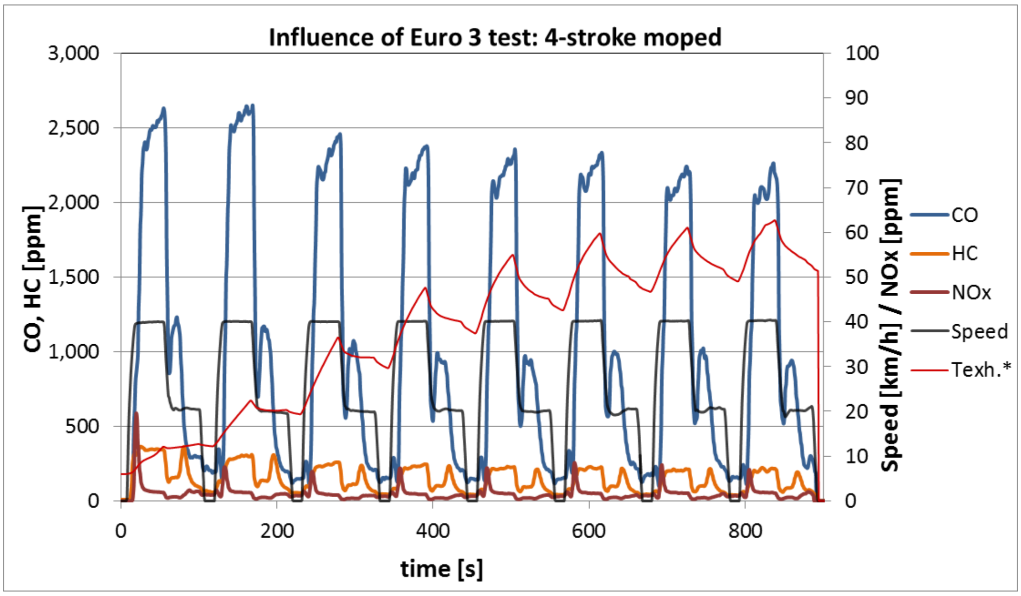

Figure 21: Influence of Euro 3 test (includes cold start): 4-stroke moped
*Texh. (exhaust gas temperature) is divided by four.

In Figure 21 the eight repeated cycles of the R47 cycle are shown with a black line. The Euro 2 results only take the emissions over the last 4 cycles into account, the Euro 3 test takes the whole cycle into account. During the test the exhaust gas temperature increase shown with exhaust gas temperature (Texh). With higher temperatures of the exhaust gas, the catalyst start working more efficiently, reaching light-off temperatures. Over time the influence of the cold start gradually minimizes. Here the standard 45km/h version is shown. Similar trends were found for all configurations. NO_x emissions reduce relatively most compared with CO and HC.

4.6.2 *Results of the 2-stroke moped over the R47 cycle with and without cold start*

In Figure 22 and Figure 23 the measurements of the standard and modified versions of the 2-stroke moped are compared for the Euro 2 and Euro 3 test.

