

Regulated and Non-Regulated Emissions of Selected State-of-the-Art European Mopeds

C. Favre¹, J. May¹, D. Bosteels¹, J. Tromayer², G. Neumann², R. Kirchberger², H. Eichlseder²

¹ AECC, Association for Emissions Control by Catalyst, 80 bld Auguste Reyers, 1030 Brussels, Belgium

² Institute for Internal Combustion Engines and Thermodynamics (IVT), Graz University of Technology, Graz, Austria

Abstract: A test program aiming at demonstrating state-of-the-art mopeds emissions performance was conducted, including emissions measurements of not only regulated emissions (HC, CO and NOx) but also particulate mass, particle number and non-regulated gaseous emissions.

Four commercially available test vehicles were selected to represent a large variety of technologies currently in operation on the street. One additional prototype moped, developed by IVT, was also included in the test program as it is representative of likely future engine technology.

In order to evaluate the influence of different driving patterns, the selected two-wheelers were not only operated on the current and proposed future UNECE R47 test cycles, but also on the reduced speed WMTC part 1 cycle, which is the closest match available for moped specifications. Beside currently regulated gaseous emissions, the emissions of particulate matter were also measured using a gravimetric measurement method combined with a particle counter to provide data on the mass of particulate and number of particles.

Keywords: Pollutant emissions, mopeds, European legislation.

1 Introduction

The European emission legislation for two-wheeler vehicles driven by engines of ≤ 50 cc is continuously developing. In October 2010, the European Commission published a proposal for a European Parliament and Council regulation on the approval and market surveillance of two- or three-wheel vehicles and quadricycles. This new legislative proposal [1] includes three new emissions stages for mopeds (Euro 3, 4 and 5). In that context, it became relevant to examine the emissions of current and likely future technologies.

A test program aiming at demonstrating state-of-the-art mopeds emissions performance was therefore conducted by the Association for Emissions Control by Catalyst (AECC) at the Institute for Internal Combustion Engines and Thermodynamics of Graz University of Technology (IVT). Emissions measurements not only included regulated emissions (HC, CO and NOx) but also particulate

mass, particle number and non-regulated gaseous emissions such as nitrogen dioxide and ammonia.

Exhaust emissions of state-of-the-art vehicles were measured without any modifications to the engines. Four commercially available test vehicles were selected to represent a large variety of technologies currently in operation on the street. One additional prototype moped, developed by IVT, was also included in the test program as it is representative of likely future engine technology. The European moped segment comprises low-cost and high-end technology solutions for engine control and exhaust gas aftertreatment. In this program, both two-stroke and four-stroke engines were evaluated.

In order to evaluate the influence of different driving patterns, the selected two-wheelers were not only operated on the current and proposed future UNECE R47 test cycles, but also on the reduced speed WMTC part 1 cycle, which is the closest match available for moped specifications. Beside currently regulated gaseous emissions, the emissions of particulate matter were also measured using a gravimetric measurement method combined with a particle counter to provide data on the mass of particulate and number of particles. Those measurements were conducted along the lines of the Particulate Measurement Program (PMP) procedures developed at UNECE for light-duty vehicles and heavy-duty engines. In addition, an FTIR measurement was included to provide data on the nitrogen speciation of the exhaust gas. With respect to the proposed Euro 3 legislation for mopeds which includes cold start emissions, bag sampling was divided in two parts on all test cycles, so that emissions results could be weighted with different factors. In addition, online recording of air/fuel-ratio, exhaust gas temperatures and cumulative emissions provided more insight. Eventually, particulate matter was analyzed with a Thermo Gravimetric Analyser (TGA) to identify the respective shares of elemental and organic carbon.

2 Emission legislation and test cycles

Directive 2002/51/EC of the European Parliament and the Council of the European Union was published in June 2002 to tighten emission

standards for two- and three-wheeled vehicles to the Euro 3 standard. However, at that time, moped emissions were not changed in the new Directive. To date, mopeds emissions are still covered by Directive 97/24/EC. However, in October 2010, the European Commission published a proposal for regulation on the approval and market surveillance of L-category vehicles (two- or three-wheeled vehicles and quadricycles) including three new emission stages for mopeds: Euro 3, 4 and 5 [1].

Mopeds emissions limits from Euro 1 to the proposed Euro 3, 4 and 5 are shown in Figure 1. Emissions limits for CO and HC + NO_x have drastically reduced from Euro 1 to Euro 2. They are proposed to stay the same for the cold-start Euro 3 and also at Euro 4 and 5 for CO. Proposed HC and NO_x limits are proposed to be separated and further reduced at Euro 4 and 5 stages.

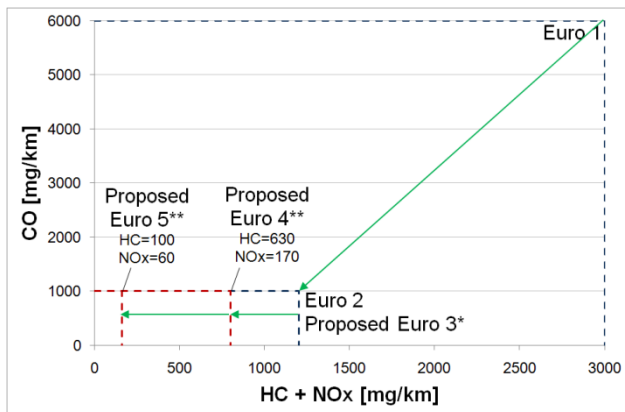


Figure 1: European emissions limits for 50 cc mopeds, including future proposed scenarios

* includes cold start

** includes cold start and separate HC and NO_x limits.

The mopeds test cycle speed trace from Euro 1 to the proposed Euro 3, 4 and 5 are shown in Figure 2. The UNECE R47 test cycle is the current legislative test cycle in Europe for L-category vehicles with engine capacities below 50 cc. It comprises 8 sub-cycles that contain sequential full load operation at maximum permitted speed and part load operation at 20 km/h. For Euro 1 and Euro 2 standards, emission sampling into bags starts after the 4th cycle, whereas the proposed Euro 3 standard includes cold start emissions. For Euro 3, it is proposed to start emissions sampling right from key-on (at 0 s).

For the measurement campaign, sampling started on all tests right from the beginning of the driving cycle. Emissions were then collected in two bags, one for the first 4 sub-cycles (cold phase) and a second one for the remaining 4 sub-cycles (hot phase). This provided information about the influence of cold start. A 30% weighting was applied to cold start emissions as this had been considered by the European Commission back in 2005 [2].

