Tailpipe emissions of Euro 5 mopeds

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Summary

The ubiquitous Euro 2 mopeds have been the primary subject of TNO's emissions measurement studies in the past. In general, the pollutant emissions of the previously tested Euro 2 and Euro 3 mopeds substantially exceed the emissions of modern petrol passenger cars. Currently, the share of Euro 4 and Euro 5 mopeds on the Dutch market are growing (Euro 3 was hardly sold in the Netherlands). It is necessary to understand the emission performance of these modern mopeds and to compare them to the well-documented Euro 2 mopeds.

The aim of this research was to determine emission performance of Euro 5 mopeds with a variety of characteristics. The impact of cold start emissions on emissions was investigated as well. This research was carried out on behalf of the Dutch Ministry of Infrastructure and Water Management.

Four in-use Euro 5 mopeds were selected for the testing program. The selected mopeds are representative for the Dutch moped fleet. The moped characteristics varied in maximum vehicle speed (25 and 45 km/h), mileage, price range, brand and type. The tests were performed with in-use mopeds, with a mileage between 350 and 6.000 km. The mopeds were all subjected to two tests on a chassis dynamometer. Including the legislative test cycle (WMTC) for Euro 5 mopeds, and the former legislative test cycle (ECE-R47).

Emission results

Overall, the measured Euro 5 mopeds show substantially lower pollutant emissions compared to the earlier tested Euro 2 and Euro 3 mopeds. For example, the worst performing Euro 5 moped still has lower THC (Total Hydrocarbons) emissions than any earlier measured moped. In particular, the THC, CO (Carbon monoxide), NO_x (Nitrogen Oxides) and PN (Particle Number) emissions are significantly reduced. When comparing Euro 5 mopeds with 4-stroke engines to Euro 2 mopeds with 2-stroke engines, the Euro 5 mopeds exhibit THC and PN emissions that are, on average, more than 30 times lower. When comparing 4-stroke Euro 5 mopeds to 4-stroke Euro 2/3 mopeds, the THC emissions of the Euro 5 mopeds are on average six times lower, the NO_x emissions 10 times lower and the CO emissions seven times lower. Most of the tested Euro 5 mopeds demonstrate NO_x and THC emission levels which are in the same order of magnitude as emissions from modern passenger cars (THC of mopeds are slightly higher). However, individual moped models can still vary significantly in their emission performance. As the measurement campaign was limited to four mopeds, it is likely that this variation is larger than observed during this study.

Cold start emissions

This study also investigated the effect of a cold start on emissions. A cold catalyst does not convert pollutants, so with warm-up one expects to see a decrease in pollutants with a well-functioning catalyst. In this study, three out of four mopeds show substantially decreased CO, THC and NO_x emissions after warm-up. One moped showed a limited decrease, indicating a poor functionality of the applied emission control devices.

The dominant source of emissions for Euro 5 mopeds is the cold start, with up to 90% of the total trip (900 seconds) emissions during the first 100 seconds.

Emission factors

Emission factors are values which are representative for the emission performance of specific vehicle types in certain conditions, for example, an Euro 5 moped during urban driving. Based on the measurement results, the current emission factors for Euro 5 mopeds are in line with the worst performing moped. The other three measured Euro 5 mopeds perform substantially better. The average of the four mopeds would lead to roughly to 50% of the current emission factor values for CO, THC and NO_x. For PM the average level is comparable.

Lifetime emissions

The moped with the highest mileage showed the highest result, while the moped only had driven 6.000 km. The vehicle with the lowest mileage showed in general the lowest emissions. As this measurement campaign only involves four Euro 5 mopeds, it is not possible to draw a conclusion on the impact of mileage. It must be noted that, the legislative durability demands for Euro 5 mopeds are not stringent. Therefore, there is a risk that emissions levels will rise at a higher mileage, with deterioration of engine and catalyst. When Euro 5 mopeds are more common in the fleet, it is recommended to measure the emission performance of moped with a higher mileage.

Contents

1 Introduction

1.1 Background

Road-traffic emissions play a significant role in the degradation of air quality, particularly in urban areas where they impact the quality of human living spaces. Many residents, especially those living in metropolitan areas in the Netherlands, express concerns about issues such as driving behaviour, noise, and the odour emanating from mopeds [1]. While mopeds account for a relatively small portion of total road transport activity, they contribute approximately 8% to hydrocarbon (HC) emissions [2]. Furthermore, in certain specific areas, local emissions from mopeds can be substantial, potentially negatively affecting public health [3] & [4].

Emission standards for new mopeds have been in effect since the mid-1999s, as outlined in Directive 97/24/EC. This directive initially introduced the Euro 1 standard, which was subsequently tightened twice with the introduction of the Euro 2 (2002) and Euro 3 (2014) standards for mopeds. The emission regulations were comprehensively updated for the entire L-category, as detailed in Regulation (EU) 168/2013 and Delegated Regulation (EU) 134/2014. These revised regulations established Euro 4 emission limits and procedures, which became effective in 2017, and Euro 5 limits, which took effect in 2020.

While the most common Euro 2 mopeds have been the primary subject of TNO's emissions measurement studies in the past, the share of Euro 4 and Euro 5 mopeds on the Dutch market are growing (Euro 3 was hardly sold in the Netherlands). It is necessary to understand the emission performance of these modern mopeds and to compare them to the well-documented Euro 2 mopeds. This research was carried out on behalf of the Dutch Ministry of Infrastructure and Water Management.

1.2 Aim and approach

The aim of this research is to determine moped emissions performance of Euro 5 mopeds with a variety of characteristics. The results of this study must provide insights into the emission performance of Euro 5 mopeds. The following regulated emissions were measured: CO (carbon monoxide), HC (hydrocarbons) and NO_x (nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number) were measured. The results are input for moped emission factors.