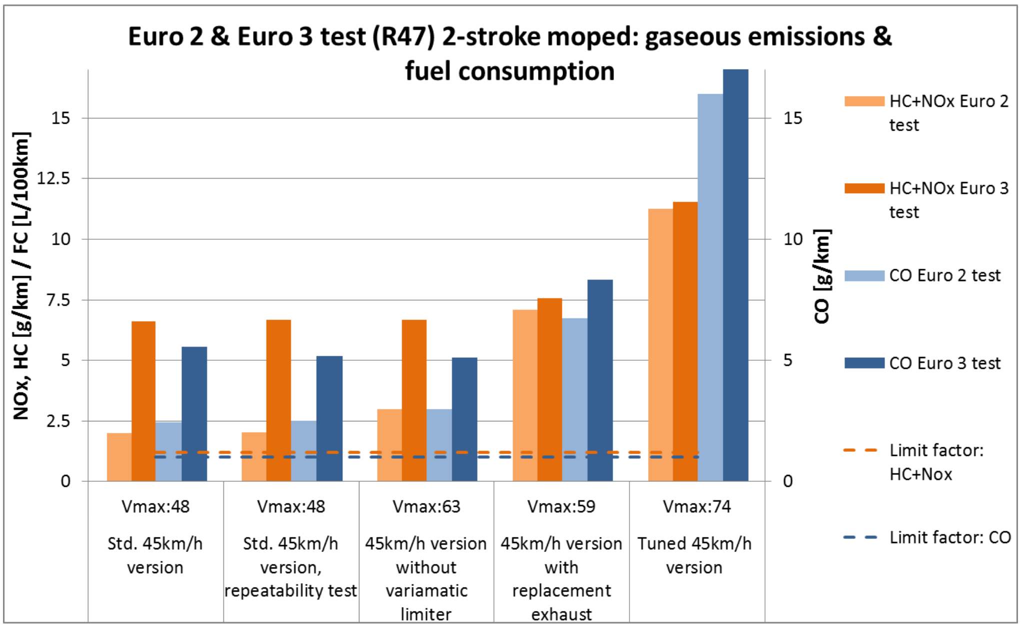

Figure 22: Euro 2 and Euro 3 test for the 2-stroke moped: gaseous emissions and fuel consumption

In all configurations the emissions on the Euro 2 test cycle were lower than on the Euro 3 test cycle. There is almost no effect on fuel consumption. For the 2-stroke the influence of the cold start is bigger than for the 4-stroke. The gaseous emissions over the Euro 3 tests are approximately a factor 2 higher than the emissions over the Euro 2 tests for the configurations with catalyst.

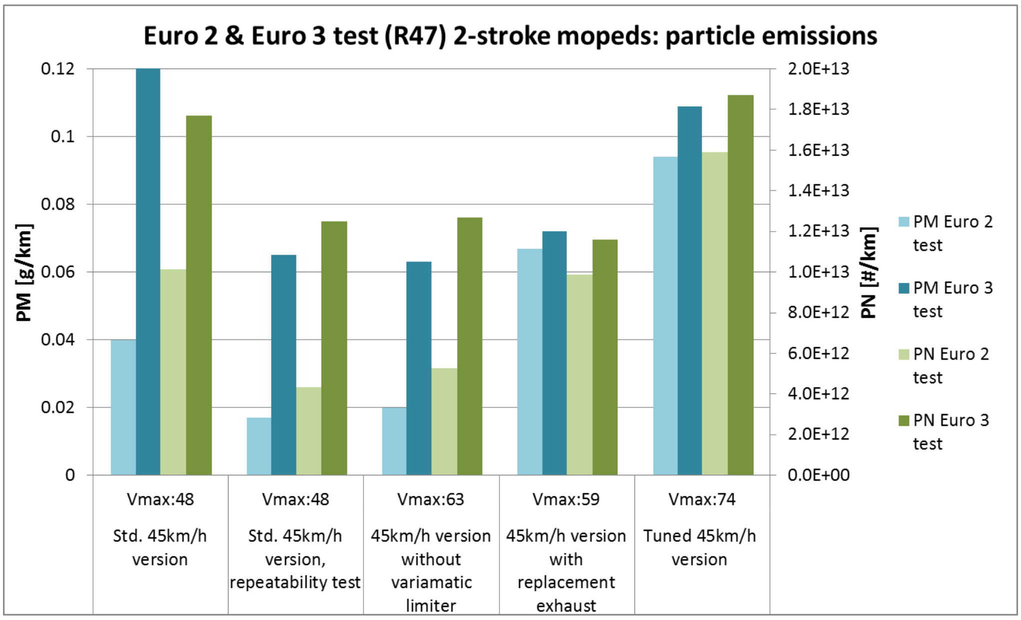

Figure 23: Euro 2 and Euro 3 test for the 2-stroke moped: PM and PN emissions

In all configurations the PM emissions and PN on the Euro 2 test cycle were lower than on the Euro 3 test cycle. Also here the cold start effects are high: PM emissions are up to a factor 3 higher during the Euro 3 test.