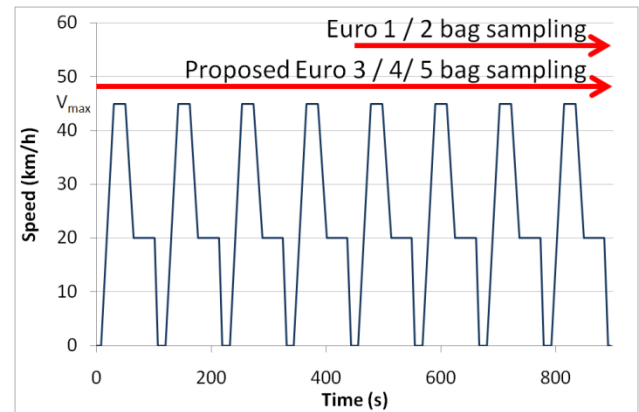


Figure 2: UNECE R47 speed profile

WMTC [3] is offered as an alternative legislative test cycle for type-approval of motorcycles with engine displacements bigger than 50 cc but the UNECE gtr n°2 does not contain a WMTC for mopeds with an engine displacement ≤ 50 cc and a maximum vehicle speed ≤ 45 km/h. However, the European Commission has proposed a 'revised WMTC' for Euro 5 mopeds. The closest match chosen for this test campaign was WMTC part 1 with reduced speed which applies to Class 1 motorcycles having an engine capacity between 50 and 150 cc and a maximum vehicle speed between 50 and 100 km/h. Figure 3 shows the speed profile of this test. Two repeats of the cycle were conducted, one in cold condition and a second one in hot condition. To facilitate WMTC cycle weighting, emissions were also collected in separate bags for the first and the second half of the test.

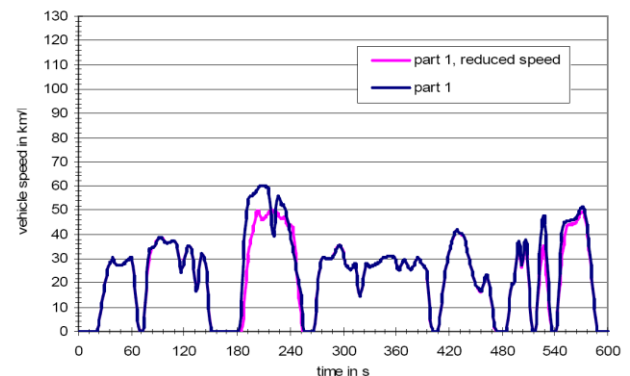


Figure 3: Speed profile of WMTC Part 1 with reduced speed

Weighting factors of 0.5 were attributed to each bag (cold cycle and hot cycle) as required in gtr n°2 for class 1 motorcycles, the closest match to mopeds.

Both test cycles, UNECE R47 and WMTC, were repeated three times for each of the five mopeds to ensure good repeatability of the results.

3 Mopeds selection

Test mopeds were chosen to be representative of the European market. To cover the full variety of technologies available on the market, two-stroke and

four-stroke engines, carburettor and fuel injection, oxidation catalysts and three-way catalyst applications were selected. Due to its higher power output the two-stroke engine is very popular in Europe, especially in the moped class. From the emission side, this engine has a “bad reputation” and was banned from some cities (e.g. in Tuscany, Italy). Within the last few years, sales of vehicles powered by four-stroke engines have grown as a result of the reduced impact perceived on air quality. Five different vehicles were tested as shown in Table 1.

Vehicle	Specifications	Mixture preparation	Exhaust system	Max. speed	Emission standard
A	4-stroke / 4-valve SOHC	EFI with λ -sensor	3-way catalyst	44 km/h restricted by leaning	Euro 2 ECE R47
	Power [kW] / [rpm] : 3 / 7500				
	Cooling : liquid				
	Reference mass [kg] : 85				
B	4-stroke / 2-valve SOHC	carburetor (constant depression)	1 catalyst secondary air	48 km/h restricted by ignition retarding	Euro 2 ECE R47
	Power [kW] / [rpm] : 2.88 / 8500				
	Cooling : fan				
	Reference mass [kg] : 111				
C	2-stroke	Low Pressure Direct Injection	1 catalyst	47 km/h restricted by leaning	Designed according to proposed Euro 3 standard ECE R47
	Power [kW] / [rpm] : 3.7 / 7200				
	Cooling : liquid				
	Reference mass [kg] : 95				
D	2-stroke	carburetor (slider)	1 catalyst secondary air	>50 km/h unrestricted	Euro 3 motorcycle regulation ECE R40
	Power [kW] / [rpm] : 2.3 / 6250				
	Cooling : fan				
	Reference mass [kg] : 103				
E	2-stroke	Air Supported Direct Injection	1 catalyst	42 km/h restricted by leaning	Euro 2 ECE R47
	Power [kW] / [rpm] : 4 / 7750				
	Cooling : liquid				
	Reference mass [kg] : 108				

Table 1: Specifications of mopeds selected

All vehicles were equipped with a Continuous Variable Transmission as this is the most popular moped type. This prevented any driver's influence on the emission tests resulting from gear shifting. Four vehicles were popular mass production vehicles and one was a pre-serial prototype. Mass production models included 2 two-stroke engines and 2 four-stroke engines. One of the two-stroke engines (B) and one of the four stroke engines (D) were equipped with a carburetor for mixture preparation and an oxidation catalyst with secondary air system for exhaust gas aftertreatment. They were both air-cooled. All other engines were water-cooled and equipped with a fuel injection system. The four-stroke engine with fuel injection (A) was equipped with a λ -sensor enabling the use of a 3-way catalyst. This engine was therefore the closest to common automotive technology. One of the mass production two-stroke engines (E) was equipped with a special direct injection system called Air-Supported Direct Injection using pre-compressed air being blown into the cylinder together with the fuel. Finally there was the prototype two-stroke engine (C) that had been developed by IVT. It was also water-cooled and using a Low Pressure Direct Injection (LPDI) system. Almost all vehicles were homologated according to the Euro 2 standard. Vehicle D, powered by a two-stroke engine with carburetor, was a Swiss model homologated for the Euro 3 motorcycle standard.

The prototype C (2S LPDI) had been developed to be homologated according to the proposed Euro 3 standard.