Four Euro 5 mopeds were selected for the testing program. The selected mopeds are representative for the Dutch moped fleet. The moped characteristics varied in maximum vehicle speed (25 and 45 km/h), mileage, price range, brand and type. The mopeds were all subjected to two tests on a chassis dynamometer.

The testing program was designed in such a way that the effects of the following aspects on emissions could be assessed:

- Cold start;
- 25 km/h versus 45 km/h construction speed;
- Impact of vehicle speed limiter.

1.3 Structure of the report

In Chapter 2 earlier measurement results are explained. In Chapter 3 the method of the test program is described. Also, the test cycle and vehicle selection are explained. Chapter 4 gives an overview and analysis of the test results. Moreover, the cold start emissions are described well as the current official Dutch emissions factors which are related to the measurement results collected in this study. In Chapter 5 the conclusion of this study is presented.

2 Summary of previous results

In this chapter a concise summary is presented of earlier performed emission measurements. Beginning with the results of the measurement campaign of 2013, followed by the results of a more extensive measurement campaign in 2017. More details on these studies can be found in report [5] and [6]. This report begins with this summary to provide an overview of the emission performance of earlier tested Euro 2/3 mopeds, and to place the new results in context. The last time before 2013 TNO has investigated powered two-wheelers was in 2003, with impact assessment of Euro-3 legislation under development.

<u>2013 measurement campaign</u>

During the 2013 measurement campaign, emissions and fuel consumption were assessed for both standard and tampered versions of a 2-stroke and a 4-stroke moped, both were classified as Euro 2 mopeds. The primary testing regime employed was the ECE-R47 test cycle, which served as the legislative test cycle for Euro 2 (and Euro 3) mopeds. The speed profile of this cycle is depicted in Figure 4 in Chapter 3. This campaign encompassed the measurement of both regulated emissions (CO, NO_x and HC) and, at that time, unregulated emissions (CO_2, PM and PN).

The tested 4-stroke moped exceeded the EU emission limits by far, especially for the CO emissions (exceeding 20 g/km compared to an emission limit of 1 g/km). No technical defect or abnormalities were identified. Compliance with the limits was only achieved after replacing the fuel pump, the carburetor and the exhaust (with catalyst). The 2-stroke moped also fell short of compliance due to elevated HC emissions (exceeding 2 g/km).

Impact of speed limiters

The 4-stroke and 2-stroke mopeds were also subjected to modifications to assess the influence of tampering on emissions and fuel consumption. One of the most notable findings was the adverse effect of the applied speed limiters, designed to restrict the moped's speed to 25 or 45 km/h. Commonly applied speed limiters for Euro 2 (4-stroke) mopeds are 'engine speed limiters' (often applied for vehicles which use a carburetor for the fuel supply) and 'variomatic limiters' (transmission ratio limiters). Both types of speed limiters showed a negative effect on the fuel efficiency. The 'engine speed limiter' caused the largest negative effect in that study. The engine speed limiter delays the ignition timing for the combustion to restrict the engine speed. By doing so, the combustion is incomplete which leads to a reduction in engine power, resulting in a high fuel consumption. By driving only just below the limited speed of the vehicle, the negative effect of the engine speed limiter reduced, even to zero. Figure 1 below visualizes the increase in fuel consumption for various configurations of the tested 4-stroke moped.

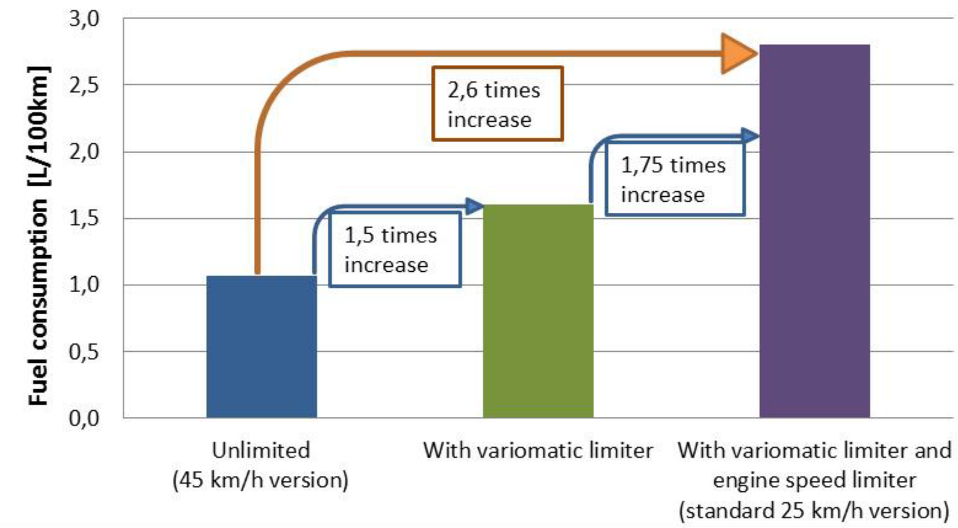

Figure 1: Visualization of the increase in fuel consumption for various configurations of mopeds

2017 Measurement campaign

In the program of 2017, the mopeds were driven twice over a full ECE-R47 cycle. Out of the fifteen tested mopeds, only 1 vehicle showed compliance to the Euro 2 emission limits, the 14 others exceeded the CO and/or HC+NO_x emission limits. It is important to note that these were in-use vehicles, and certain aspects deviated from the official test procedure.

Table 1 shows the average results for CO, THC, NO_x, CO_2, PM and PN emissions. Although PN and PM emissions are not regulated for Euro 2 and Euro 3 mopeds, particle emissions were investigated in this program as well, given their health impact. This table clearly shows that the results per emission constituent varied significantly per moped. This was not only the case for the pollutant emissions, but for the CO_2 emissions as well. In general, it was shown that 2-stroke mopeds had significant higher PM and HC emissions compared to 4-stroke mopeds. Mopeds with an electronic fuel injection system had lower CO, THC and PN emissions than the mopeds with a carburetor. On the contrary, the level of NO_x emissions for the 4-stroke mopeds with electronic fuel injection, especially the Euro 3 variants, were significantly higher than the other mopeds.