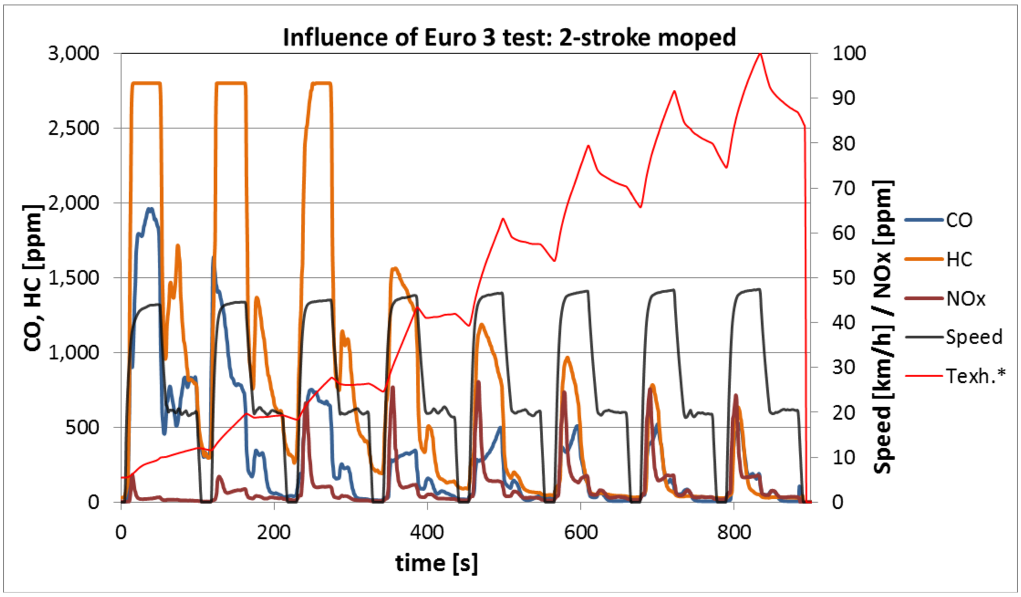

Figure 24: Influence of Euro 3 test (includes cold start): 2-stroke moped
*Texh. (exhaust gas temperature) is divided by four.

In Figure 24 the eight repeated cycles of the R47 cycle are shown with a black line. The Euro 2 results only take the emissions over the last 4 cycles into account, the Euro 3 test takes the whole cycle into account. During the test the exhaust gas temperature increase is shown with exhaust gas temperature (Texh). The HC emissions in the first three cycles are cut off because the values are higher than the measurement range.

A significant decrease for the gaseous emissions during and after the warming up phase is shown, in this case, of the standard 45km/h version. Similar trends were found for all configurations. There is no reduction of NO_x emissions because the 2-stroke moped is equipped with an oxidation catalyst, which only reduces CO and HC emissions. The NO_x emission seems to increase while the engine and exhaust warm up.

It will be much harder for a 2-stroke moped with current technology to comply with the Euro 3 limits compared to the 4-stroke moped.

From the results shown in paragraph 4.1 the conclusion was drawn that the mopeds did not meet the limits. The results from the official type approval did not show these results. Therefore, the results were presented to the importer of the 4-stroke moped and the manufacturer and the importer of the 2-stroke moped. After this a second test program was set up to try to improve the emissions of the mopeds tested and test other comparable mopeds. The results are presented below.

4.7 Do other mopeds comply with the limits and can the emissions of the tested mopeds be improved by replacing components?

The importer of the 4-stroke moped provided four mopeds (which were directly delivered from the OEM), two types (one type is the same type as the previous tested moped) and of both types a 25km/h version and a 45km/h version. The importer was responsible for the right preparation of the mopeds. The 4-stroke moped tested in the first test program was adjusted with instructions provided by the importer. A smaller main jet and new fuel pump were installed. All five mopeds were tested at the R47 test cycle.