All mass production vehicles were procured new, directly from the retailers, as they are sold in Europe. They were first degreened on a dyno test bench for 250 km. Before the test campaign, the prototype C had already been operated for more than 2 000 km. Emissions tests were conducted after degreening without any modification to the engines or the vehicles except for the fitting of temperature sensors at the spark plug and at the exhaust system (before and after catalyst) and of a λ -sensor at the exhaust of the four stroke vehicles A and B.

4 Test equipment

All tests were conducted on a two-wheeler chassis dynamometer. The test cell was equipped with an open-type Constant Volume Sampling (CVS) system including a dilution tunnel for particle sampling as shown in Figure 4. The CVS was sucking exhaust gas and ambient air into a dilution tunnel without a separate dilution air inlet, so that the CVS inlet pipe was not closed around the exhaust and dilution air was not filtered. This was used to mitigate the effects of exhaust pressure changes on small engines and to allow measurement of emissions closer to real world emissions.

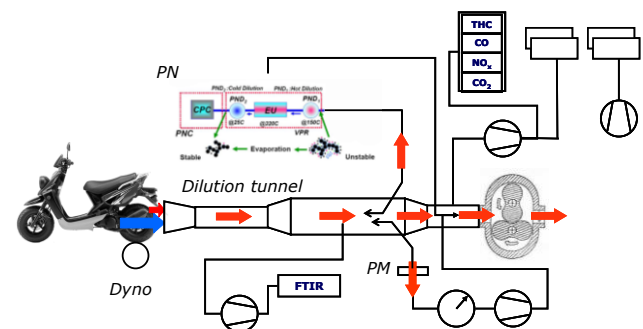


Figure 4: CVS system set-up

The constant volumetric flow was provided by a Roots blower. After the exhaust gas was diluted, it went to a gas analyzer for measurement of regulated gaseous components. Here an AVL[®] AMA i60 was used. A portion of diluted exhaust gas and a sample of ambient air were pumped into bags for regulated emissions measurement. In addition, non-regulated emissions were measured via an FTIR analyser (IAG[®] MKS Multigas 2030) and particulate matter sampling. To measure particulate mass, a portion of the exhaust gas flow was sampled from the dilution tunnel by a particulate probe sampling configured as required by UNECE Regulation No. 83 [4] and then lead through a filter holder and gas meter. The mass of particulate matter emitted during the whole test could then be derived by weighing the filter papers before and after the tests. Also the Elemental Carbon (EC) and Organic Carbon (OC) fractions deposited on the filter were analysed by Thermo-

Gravimetric Analysis (TGA). Two different types of filter papers were used: A PTFE coated filter standardized for regulated PM measurement and a Tissuquartz, a pure glass fibre without coating. The Tissuquartz filter was needed as it can sustain high temperatures during TGA (~ 600°C).

Also, a portion of the diluted exhaust gas was sent through a secondary two-step dilution (hot dilution for evaporation and cool dilution to prevent particles from nucleating) to a Continuous Particle Counter (TSI® CPC 3775) to count the particles emitted. The dilution rate had to be adjusted to ensure a volumetric particle concentration below $10^4/\text{cm}^3$. As the CVS system was open the dilution air was not filtered. Background particle number concentration and particulate mass were therefore initially measured by operating the system for 1 200 seconds and simply sampling ambient air. Both background particles number and particulate mass measured were far below the values of the vehicle measurements. Background air influence was therefore neglected.

5 Test protocol

Specifications of the fuel used for the whole test campaign are shown in Table 2.

Fuel specifications	
type	gasoline
RON	98
density	740.4 [kg/m ³]
calorific value	42.24 [MJ/kg]
percent carbon	83.68 [Wt.%]
percent hydrogen	13.38 [Wt.%]
percent oxygen	2.94 [Wt.%]
C : H : O ratio	0.52 : 1 : 0.0138

Table 2: Fuel specifications.

Mopeds were initially degreased for 250 km. Then, the following measurements were conducted and recorded:

- Engine speed (1 Hz)
- Temperatures - engine and exhaust (1 Hz)
- λ on the four-stroke engines (1 Hz)
- Bags regulated gas mass emissions (CO, HC, NOx)
- One-second regulated gas mass emissions (CO, HC, NOx).
- One-second unregulated gas mass emissions (CO₂, hydrocarbons speciation, nitrogen speciation)
- Overall particulate mass
- Composition of PM (VOC and OC)
- One-second particles number

Each vehicle was first driven on two WMTC test cycles. Once reproducible results were obtained, the vehicles were run twice on the UNECE R47 cycle. The CVS sampling rate was adjusted to 4000 l/min to reach a suitable particle number dilution in the CPC measurement device. In addition, the sample

rate was adapted to achieve a certain dilution and avoid concentrations of HC, CO and NOx above the respective measurement ranges of the analyzers. During these tests the particulate mass sampling was done by means of the standardized EMFAB filter. In a last step, vehicles were tested again on one WMTC and one UNECE R47, using the Tissuquartz filter for PM sampling. As the absolute mass of particulate matter deposited on the filter during one test was very small (see results) the CVS sampling rate was halved to 2000 l/min. With this reduction of the dilution rate the deposition of particles roughly doubled the value of the previous tests conducted at 4000 l/min. Thanks to this change in dilution rate, accurate TGA analysis could be performed. However, these additional tests were only used for the TGA since the lower dilution rate made maximum gaseous concentrations higher than the analyzers operating ranges.

6 Results

6.1 Regulated Emissions

6.1.1 UNECE R47 Cycle

Cumulative emissions of the 5 vehicles tested on the two repeats of UNECE R47 cycle (cold and hot) are compared in Figures 5, 6 and 7 (HC, CO and NOx respectively). Data shown in these 3 charts relate to a single test for each moped.

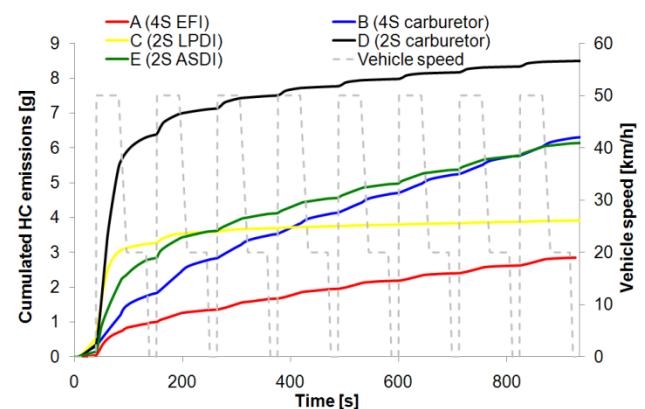


Figure 5: Cumulative HC emissions measured on UNECE R47

Figure 5 shows that vehicle D (2S carburetor) produces the highest amount of HC, most of it being emitted during cold start. Mopeds B (4S carburetor) and E (2S ASDI) achieve similar levels of HC, but with a lower gradient after cold start for the 2-stroke model. The lowest HC emissions are achieved by vehicles A (4S EFI) and C (2S LPDI). However, cumulative emissions curves for these two concepts are completely different from one another. Moped C emits most of its HC during cold start while moped A produces HC at a roughly constant rate throughout the whole cycle.