Most of the tested mopeds had a poor functionality of the applied catalyst. The mopeds equipped with electronic fuel injection showed a proper functioning catalyst. Moreover, the negative effects on fuel consumption due to the speed limiters, as described in the 2013 measurement campaign, were also shown in this study.

The pollutant emissions of these tested mopeds commonly exceed the emissions of modern petrol passenger cars, except for NO_x and CO_2. Given these high emission levels, and considering the high number of Euro 2 mopeds in the Netherlands and their significant presence in the current moped fleet [2], mopeds are a relevant source for air quality.

Table 1: Average results of two R47 tests.

Engine type	Speed	Euro Class	Vehicle ID	Make / type	CO	THC	NO_x	PM	PN	CO_2	Fuel con-sumption
	km/h		*#*	-	*g/km*	*g/km*	*g/km*	*mg/km*	*#/km*	*g/km*	*L/100 km*
2-stroke	25 km/h	Euro 2	1	Peugeot Fox	4.11	3.95	0.04	242,5	1.48E+13	25.24	1,87
			2	Tomos Quadro	10.46	4.82	0.01	86,6	1.20E+13	18.71	2,14
	45 km/h		3	Yamaha Aerox	15.32	3.48	0.01	57,1	3.38E+13	58.24	3,95
			4	Kymco Agility	6.96	10.11	0.22	261,9	4.66E+13	33.41	3,24
4-stroke	25 km/h		5	Piaggio Vespa	7.49	2.04	0.10	6,3	3.87E+12	61.38	3,37
			6	Kymco Agility	10.59	0.52	0.06	4,0	3.10E+12	45.15	2,69
	45 km/h		7	Piaggio Zip	4.66	0.86	0.22	2,9	3.06E+12	39.64	2,10
			8	Piaggio Zip	6.34	0.90	0.13	12,9	4.19E+12	36.75	2,10
			9	La Souris	13.04	1.19	0.15	4,6	3.42E+12	35.79	2,54
			10	Peugeot Vivacity	20.32	1.55	0.08	9,0	2.93E+12	36.74	3,12
			11	Honda NSC*	0.44	0.36	0.26	1,9	1.00E+12	41.83	1,85
			12	Baotian Rebel	8.33	0.64	0.19	10,1	5.90E+12	35.19	2,13
		Euro 3	13	Piaggio Liberty*	1.81	0.92	0.32	5,9	2.62E+12	43.90	2,10
			14	Piaggio Liberty*	2.02	1.14	0.42	7,8	1.55E+12	45.53	2,22
			15	Piaggio Liberty*	2.05	1.02	0.35	5,5	2.87E+12	43.01	2,10

* Mopeds with electronic fuel injection systems instead of carburettor.

3 Method

In this chapter the selection criteria for the Euro 5 mopeds are explained and an overview of the selected vehicles is presented. Furthermore, the measurement protocol and program are explained.

3.1 Tested vehicles

In this 2023 study the aim was to set up a testing program with a variety of Euro 5 mopeds.

Therefore, the moped selection is based on:

- Representativeness for the Dutch moped fleet (make / model / Euro class).
- 25 km/h versus 45 km/h construction speed;
- 4-stroke engines with electronic fuel injection;
- Mileage: new and used;
- Budget and higher segment mopeds.

Four Euro 5 mopeds are selected for the testing program. The selected mopeds are representative for the Dutch moped fleet, i.e., these mopeds are registered frequently in the Netherlands. The moped characteristics varied in maximum vehicle speed (25 and 45 km/h), mileage, price class, brand and type. In contrast to the earlier tested Euro 2 mopeds, all tested Euro 5 mopeds are equipped with an electronic fuel injection system instead of the conventional carburetor. This makes it possible to have a well-functioning aftertreatment system, and to apply an efficient way of speed limitation.

Before the start of the program, the condition of all vehicles was inspected by official dealers. According to the moped dealers, the original anti-pollution components in the exhaust system of these vehicles were still present and the speed limiters were not removed. In addition, the lambda value (air–fuel equivalence ratio) was checked during an idling test, during the test the lambda value was around 1, i.e., stoichiometric, as it should be.

One of the vehicles (AGM), initially had a maximum construction speed of 25 km/h, which was changed to 45 km/h by the dealer. This requires only the adjustment of the settings in the Electronic Control Unit (ECU), without making any hardware changes. Such adjustments in the ECU settings, from 25 to 45 km/h, have become quite common in the Netherlands. This is because, as of 2023, wearing a helmet has become mandatory for 25 km/h mopeds, while this was already mandatory for 45 km/h.

At the start of the program all mopeds had driven at least 350 km before the emission tests were performed. Mopeds with a higher mileage could not be found, however, as Euro 5 mopeds are relatively new in the fleet, it was not possible to find Euro 5 mopeds with a high mileage.

The details of the selected mopeds are shown in Table 2.

Table 2 : Moped selection for this test program.

Engine type	Construction speed	Euro class	Make / type	Odometer	Year of production	Power	Empty mass
-	*[km/h]*	-	-	*[km]*	*[yyyy]*	*[kW]*	*[kg]*
4-stroke	25 km/h	Euro 5	Piaggio Vespa Primavera 50	352	2021	1.5	108
	45 km/h		Peugeot Kisbee	1427	2022	2.6	90
			AGM VX50	3852	2022	1.9	86
			La Souris Sourini S	5837	2021	1.9	89

Figure 2: Pictures of the tested Euro 5 mopeds, clockwise: Peugeot Kisbee, Piaggio Vespa Primavera, AGM VX50, La Souris Sourini S

3.2 Test program

All four mopeds underwent two tests on a chassis dynamometer. Both the Worldwide Harmonized Motorcycle Test Cycle (WMTC) and the R47 were applied as driving cycles. As stated in Regulation (EU) No 168/2013, the WMTC is applied during the type approval process for Euro 5 mopeds, whereas the R47 served as the official cycle up to Euro 4. Emissions were collected per sub cycle, e.g., cold part and warm part, so different phases of the test could be evaluated separately.