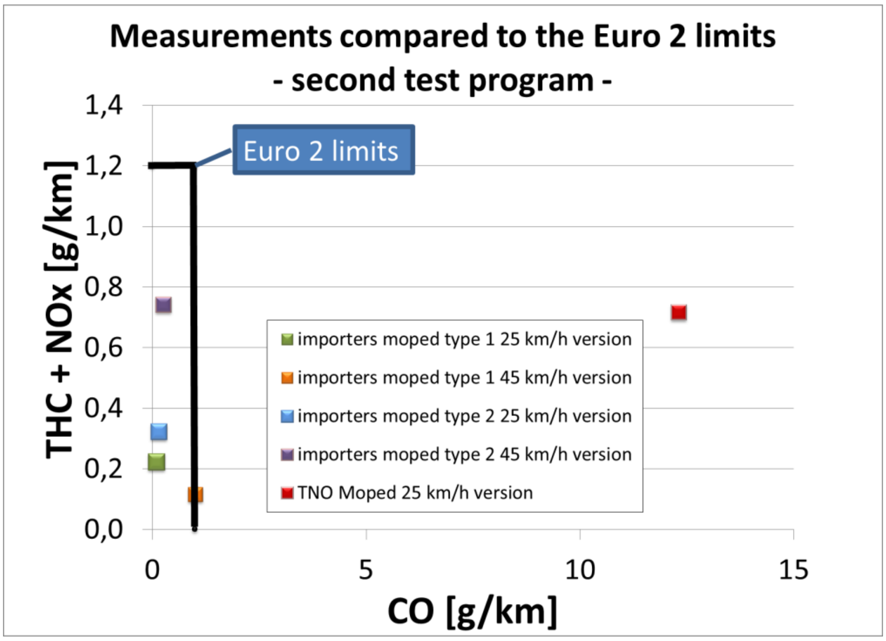

Figure 25: Results for the R47 cycle in the second test program

Three of the importers mopeds met the Euro 2 limits, the ‘importers moped type 1 45km/h version’ exceeded the limit for CO emission by 0,02 g/km. This moped couldn’t reach a higher speed than on average 33km/h, so maybe there was a technical malfunction in this moped. All four mopeds complied with the Euro 3 limit (see Table 14). The scooters did not reach their maximum speed during the first 4 minutes, possibly this is caused by a lean air-fuel mixture.

As can also be seen in Figure 25, the moped from the first test program (Std. 4S 25km/h version – adjusted) again did not meet the limits, although emissions were 50% reduced compared to the first tests performed. Also for the Euro 3 test procedure CO emissions were too high to meet the limits. These are averaged results of two R47 tests.

The R47 test was repeated for the Std. 4S 25km/h version - adjusted, only this time with a hot start. The hot start was performed by warming up the vehicle firmly (10 minutes full speed driving) before the start of the R47 test cycle. This is not an official test procedure. During this test the moped did not comply with the CO limit either and CO emissions increased over time, see figure below.

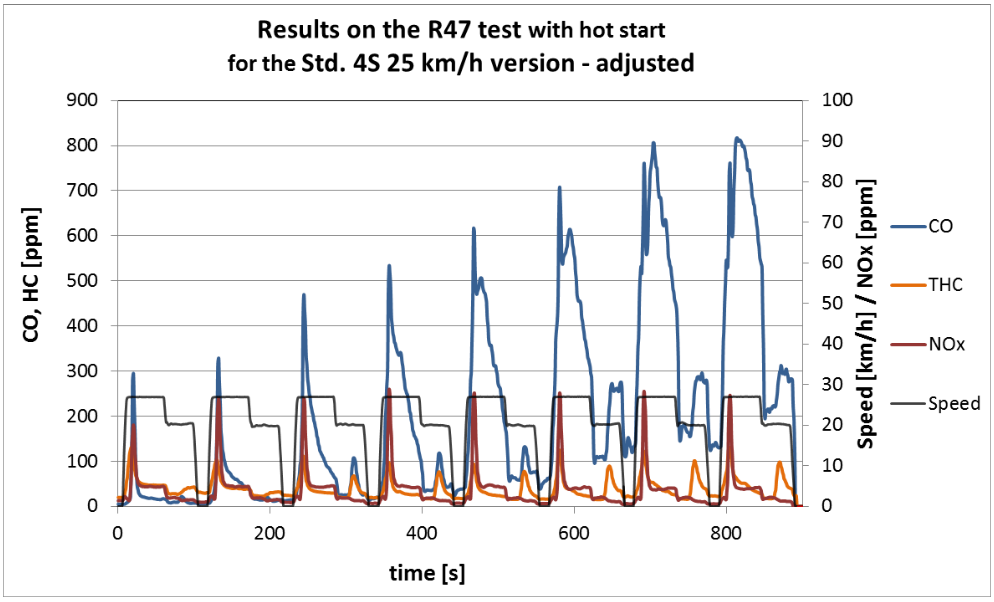

Figure 26: Test results with hot start during the R47 test

To figure out what causes the high CO emissions of the standard 4-stroke 25km/h version, additionally a maximum constant speed cycle at 26,9km/h was driven and emissions and fuel consumption were measured. Compared to the measurements from the first test program, emissions dropped from 16,4 g/km to 1,5 g/km. During the maximum constant speed cycle the CO emissions dropped significantly after warming up.

To try to reduce the CO emissions, finally measurements were performed after adjustments of the moped. The carburettor and/or exhaust were taken of the importers moped type 1 25km/h version (same type of scooter) and placed on the Std. 4S 25km/h version - adjusted. The effect on CO emissions were as follows:

1. After the replacement of the carburettor CO emissions decreased from 12,3 g/km to 2,5 g/km
2. After the replacement of the exhaust CO emissions decreased from 12,3 g/km to 6,4 g/km
3. After the replacement of the carburettor and the exhaust CO emissions decreased from 12,3 g/km to 0,2 g/km. This is conform to the CO emission limit

For the 2-stroke moped no additional results are available yet.