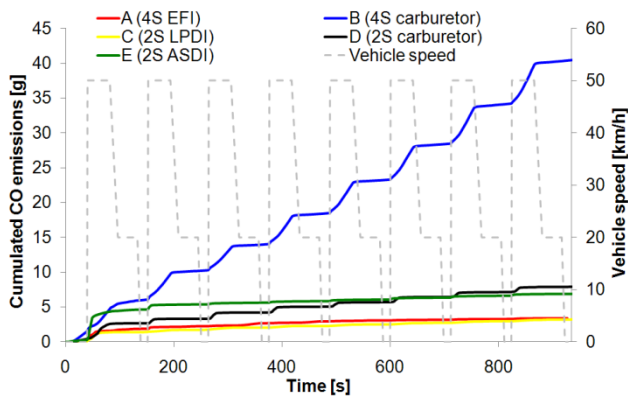


Figure 6: Cumulative CO emissions measured on UNECE R47

Comparing CO emissions over cycle time (Figure 6) highlight major differences between the tested vehicles. Moped B (4S carburetor) emits about 5 times more CO than the closest competitor. The overall CO emissions of mopeds D (2S carburetor) and E (2S ASDI) are quite similar even though their cumulative rates are different. Moped E produces CO mostly during cold start while moped D emits CO over the whole test, especially during accelerations. The lowest level of CO, about half of level of vehicles D and E, was achieved by vehicles A (4S EFI) and C (2S LPDI); A showing slightly better CO control after cold-start than C.

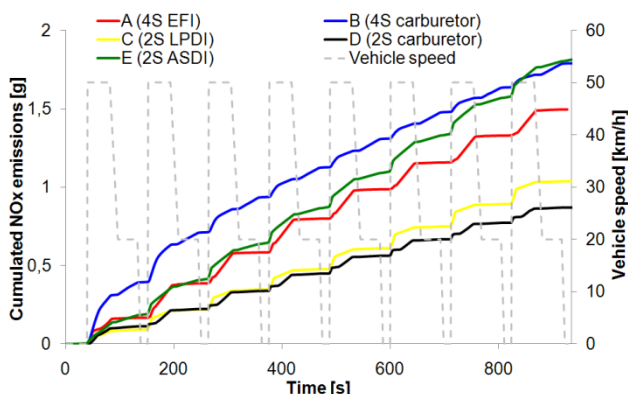


Figure 7: Cumulative NOx emissions measured on UNECE R47

Although the levels of overall NOx emissions, shown in Figure 7, are very scattered amongst the five vehicles, their characteristics are relatively similar. The majority of NOx are produced during accelerations and at maximum high speed. The lower NOx values are achieved by moped D (2S carburetor) and C (2S LPDI). Other vehicles emit similar level of NOx but the cold start contribution is the highest for moped B (4S carburetor).

Emissions measured in the hot cycle bags are then presented in Figure 8 to 11 (CO, HC, NOx and HC+NOx respectively). Each bar represents the average of 3 test repeats. They show that despite moped B (4S carburetor) was only degraded for 250 km, it emitted about 6 folds the Euro 2

permissible CO. All five mopeds meet the Euro 2 HC+NOx limit.

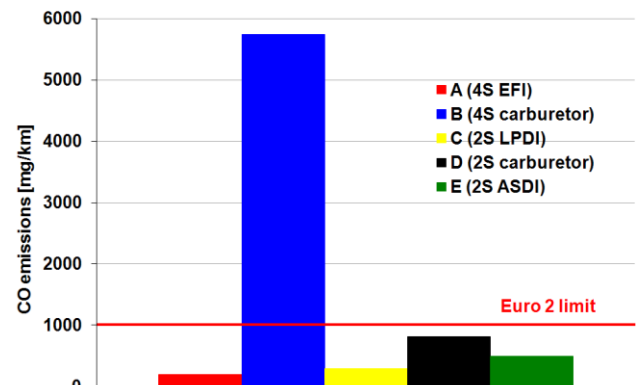


Figure 8: CO emissions measured on UNECE R47 (hot cycle only)

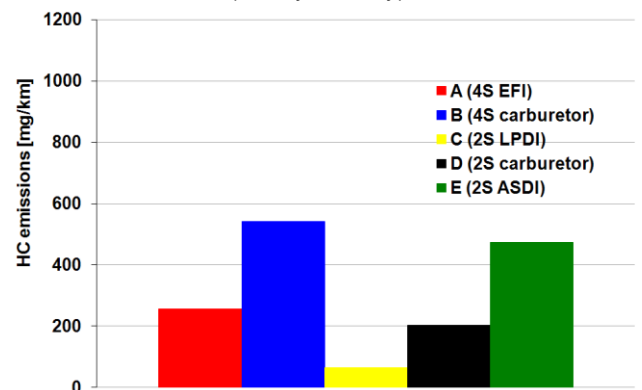


Figure 9: HC emissions measured on UNECE R47 (hot cycle only)

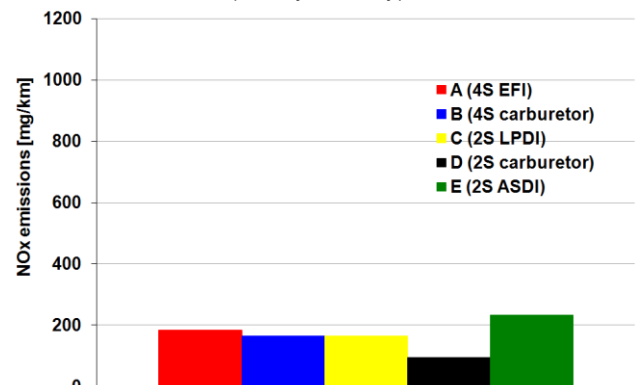


Figure 10: NOx emissions measured on UNECE R47 (hot cycle only)