WMTC
Different versions of the WMTC are utilized for different vehicle categories. According to Annex II, Appendix 6, of Regulation (EU) No 134/2014, the WMTC (Stage 3) driving cycle at the Euro 5 stage applies to (amongst others) mopeds with a maximum vehicle speed of 25 and 45 km/h. The speed profile of the cycle is truncated to 25 km/h for vehicles with a maximum construction speed of 25 km/h. Figure 3 below shows the speed trace of the applicable WMTC.

Officially, the WMTC is required to be conducted with a cold engine start. However, in this study, only one of the two tests could be performed with a cold engine start. This choice was necessary as a second cold start test for each vehicle would have extended the testing time significantly, as the vehicle should be cooled down between the tests. This would exceed the available project resources. As a result, the decision was made to initiate the R47 test with a cold engine start, while the WMTC was conducted with a warm engine start. The R47 was chosen for the cold engine start as it starts directly with a wide-open throttle acceleration, followed by a part of maximum speed driving. It is expected that this is the most challenging condition for the emission performance, and representative for real-world driving at the same time. As the WMTC was driven with a warm engine start, the WMTC is not driven in complete accordance with the legislative requirements. Nevertheless, the emission results of the WMTC test are used to make a comparison with the official emission limits as shown in Table 3. These emission limits are meant for pollutant emissions, not for CO_2.

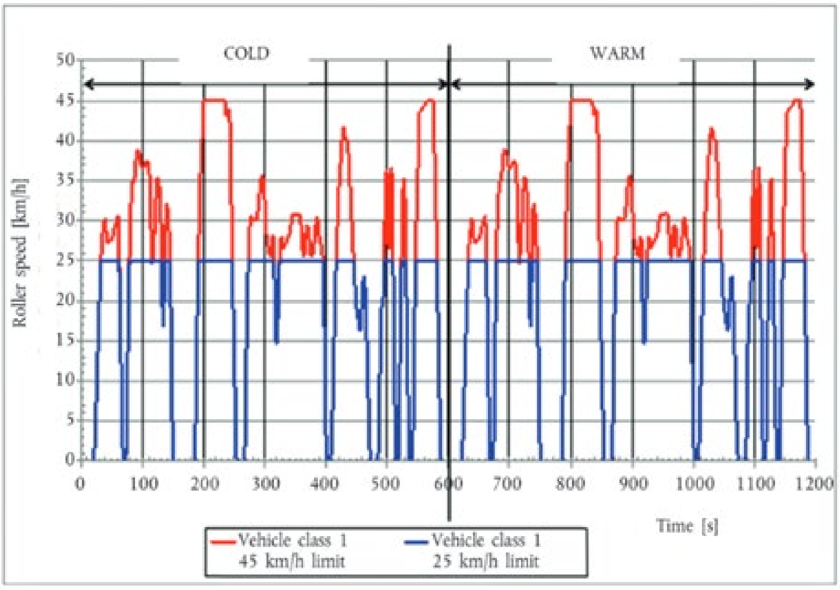

Figure 3: Vehicle speed time series of the WMTC cycle, the cold and warm phase are identical.

Table 3 : Emission limits L-category vehicles relative to M1 vehicles.

Stage	Category	Date	CO [mg/km]	HC [mg/km]	NO_x [mg/km]	PM [mg/km]	PN [#/km]
Euro 5	Complete L-category	2020	PI[1]: 1.000 CI[2]: 500	PI/CI: 100	PI: 60 CI: 90	PI*/CI: 4,5	-
Euro 6	Passenger cars	2014	PI: 1.000 CI: 500	PI: 100	PI: 60 CI: 80	PI*/CI: 4,5	PI/CI: 6,0*E11

* Direct injection

ECE-R47 test cycle

Earlier performed measurement of Euro 2 mopeds showed that driving a moped at maximum construction speed with wide open throttle may lead to elevated emissions and significantly increased fuel consumption. As described in Chapter 2, this was caused by the installed speed limiters. This was found to be the case for mopeds with a carburetor, but it is not clear what the impact is for mopeds with electronic fuel injection. Moreover, in general it was found that wide open throttle accelerations (next to wide open throttle at maximum speed) led to elevated emissions.

In real-world circumstances, with the limited engine power of mopeds, operating mopeds at wide open throttle is quite common. Figure 4 illustrates that the WMTC includes minimal driving at maximum configuration speed for mopeds. Furthermore, the WMTC does not explicitly prescribe wide open throttle operation and includes it only if the vehicle requires it to match the speed profile. In contrast, the R47 test cycle incorporates multiple instances of wide-open throttle accelerations and driving at maximum speed. This is considered to be reasonably representative simulation of urban moped driving.

Therefore, it was decided to conduct tests using the ECE-R47 test cycle. This test cycle comprises eight repetitions of the same elementary cycle, each of which consists of seven phases. The test was started with a cold engine. The cold engine in combination with wide open throttle operation is included to assess the emission performance during such a challenging condition.

[1] PI: Positive Ignition, mainly gasoline engines.
[2] CI: Compression Ignition, mainly diesel engines.