4.8 What is the fuel consumption at various speeds and what is the influence of speed limiters on fuel consumption?

In paragraph 2.4.4 the test cycles for the investigation of the fuel consumption at various speeds was presented. This was tested on the importers moped type 1 25 km/h version (which complied to the Euro 2 limit), which was adjusted with the speed limiters in different configurations. Four configurations were tested. Results are presented below:

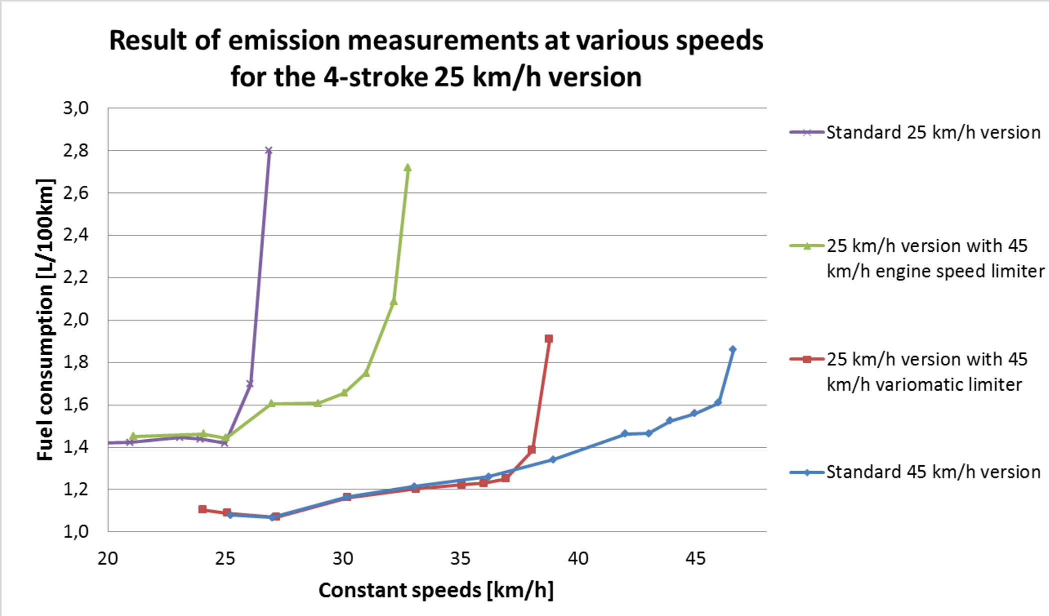

Figure 27: Results of emission measurements at various speeds for the 4-stroke 25km/h moped

In all cases the fuel consumption increases if the moped almost reaches maximum configuration speed. If the speed increases from 90% to 100% of the maximum configuration speed, fuel consumption increases by 1,27 times for the standard 45 km/h version to almost 2 times for the standard 25 km/h version. So, driving at maximum configuration speed increases the fuel consumption dramatically due to the applied speed limiters.

Also the fuel consumption between the various types tested varies at the same speed driven. For the standard 25 km/h version the fuel consumption at 27 km/h is 2,6 times higher than the fuel consumption of the standard 45 km/h version at the same speed due to the applied speed limiters.

In Figure 28 a graph of the fuel consumption visualizes the increase in fuel consumption for various configurations of mopeds. As a result of the engine speed limiter the fuel consumption at full speed is 1,75 times higher than with the 45 km/h engine speed limiter at the same speed. An increase of 1,3 to 1,5 times (depending on engine speed) in fuel consumption is measured as a result of the variomatic limiter (at the same vehicle speed).