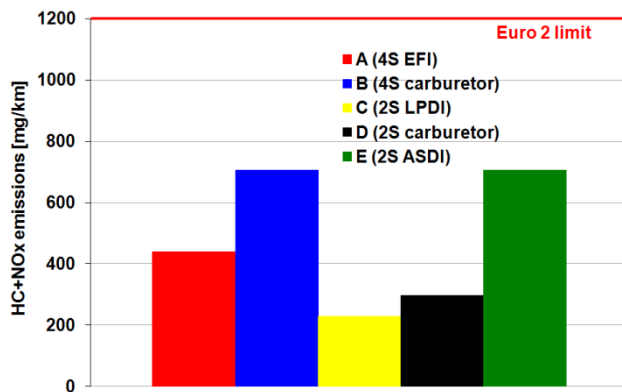


Figure 11: HC+NOx emissions measured on UNECE R47 (hot cycle only)

In order to evaluate the performance of the five mopeds in view of proposed future Euro 3 and Euro 4 limits, the emissions measured in both cold and hot cycles and weighted 30 and 70% respectively are shown in figures 12 to 15 (CO, HC, NOx and HC+NOx respectively). Again, each bar represents the average of 3 test repeats.

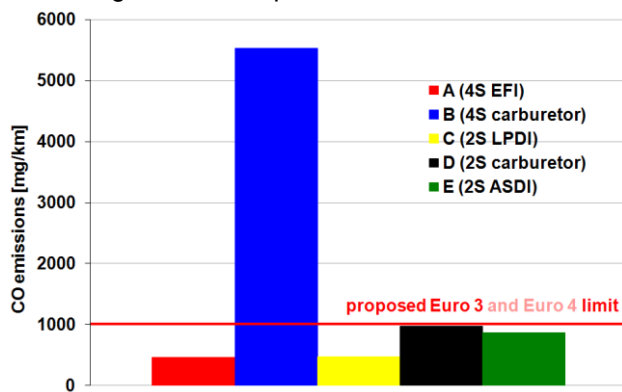


Figure 12: CO emissions measured on UNECE R47 (30% cold + 70% hot cycles)

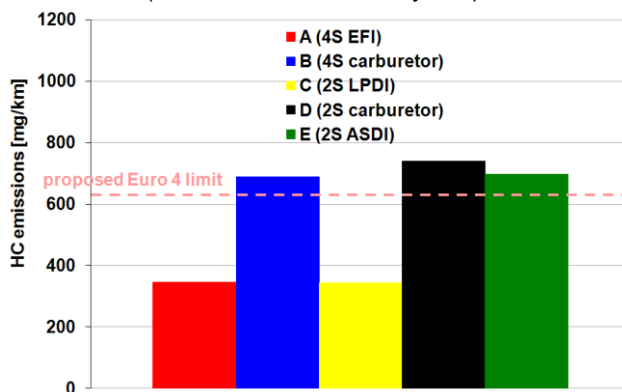


Figure 13: HC emissions measured on UNECE R47 (30% cold + 70% hot)

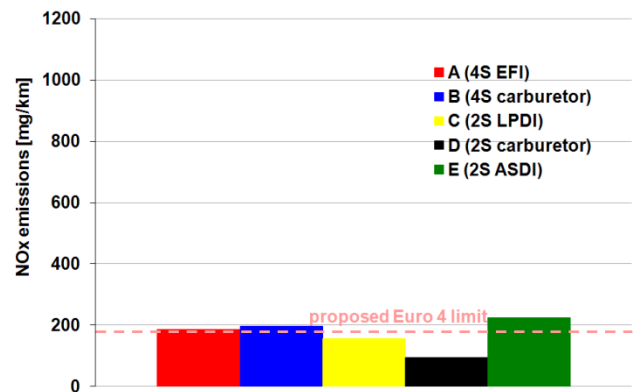


Figure 14: NOx emissions measured on UNECE R47 (30% cold + 70% hot)

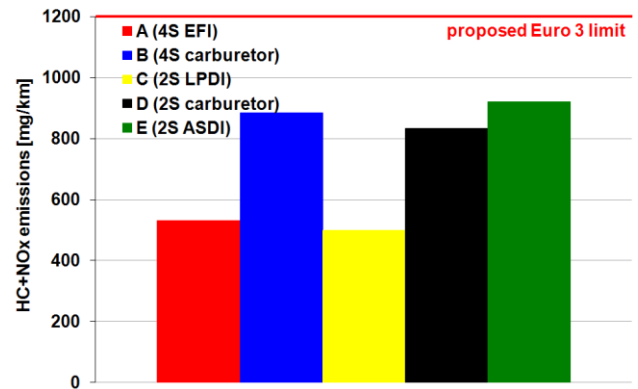


Figure 15: HC+NOx emissions measured on UNECE R47 (30% cold + 70% hot)

Not only do all five mopeds except B (4S carburetor) meet the proposed Euro 3 limits but C even meets Euro 4 individual limits. These results demonstrate that little improvement on the emissions will be required to meet the proposed Euro 4 limits. It is to be mentioned that these results do not account for durability though.

One main difference between proposed Euro 3 and proposed Euro 4 and 5 is the separate limitation of HC and NOx. Therefore a compensation of high NOx emissions by enhanced oxidation of HC in the catalyst will no longer be possible. Separate limits for HC and NOx require a simultaneous control of all 3 regulated components.

6.1.2 WMTC Cycle

In comparison to UNECE R47, WMTC offers less wide-open throttle operation and is more transient.

Cumulative emissions of the 5 vehicles tested on the two repeats of WMTC Part 1 with reduced speed (cold and hot) are compared in Figures 16, 17 and 18 (HC, CO and NOx respectively). Data shown in these 3 charts relate to a single test on each moped.