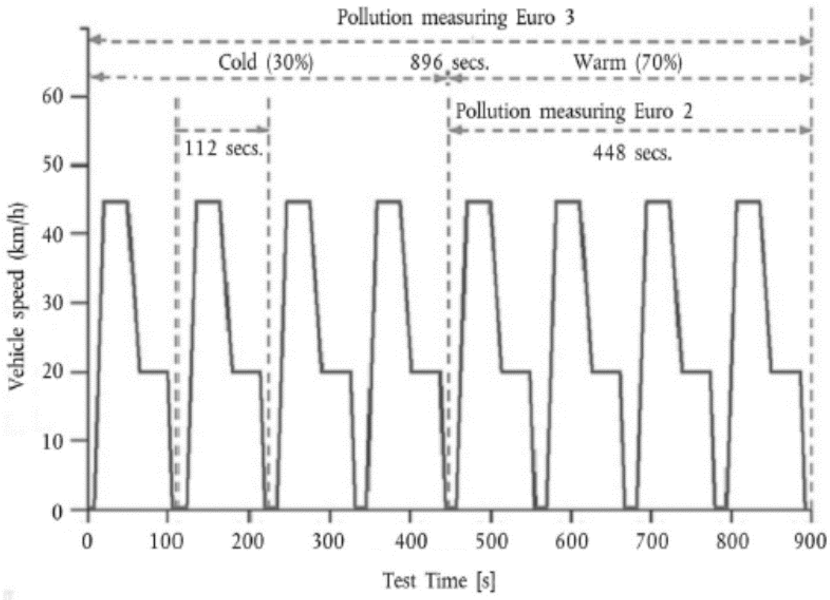

Figure 4: ECE-R47 test cycle from Directive 97/24/EC

Specific instructions
To examine the impact of a cold engine start on emissions and the effect of driving at maximum speed with wide open throttle, the emission sampling process during the R47 was divided into three parts for each test. Additionally, certain segments of the test saw modifications to the official driver instructions as part of this measurement program. These adjustments were made to gather detailed information of the emission performance and fuel consumption during maximum speed driving. Evaluating the cold start performance also provides valuable insights into the catalyst's efficiency. The modified emission sampling and driver instructions are outlined in Table 4.

Table 4: Test programme

Emission sampling	ECE-R47		WMTC	
	Phase 1: cold	Phase 2: warm	Phase 1: warm	Phase 2: warm
	Sampling divided in two sub phases	Sampled as one phase	Sampled as one phase	Sampled as one phase
Driver instruction	Wide open throttle during accelerations and constant driving	Wide open throttle during accelerations and following speed trace during constant driving (without wide open throttle)	Follow speed trace	Follow speed trace

The tests are conducted with regular E10 market fuel from the Netherlands.

3.3 Data analyses

Similar to the official type approval procedure, exhaust gasses were collected in sampling bags for this study. Specifically, three bags were used for the R47 emission sampling and two for the WMTC, as detailed in Table 4. After the test, the concentrations of the components in the bags were analysed. The total emission of each component is calculated based on the measured concentrations, exhaust mass flow and driven distance. The final emission results, presented in grams per kilometre, represent an average of all bags per test. In addition, the second-by-second data is utilized for the analyses.

3.4 Emission measuring methods

All emission tests were performed on a chassis dynamometer at the University of Applied Sciences in Biel/Bienne (Switzerland). This laboratory is very experienced in measuring powered two-wheeler emissions. The laboratory is certified to perform official type approval tests according to the European emission regulations. The following regulated emissions were measured: CO (carbon monoxide), HC (hydrocarbons) and NO_x (nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number) were measured. Table 5 gives an overview of the measuring methods used in Biel/Bienne.

Table 5: Measuring methods

Emission component	Method
CO	NDIR (Non-Dispersive Infrared)
THC	H-FID (Hydrogen Flame Ionization Detector)
CH4	H-FID (Flame Ionization Detector)
NOx	CLD (Chemi-Luminescence Detector)
CO2	NDIR (Non-Dispersive Infrared)
PM	Gravimetric
PN	CPC (Condensation Particle Counter) with VPR (Volatile Particle Remover)

4 Results

In this chapter the emission measurement results of the four Euro 5 mopeds are presented.

4.1 Measurement results and a comparison to the type-approval standards

As stated above, in the program the mopeds were driven over an ECE-R47 cycle with a cold engine start and a WMTC with a warm engine start. Table 6 shows the average results for CO, THC, NO_x, PM, PN and CO_2 emissions, as well as the fuel consumption. Although PN emissions are not regulated for mopeds, these emissions are investigated in this program as well. In addition to Table 6, Figure 5 displays the emission results. The values in Table 6 and Figure 5 represent the average emission results of the complete test. In the next paragraphs the test results are described in a more detailed level.

A comparison with the emission limits (as shown in Table 3) is made as well[3]. According to the legislation, the emission limits may only be applied on the WMTC results for Euro 5 mopeds, because the R47 is not applied during type approval testing. Moreover, it should be noted that most of the vehicles were in-service, which is not the case for mopeds during type approval. Furthermore, some details in the test preparation deviated from the official type approval procedure. For example, the procedures for preconditioning and soaking of the vehicle was not in accordance with the official procedure, the WMTC started with a warm engine and market fuel was used rather than reference fuel.

Table 6 and Figure 5 clearly show that the results per emission constituent vary significantly per moped and per test. In general, the R47 – performed with cold engine start – shows higher emissions results than the WMTC. This is particularly true for the CO and THC emissions. This was also expected, as the catalyst only reduces emissions when the exhaust temperature is sufficient. Moreover, the PN emissions are clearly elevated during the R47 with cold engine start, with emission levels which are around or somewhat higher than Euro 6 emission limits for passenger cars. During the WMTC with a warm engine start, the PN emission levels are substantially lower in most cases. The NO_x emission levels are very low, comparable with modern passenger cars.