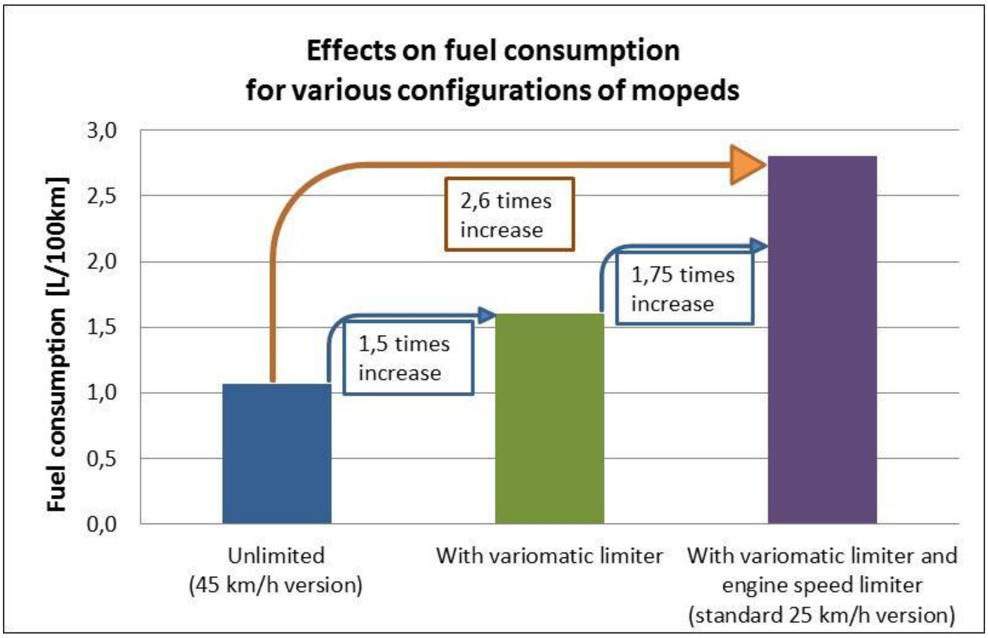

Figure 28: Visualization of the increase in fuel consumption for various configurations of mopeds

5 Conclusions

In the upcoming paragraphs the conclusions are discussed for each research question.

5.1 Compliance of the mopeds with the current EU emission limits and improvement of the emissions by replacing components

The standard moped versions tested did not comply with the current European limits. Both the standard 4-stroke moped versions (25 and 45 km/h version) had high CO emissions, exceeding the limit by more than 18 times. The 2-stroke moped had especially high HC emissions exceeding the limit by 1,7 times. The importers and manufacturers helped with adjustments to decrease emissions, finally the 4-stroke moped complied with the limits. For the 2-stroke no results are available yet.

The in-use compliance test program is set up to notice vehicles that do not comply with the emission limits. The results are discussed with the Dutch type approval authority and manufacturers. The Dutch type approval authority can take further action by for example checking the conformity of production by testing other samp-les sold on the Dutch market. The manufacturers and the national type approval authority are responsible for compliance with the limits for mopeds on the European market.

No technical defects or abnormalities were found for the high emissions, with all technical specifications and functions checked thoroughly. Although it cannot be excluded that another technical problem might have caused the high CO emission.

The 4-stroke mopeds delivered by the importer (directly delivered from the OEM) did almost in all cases comply with the Euro 2 limits. Remarkably, all mopeds did not reach maximum speed in the first phase of the R47 cycle during warming up, possibly this is caused by a lean air-fuel mixture. One 45 km/h version of a moped only reached a maximum speed of 33 km/h during the complete cycle.

The standard 4-stroke moped tested again in this second test program did not meet the limits, even after several adjustments (smaller main jet and new fuel pump). The CO emission was reduced by more than 50% compared to the emissions at earlier measurements. Although CO emissions dropped significantly after warming up during a maximum constant speed cycle, a test on the R47 cycle with a hot start did not reduce CO emission enough to comply with the limits. Finally, only with the exhaust and carburettor of the 25 km/h version of the importers moped the CO emissions dropped enough to meet the limits. The high emissions were caused by a rich air-fuel mixture (carburettor configuration) and a catalyst which was not working for 100%.

For the 2-stroke moped no additional results were available upon the release of this report.

In other studies also mopeds were tested that apparently did not comply with the limits. AECC tested five mopeds, including one 4-stroke carburetted one that also showed very high CO emissions on the R47, although HC+NO_x was below the limits. PM was comparable, but a higher PN was detected (AECC 2011).

Although the catalysts can reduce emissions well, in practice they may break down easily and are probably not robust enough for practical circumstances.
For example, high temperatures of the exhaust gas can decrease the conversion rate and increase the light-off temperature over time (Rijkeboer 2002). Especially in the case of 2-stroke engines with oxidation catalyst, durability of the catalyst can be a relatively critical aspect. In a study performed by EMPA, four out of six almost brand new and original scooters tested failed the legislative test. It could not be excluded that some catalyst were defect before delivery (IPN 2004).

The mopeds tested did not comply with current EU emission limits. No technical defects could be found. The 4-stroke mopeds delivered by the importer met the limits. The earlier tested 4-stroke moped met the limits only after the fuel pump, the carburettor and the exhaust (with catalyst) were replaced.