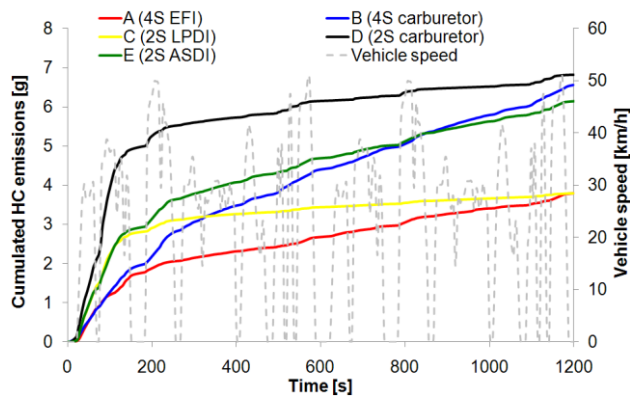


Figure 16: Cumulative HC emissions measured on WMT Part 1, reduced speed

The cumulative curves of HC emissions measured over WMTC are quite similar to those obtained on the UNECE R47 test cycle, both in terms of cold start and catalyst light-off performances. Overall, mopeds B (4S carburetor), D (2S carburetor) and E (2S ASDI) emit approximately the same HC quantity when tested on WMTC. This does not reflect the better hot HC conversion observed on moped D (2S carburetor) which is somewhat hidden at the end of the test cycle because of the longer duration of WMTC compared to UNECE R47 (1200 s vs. 900 s).

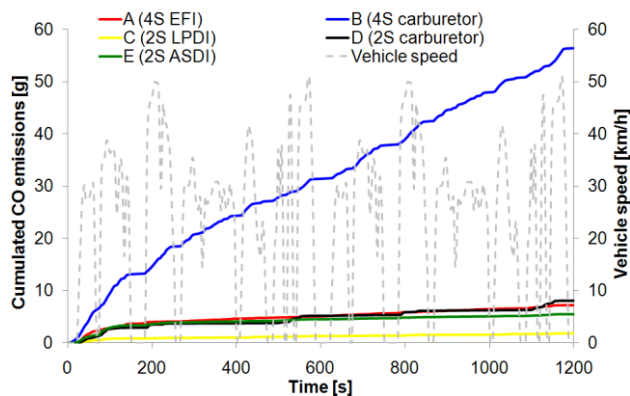


Figure 17: Cumulative CO emissions measured on WMT Part 1, reduced speed

The overall CO emissions obtained on the WMTC part 1, reduced speed cycle are different from the UNECE R47 results, highlighting the impact of the test cycle itself. The highest amount of CO was emitted by moped B (4S carburetor) due to its weak interaction between mixture preparation, secondary air supply and catalyst. Moped C (2S LPDI) emitted the least CO. All other vehicles were at a similar level.

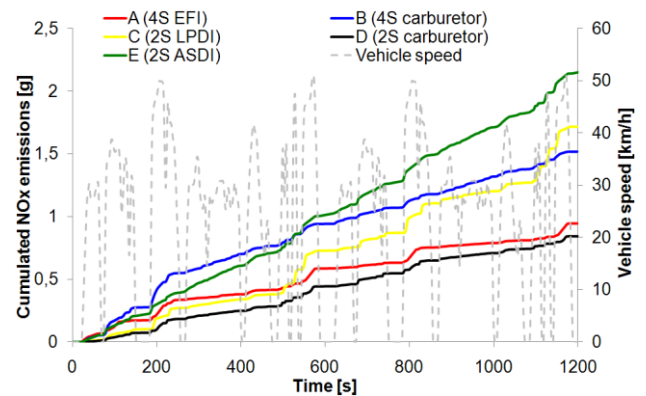


Figure 18: Cumulative NOx emissions measured on WMT Part 1, reduced speed

The overall NOx results on the WMTC cycle are comparable to those on UNECE R47, but the cumulative curves look different. In the case of WMTC, NOx emissions from moped C (2S LPDI) were higher, mainly in acceleration phases. All other vehicles showed NOx emissions breakthroughs on acceleration too, but with relatively lower emissions levels.

Figures 19 to 21 show respectively emissions of HC, CO, and NOx measured in bags during the WMTC drive cycle and weighted with 50% attributed to the cold cycle and 50% to the hot cycle. Each bar represents the average of 3 test repeats.

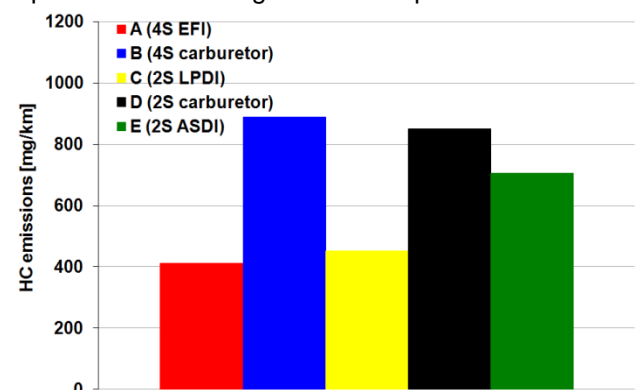


Figure 19: HC emissions measured on WMTC Part 1, reduced speed (50% cold + 50% hot)

HC emissions performances of the five mopeds were similar to those observed on UNECE R47 test cycle. Moped A (4S EFI) and C (2S LPDI) emitted about 60% of HC emissions from the other vehicles.

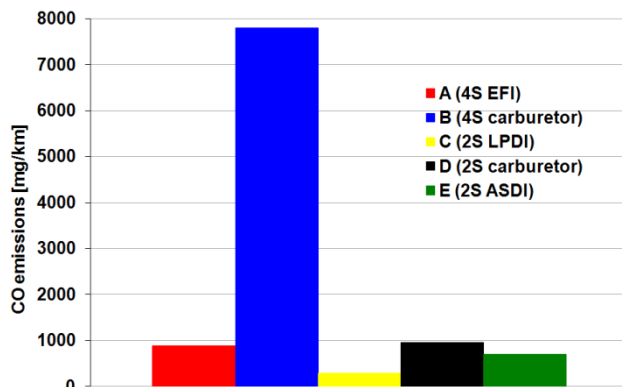


Figure 20: CO emissions measured on WMTC Part 1, reduced speed (50% cold + 50% hot)

The bad CO emissions performance of moped B (4S carburetor) was confirmed on WMTC as seen earlier on the cumulative chart. Moped C (2S LPDI) emitted the least CO. All other vehicles were at a similar level.