In comparison to the earlier measured Euro 2 and Euro 3 mopeds, which are described in chapter 2, most of the measured Euro 5 mopeds show substantially lower pollutant emissions. Especially the THC emissions are clearly lowered, the worst performing Euro 5 moped still has lower THC emissions than all earlier measured mopeds. When comparing 4-stroke Euro 2/3 mopeds to (4-stroke) Euro 5 mopeds, the THC emissions are on average six times lower (only comparing the R47 test). When compared to the 2-stroke mopeds (Euro 2), the Euro 5 mopeds show on average more than 30 times lower THC emissions. The same order of magnitude is true for the PN emissions. But also the CO and NO_x emissions are for most cases substantially lower.

[3] These emission limits are meant for pollutant emissions, not for CO_2.

For example, when comparing Euro 2/3 mopeds with a 4-stroke engine to the Euro 5 mopeds, the NO_x emission are on average 10 times lower, for CO emissions this is on average 7 times lower. Most of these tested Euro 5 mopeds show NO_x and THC emission levels which are in the same order of magnitude as modern passenger cars.

The Piaggio Vespa shows already very low results during the R47, with emission levels well below the legislative limits, these results are lowered further during the WMTC. On the other hand, the PN emissions are relatively high during the R47 with cold engine start. The fuel consumption and CO_2 emissions are quite high in comparison to the other mopeds. Possibly this is the result of the maximum speed of 25 km/h. The Peugeot Kisbee and the AGM VX50 showed THC emissions during the R47 test which are somewhat higher than the Euro 5 legislative emission limit of 100 mg/km. During the WMTC, all emissions are very low. The La Souris Sourini S showed the highest emission levels of these four Euro 5 mopeds. The emission levels for THC and CO exceeded the Euro 5 emission limits (100 mg/km and 1000 mg/km respectively), both during the R47 and the WMTC. This is remarkable, as the WMTC is driven with a warm engine/exhaust. In the next paragraph, this emission behaviour is shown in more detail.

For two of the four Euro 5 mopeds PM emission results are available, it is clear that the R47 with cold engine start leads to significant higher PM emissions than the WMTC with warm engine start. Moreover, the La Souris has the highest PM emissions of the two mopeds. The measurement value of 5,1 mg/km during the R47 slightly exceeds the emission limit of 4,5 mg/km. Compared to the earlier tested Euro 2 and Euro 3 mopeds, the Peugeot Kisbee has the lowest PM emissions measured, while the La Souris is comparable to other 4-stroke mopeds. The Euro 2 mopeds with 2-stroke engines had with emissions up to 240 mg/km substantially higher emissions.

Table 6: Emission results of the ECE-R47 with cold engine start and the WMTC with warm engine start. As a point of reference for these results; the legislative emission limits for Euro 5 (during the WMTC) are set at 1000 mg/km for CO, 100 mg/km for THC, 60 mg/km for NO_x, and 4.5 mg/km for PM. It's important to highlight that these tests were not conducted in full compliance with the legislative requirements.

Construction speed	Make / type	Test	CO	THC	NOx	PM	PN	CO_2	Fuel con-sumption
[km/h]	-	-	mg/km	mg/km	mg/km	mg/km	#/km	g/km	L/100 km
25	Piaggio Vespa Primavera 50	R47	356	68	9	-	1,0E+12	66	2,9
		WMTC	408	25	0	-	4,6E+10	65	2,8
45	Peugeot Kisbee	R47	719	143	7	1,8	6,1E+11	46	2,0
		WMTC	48	12	42	0,2	4,0E+10	45	1,9
	AGM VX50	R47	423	160	17	-	5,6E+11	48	2,1
		WMTC	238	27	4	-	3,1E+10	47	2,1
	La Souris Sourini S	R47	2411	286	55	5,1	1,2E+12	46	2,2
		WMTC	2834	168	17	1,1	5,3E+11	45	2,2

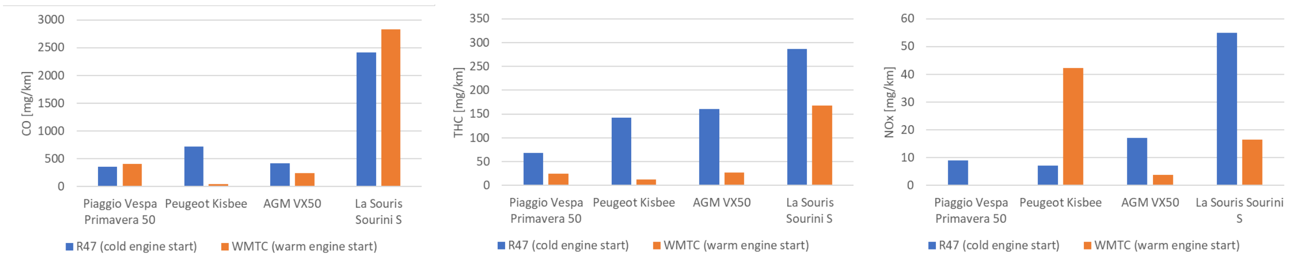

Figure 5: Emission results of the ECE-R47 with a cold engine start (blue bars) and the WMTC with a warm engine start (orange bars). The left graph shows the CO emissions, the middle one THC emissions and the right graph shows the NOx emissions.

4.2 Emissions during the different phases

Impact of cold engine start

In this test program, the ECE-R47 is divided in three phases per test. As described in chapter 3, the emissions are measured over each phase separately. To check if the emission control system is still functional, the emission results measured during the cold test phase were divided in two parts. If the catalyst is functioning well, the emissions should be decreased in the second part of the cold test phase.