5.2 Effects of tampering on emissions and fuel consumption

The effects of tampering on emissions proved to be different for the 2- and 4-stroke vehicle. The driving cycle influenced the effects. In all tested cycles both emissions and fuel consumption of the tested standard 4-stroke 45 km/h version were lower than the standard 4-stroke 25 km/h version.

During the official cycle (R47), the tampered 4-stroke moped versions had lower CO emissions than the standard configurations, HC+NO_x emissions are almost equal. The fuel consumption of the tampered versions was lower as well. On the other hand, during maximum allowed and configuration speed gaseous emissions were higher for the tampered versions. The fuel consumption was lower, like on the R47 cycle. An exception was the tampered 25 km/h version during maximum allowed speed with significantly lower CO emissions compared to the standard version.

The effect of removal of the speed limiter on emissions of the 2-stroke moped depends on the driving cycle. Tuning had a negative effect on emissions and fuel consumption regardless of the cycle. During the tests at maximum speeds the HC emissions of the versions with standard exhaust (with catalyst) were very low compared to the R47 test. This indicates the catalysts reduces HC emissions properly during maximum speeds due to the high temperature of the exhaust gas. The gaseous emissions of the 2-stroke at maximum allowed speed were lower in every aspect compared to the maximum configuration speed. The fuel consumption was reduced for the version without variomatic limiter, but rose with higher speeds.

The PM and PN of the tested 4-stroke moped versions were relatively low. The PM and PN of the tested 2-stroke were very high: PM was about 10 times higher than the 4-stroke moped, PN was approximately 2,5 times higher and both increased in the tampered versions. Probably PM consists mainly of unburned fuel and engine oil, which is expected for a 2-stroke engine. NO_x emissions were very low for both 4-stroke and 2-stroke.

Overall the 4-stroke moped performed better than the 2-stroke, with the exception of the CO emissions. The 4-stroke had lower fuel consumption and PM emissions.

For the faster configurations the standard 4-stroke also performed better on HC emissions. The 2-stroke moped can be tuned to higher speeds than the 4-stroke moped.

The question is what test cycle is most representative for real-world driving. What effects do really occur in practice? Compared to the official test cycle for passenger cars, the official R47 test cycle for mopeds represents real-world driving behaviour better. How often do mopeds drivers ride maximum allowed and configuration speed? Even if this was known, there would still be the question of how many mopeds are tampered in the total fleet and how does their driving behaviour differs from other moped drivers.

Since in the real world driving behaviour and moped configurations have a higher variation than passenger cars, it is hard to know the magnitude of the effects of tampering in practice.

Tampering has effects on emissions and fuel consumption of mopeds, but not necessarily adverse effects. Removal of the speed limiters lowered the fuel consumption of the mopeds, but with tuning it rose.

5.3 Moped emissions compared with emission factors of Euro 5 passenger cars

Both diesel and petrol Euro 5 passenger cars performed better under real-world conditions on CO and HC than the tested standard mopeds in the official test-cycle. The NO_x emissions of all the tested standard mopeds were about four times lower than those of a diesel passenger car and approximately equal to the emissions of a petrol passenger car. The 2-stroke moped emits more than 4 times the amount of PM the diesel passenger car produces. Like mentioned above, it is hard to estimate the effects in the real-world, since the occurrence of mopeds is not well known.

PM emissions of 2-stroke mopeds are substantially higher than PM emissions of 4-stroke mopeds

5.4 Moped emissions compared with current moped emission factors

The measurements showed that the tested 4-stroke mopeds emit more CO than the emission factor indicates, although measured HC, NO_x and PM are lower. The 2-stroke measurements correlate good with the emission factors for CO and HC, but less NO_x and PM was emitted by the measured mopeds than the emission factors indicate.

The emission factors represent both 2- and 4-stroke mopeds; they are made for the entire Dutch fleet (Dröge et al 2011). Differences between individual measurements and emission factors are obvious and no reason to alter the emission factors immediately. One reason that the emission factors appear to represent the 2-stroke moped emissions better is that the Dutch fleet consist of mainly 2-stroke mopeds.

The currently used emission factors for mopeds are based on several studies testing moped emissions (Dröge et al 2011). The effects of tampering are not included in the emission factors. Even if the effects of tampering on individual mopeds is known, it is hard to include them in the emission factors, since little information is available about the amount of tampered mopeds and their driving behaviour. Maybe the measurements of the effects of tampering on safety, environment and noise performed at JRC at this moment will give more indications of the effect of tampering (TRL 2011). The aim of the TRL study is to identify measures which can be implemented at type approval to reduce or prevent ‘harmful tampering’ to the drivetrain of two-wheelers.