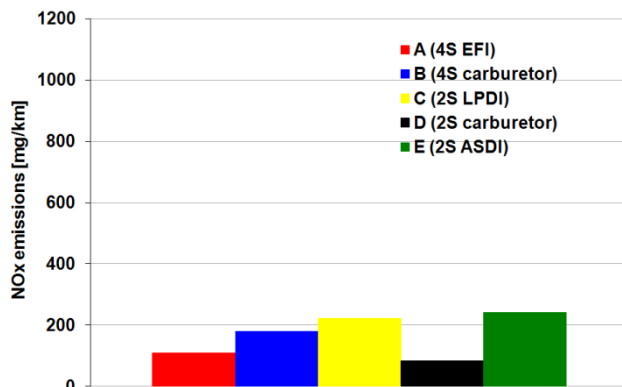


Figure 21: NOx emissions measured on WMTC Part 1, reduced speed (50% cold + 50% hot)

Mopeds C (2S LPDI) and E (2S ASDI) exhibit the higher NOx emissions when tested on WMTC; while mopeds A (4S EFI) and D (2S carburetor) emitted about half the NOx of C and E.

6.2 Unregulated Emissions: Particulate Mass and Particle Number

Particulate mass emissions of each moped were collected on a single paper filter; therefore no phase weighting was possible. Figures 22 and 23 show particulate mass emissions measured on cold and hot phases of UNECE R47 and WMTC Part 1 with reduced speed respectively.

The proposed Euro 5 stage includes a limit on PM similar to the Euro 5 passenger car requirement, at 4.5 mg/km. Here, only moped A (4S EFI) was able to meet this requirement with safety margin on both R47 and WMTC test cycles. All other vehicles emitted higher PM, up to 12 mg/km for moped D (2S carburetor) when tested on R47.

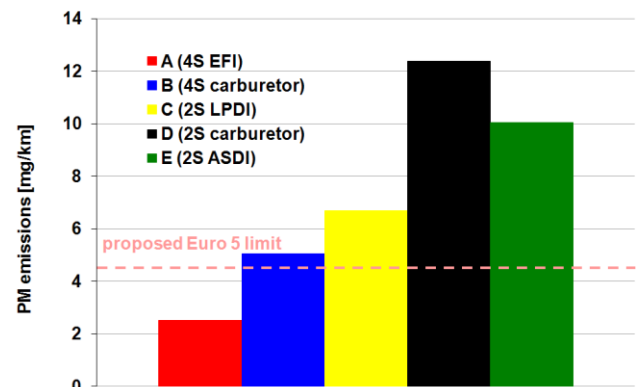


Figure 22: PM emissions measured on UNECE R47 (cold + hot)

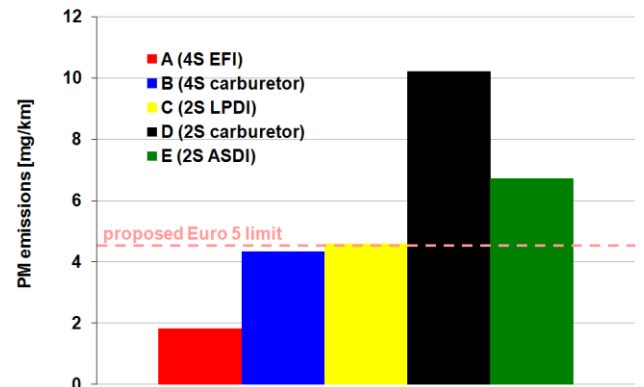


Figure 23: PM emissions measured on WMTC Part 1, reduced speed (cold + hot)

In addition to PM results, figures 24 and 25 show particle numbers emitted by the five mopeds over, respectively, the whole (both cold and hot cycles) UNECE R47 and WMTC Part 1 with reduced speed. Particles numbers range from $3 \times 10^{12}/\text{km}$ to $3 \times 10^{14}/\text{km}$ on both test cycles. These are similar levels to diesel passenger cars not equipped with Diesel Particulate Filters. Additional investigation on the composition and size distribution would be interesting to compare these emissions with those of diesel vehicles.

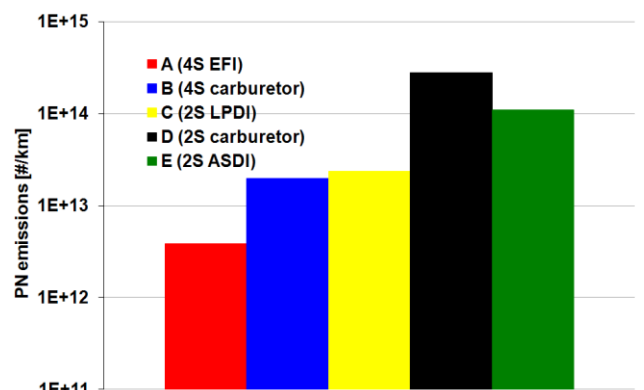


Figure 24: PN emissions measured on UNECE R47 (cold + hot)

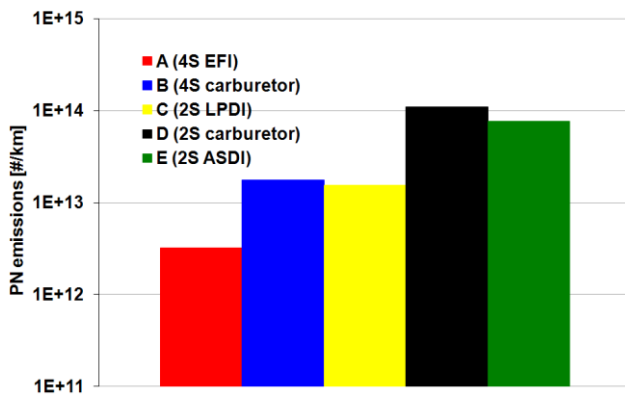


Figure 25: PN emissions measured on WMTC Part 1, reduced speed (cold + hot)

Cumulative curves of Particle Number emissions of the five mopeds during UNECE R47 and WMTC are displayed in Figures 26 and 27 respectively. These charts clearly show that the first acceleration is predominantly responsible for the high levels of PN emissions, whatever the test cycle is.