Table 7 and Figure 6 below show the emission performance during these three phases. It is clear that for all mopeds, phase 1 – which is directly after the cold engine start – shows the highest CO, THC and NO_x emissions. Phase 2 and phase 3 show emission levels which are comparable to each other. The AGM, Peugeot and Piaggio show substantial lower emissions during phase 2 and 3 compared to phase 1. For example, the THC emissions are lowered with a factor of 13 to 22. This indicates a proper functioning catalyst. However, for the La Souris this reduction is limited to a factor of 3. In addition, the CO emissions are reduced with a factor of 2, while this is factor 4 to 6 for the other mopeds. Moreover, the emission levels in phase 1 of the La Souris are substantially higher in comparison with the other mopeds. This emission levels, and the lack of emission reduction shows that the catalyst is not functioning in an optimal way.

The La Souris had – with almost 6.000 km – the highest mileage of all mopeds. However, in the emission legislation, the lifetime mileage - which is relevant for the durability requirements - is 11.000 km. Moreover, in real-world circumstances, mileages are often exceeding 6.000 km.

Table 7: Emission results per phase.

Construction speed	Make / type	Phase	CO	THC	NO_x	CO_2	Fuel con-sumption
[km/h]	-		mg/km	mg/km	mg/km	g/km	L/100 km
25 km/h	Piaggio Vespa Primavera 50	1	728	242	35	65	2,9
		2	210	19	0	69	3
		3	246	9	1	65	2,8
45 km/h	Peugeot Kisbee	1	2232	526	14	45	2,2
		2	346	24	4	49	2,1
		3	156	13	5	44	1,9
	AGM VX50	1	893	560	52	48	2,2
		2	222	40	7	50	2,2
		3	296	27	5	48	2,1
	La Souris Sourini S	1	3796	670	175	44	2,2
		2	1932	200	16	48	2,2
		3	1972	141	16	46	2,1

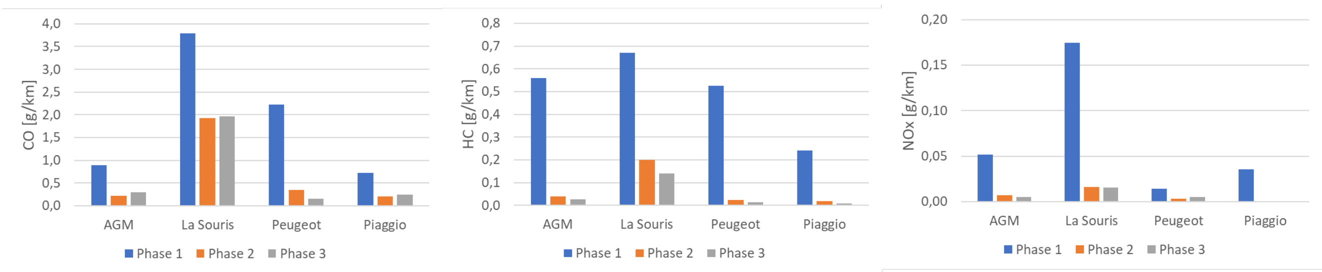

Figure 6: Emissions performance during a cold start in an unofficial ECE-R47 test cycle.

Figure 7 below, shows the HC emissions over time, of both the R47 with cold engine start as well as the WMTC with warm engine start. The colour of the line gives an indication of vehicle speed, where red is high speed, and blue is low speed. The pink line shows the cumulative emissions.

This figure shows that 80 to 90% of the HC emissions are emitted during the first 100 seconds for the AGM, Peugeot and Piaggio. At high-speed driving and accelerations there are still some elevated emissions, but the impact of a cold engine is dominant. The La Souris also shows a decrease in emissions after 200 seconds, but this effect is less dominant than for the other mopeds. Figure 7 shows only the HC emission results, however, there is a comparable trend for NO_x and CO. In addition, for PN emissions, there is a similar trend as well.