There is no reason to revise the current moped emission factors based on these measurements.

5.5 Comparison of the results for the Euro 2 test cycle with the results for the future Euro 3 test cycle

Both mopeds also did not comply with the future Euro 3 limits. These limits are the same, but the test procedure include the measurements during the cold start period.

For the 4-stroke moped the results of the Euro 2 tests compared to Euro 3 tests did not differ much in all aspects. For the 2-stroke there was a very large influence of the cold start during the Euro 3 test on total emissions. The gaseous emissions of the Euro 3 tests were a factor 2 higher compared to the Euro 2 tests for the configurations with catalyst. The PM emissions were a factor 3 higher. There was almost no effect on fuel consumption.

Similar results were found in literature. Several studies report higher emissions for mopeds during cold start. (Adam et al, 2010) found that HC emissions were four times higher and CO and PM two times higher during cold start. Czerwinski reported a doubling of CO and HC emissions in the first 1,5 min after the start and also higher PM emissions (Czerwinski et al, 2002).

For 2-stroke mopeds the cold start and warm up phase of the engines contributes significantly to the total emissions and should be taken into consideration in emission calculations from traffic since frequent cold starts are common in typical moped use patterns. The difficulty is establishing the amount of cold starts in driving in the real world.

The Euro 2 mopeds did not comply with the Euro 3 limits. It will be much harder for a 2-stroke moped to comply with the Euro 3 limits than for the 4-stroke moped.

5.6 Influence of speed limiters on fuel consumption

In the first test program was shown that the fuel consumption for both the tested 4-stroke and 2-stroke moped was much lower for the unrestricted versions, especially for the 4 stroke moped. The fuel consumption decreased significantly at faster configurations. The cause was found in the engine speed limiter (a change in the ignition timing reduced the engine efficiency) and the variomatic limiter (led to relatively high engine speeds at a low vehicle speed). The engine was operated inefficiently and this lead to an increase of the fuel consumption.

In the second test program the 4-stroke (25 km/h version) moped delivered by the importer was tested in various configurations and at various speeds to investigate the effects on fuel consumption. Driving at maximum configuration speed increased the fuel consumption dramatically. The difference between the fuel consumption at 90% and at 100% of the maximum speed was higher for the standard 25 km/h version than for the standard 45 km/h version.

Driving a moped without speed limiters at maximum allowed speed (25km/h) was the most fuel efficient. The tampered 25 km/h version was 3,5 times more fuel efficient than the standard 25 km/h version. The use of this kind of speed limiters increases fuel consumption.

At the moment no testing regulations for this are prescribed in the Directive. To test whether a fuel consumption increase is provoked by the speed limiter, a fuel consumption test at 90% and 100% of maximum speed can be performed. If the increase between these two is higher than a certain percentage, than the speed limiter is not suitable.

It should be considered to stimulate a different method of speed limiting for mopeds. The methods used to limit mopeds now, increases the fuel consumption notably. There are more elegant methods of limiting the maximum speed of mopeds, for example regulating the amount of injected fuel. To find out what the best methods are, effects on emissions and fuel consumption should be monitored for various methods.

The use of speed limiters increases the fuel consumption of mopeds.

6 Literature

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7 Signature

Delft, March 11, 2013

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A 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, 4 and 5 emission limits for mopeds have been agreed by Council and Parliament and will come into force from 2014 onwards. In Table 17 the consecutive standards are presented:

Table 17: 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**	**PM mg/km**
Euro 1 (17/6/1999)	Mopeds	6000	-	-	3000	-
Euro 2 (17/6/2002)	Mopeds	1000	-	-	1200	-
Euro 3 (1/1/2014)	Two-wheel moped (max 45km/h)	1000[3]	-	-	1200[9]	-
Euro 4 (1/1/2017)	Two-wheel moped (max 45km/h)	1000	630	170	-	-
Euro 5 (1/1/2020)	Two-wheel moped (max 45km/h)	1000	100	60	-	4.5

[9] 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.

B Current emission factors for mopeds used by the Emissieregistratie (Pollutant Release and Transfer Register, PRTR)

Table 18: Emission factors for mopeds for both urban and rural road types in g/km

Euro stage	HC	CO	NO_x	PM
0	13,9	13,8	0,02	0,19
1	2,7	5,6	0,02	0,08
2	1,6	1,3	0,26	0,04
3	1,2	1,0	0,26	0,01

Source: Dröge 2011