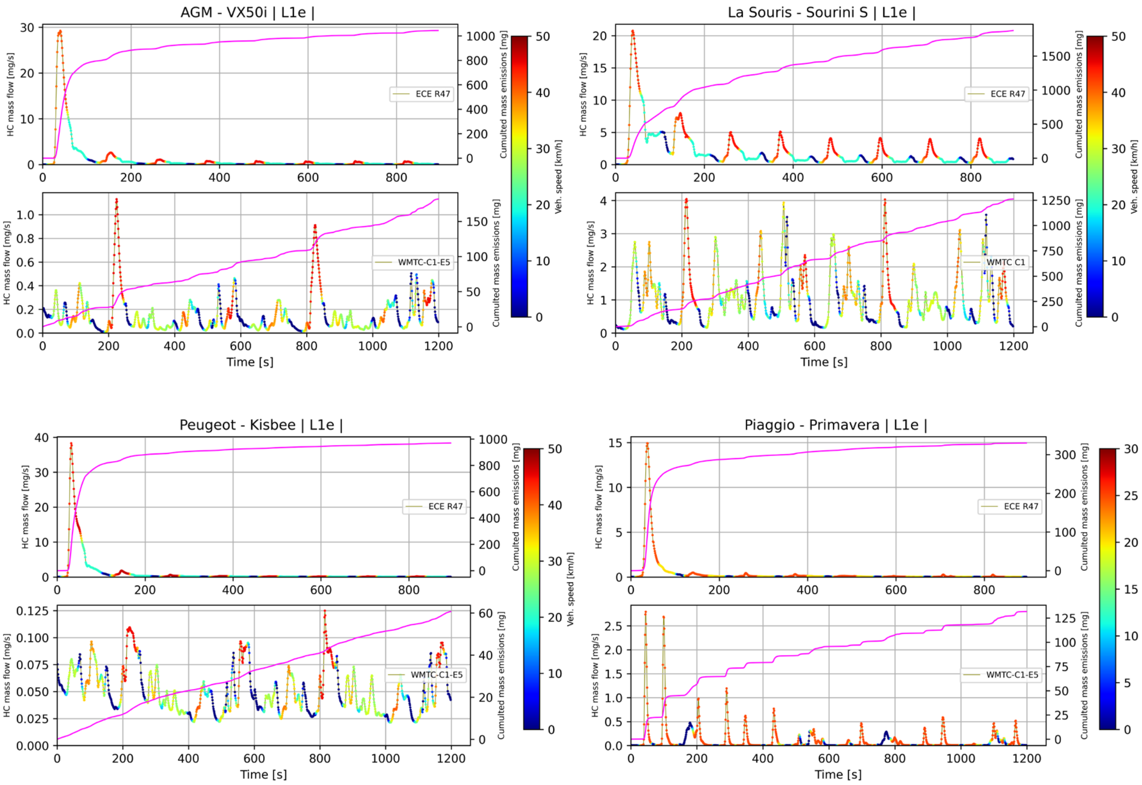

Figure 7: HC emissions during a time series, including cumulative emissions (pink line) for all four vehicles. Each figure consists of two graphs, the upper graph shows the R47 with cold engine start, while the lower graph shows the WMTC with warm engine start.

Impact of speed limiter

As mentioned in the description of the measurement programme in Chapter 3, the first half of the R47 test was driven with wide open throttle during the constant speeds, and not with wide open throttle in the second half of the test. The reason for such a test was to research possible adverse effects of the speed limiter. As described in chapter 2, many of the earlier tested mopeds showed substantial adverse effects on fuel consumption due the applied speed limiters.

For the tested Euro 5 mopeds in this study, there is no clear indication that the applied speed limiters have an adverse effect on fuel consumption. The fuel consumption was often lower in the second half of the test, but this is most likely related to the warm-up, and for some mopeds the difference in speed. It is expected that these Euro 5 mopeds are limited by injecting a delimited amount of fuel. For many of the earlier tested Euro 2 mopeds this was not possible, because they didn't have electronic fuel injection.

4.3 Comparison with current emission factors

Emission factors are values which are representative for the emission performance of specific vehicle types in certain conditions, for example, an Euro 5 moped during urban driving.

According to the national emission inventory, the emission factors for Euro 5 mopeds in urban driving are currently estimated at:

- CO: 2439 mg/km
- THC: 200 mg/km
- NO_x: 47 mg/km
- PM_{10}: 2 mg/km

Based on the current measurement results, the Euro 5 emission factors are in line with the worst performing moped. The other three measured Euro 5 mopeds perform substantially better. The average of the four mopeds would lead to roughly to 50% of the current emission factor values for CO, THC and NOx. For PM the average level is comparable.

5 Conclusions

In this study four Euro 5 mopeds were tested on a chassis dynamometer at the University of Applied Sciences in Biel/Bienne (Switzerland). The following regulated emissions were measured: CO (carbon monoxide), HC (hydrocarbons) and NOx (nitrogen oxides). Additionally, CO_2 (carbon dioxide), PM (particulate matter) and PN (particle number).

The aim of this research was to determine emission performance of Euro 5 mopeds with a variety of characteristics. The impact of cold start emissions on emissions was investigated as well. The tests were performed with in-use mopeds, with a mileage between 350 and 6.000 km. Both the R47 test cycle and the WMTC were used for this test programme.

Emission results

Overall, the measured Euro 5 mopeds show substantially lower pollutant emissions compared to the earlier tested Euro 2 and Euro 3 mopeds. For example, the worst performing Euro 5 moped still has lower THC emissions than all earlier measured mopeds. In particular, the THC, CO, NO_x and PN emissions are significantly reduced. When comparing Euro 5 mopeds with 4-stroke engines to Euro 2 mopeds with 2-stroke engines, the Euro 5 mopeds exhibit THC and PN emissions that are, on average, more than 30 times lower. When comparing 4-stroke Euro 2/3 mopeds to (4-stroke) Euro 5 mopeds, the THC emissions are on average 6 times lower, the NO_x emissions 10 times lower and the CO emissions 7 times lower. Most of the tested Euro 5 mopeds demonstrate NO_x and THC emissions levels which are in the same order of magnitude as emissions from modern passenger cars. However, individual moped models can still vary significantly in their emission performance. As the measurement campaign was limited to four mopeds, it is likely that this variation is larger than observed during this study.

Cold start emissions

This study also investigated the effect of a cold start on emissions. A cold catalyst does not convert pollutants, so during warm-up one expects to see a decrease in pollutants with a well-functioning catalyst. In this study, three out of four mopeds show substantially decreased CO, THC and NO_x emissions after warm-up. One moped showed a limited decrease, indicating a poor functionality of the applied emission control devices.

The cold start is the dominant factor for emissions of Euro 5 mopeds, with up to 90% of the total trip (900 seconds) emissions during the first 100 seconds.

Emission factors

Emission factors are values which are representative for the emission performance of specific vehicle types in certain conditions, for example, an Euro 5 moped during urban driving. Based on the measurement results, the current emission factors for Euro 5 mopeds are in line with the worst performing moped. The other three measured Euro 5 mopeds perform substantially better. The average of the four mopeds would lead to roughly to 50% of the current emission factor values for CO, THC and NOx. For PM the average level is comparable.

Lifetime emissions

The moped with the highest mileage showed the highest result, while the moped only had driven 6.000 km. The vehicle with the lowest mileage showed in general the lowest emissions. As this measurement campaign only involves four Euro 5 mopeds, it is not possible to draw a conclusion on the impact of mileage. It must be noted that, the legislative durability demands for Euro 5 mopeds are not stringent. Therefore, there is a risk that emissions levels will rise at a higher mileage, with deterioration of engine and catalyst. When Euro 5 mopeds are more common in the fleet, it is recommended to measure the emission performance of moped with a higher mileage.

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Signature

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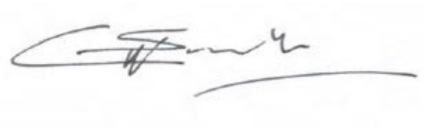

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