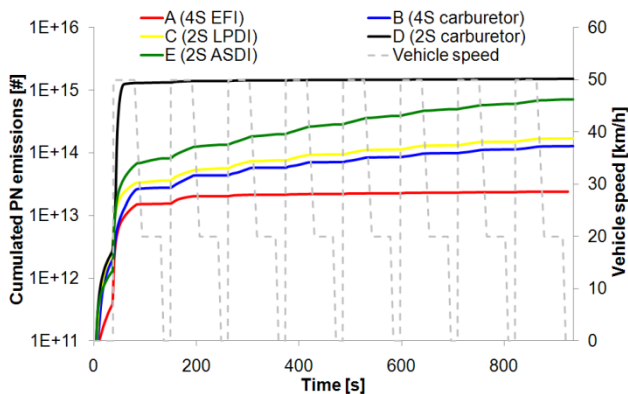


Figure 26: Cumulative Particle Number emissions on UNECE R47 (cold + hot)

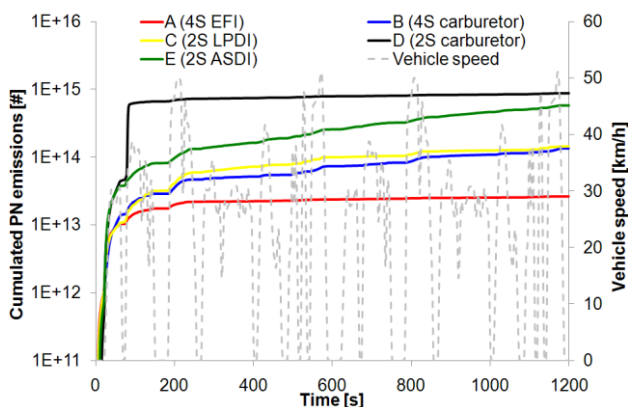


Figure 27: Cumulative Particle Number emissions on WMTC (cold + hot)

Regarding the nature of particulate matter emitted by the five mopeds, Figure 28 shows the organic carbon and elemental carbon fractions. There is very little elemental carbon in spite of the high particle numbers measures. A large portion of PM is organic carbon (>80% for most vehicles, except C), linked to lube oil or fuel.

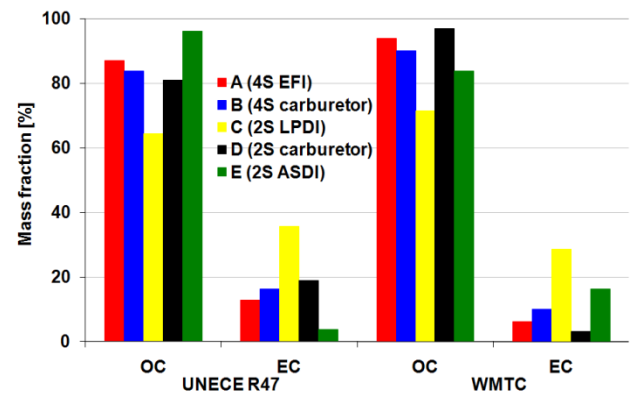


Figure 28: OC and EC shares in particulate emitted on UNECE R47 and WMTC

6.3 Fuel consumption

Figures 29 and 30 show fuel consumptions measured on the five mopeds on R47 and WMTC respectively (cold and hot phases). They are calculated from carbon balance. Overall, fuel consumption levels are relatively similar amongst the different vehicles and are quite independent from the drive cycle used. Generally, fuel consumptions are in the range of 2 to 3 l/100 km, much lower than typical European motorcycles [5]. Current mopeds appear to be calibrated for fuel economy and performance, to the detriment of emissions.

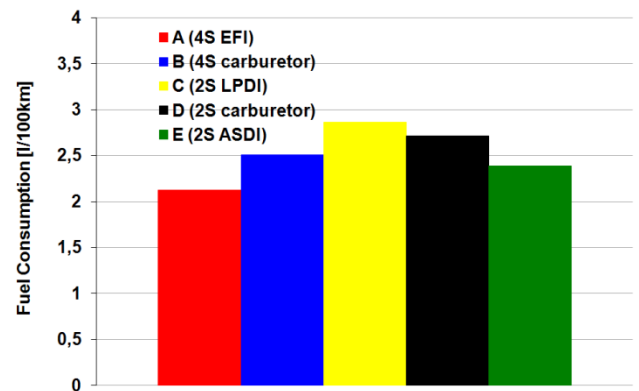


Figure 29: Fuel consumption on UNECE R47 (cold + hot)

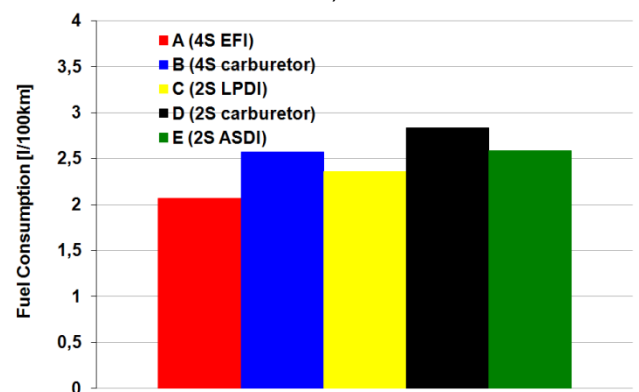


Figure 30: Fuel consumption on WMTC part 1, reduced speed (cold + hot)

7 Conclusions

The range of vehicles tested represented the variety of emission behaviour of mopeds that is encountered in the European market. Emissions levels of mopeds mainly depend on the quality of the air-fuel mixture preparation and its interaction with the aftertreatment device.

Technologies are available to permit 2-stroke engines to meet anticipated Euro 3 limits, but proper Air-Fuel ratio control is a pre-requisite for effective application of catalysts to 4-stroke mopeds.

All tested mopeds emitted particles at a similar level to diesel passenger cars not equipped with Diesel Particulate Filters.

The cold start phase has a major impact on the overall emissions of gaseous components as well as particulate mass and particles number.

The current legislative limit combining HC and NO_x allows quite high NO_x emissions as long as HC levels can be controlled. A separate limitation of all 3 components, as proposed by the European Commission for Euro 4 and 5 stages, would require more sophisticated strategies to control all components simultaneously.

8 References

- [1] COM(2010)0542, <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0542:FIN:EN:PDF>.
- [2] European Commission, Enterprise Directorate-General, *Status Report: Emissions of 2- and 3-wheelers*, 4 May 2005, moto_87.
- [3] UNECE gtr n°2, Measurement procedure for two-wheeled motorcycles equipped with a positive or compression ignition engine with regards to the emission of gaseous pollutants, CO₂ emissions and fuel consumption. www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29registry/gtr02.html.
- [4] UNECE Regulation No. 83, Rev.1/Add.82/Rev.4, p 135, Annex 4a – Appendix 4 <http://live.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r083r4e.pdf>.
- [5] Cécile Favre, Dirk Bosteels, John May, Ian De Souza, Leon Beale, Jon Andersson, *An emissions performance evaluation of state-of-the-art motorcycles over Euro 3 and WMTC drive cycles*, SAE 2009-01-1841.

9 Glossary

2S: 2-stroke
4S: 4-stroke
AECC: Association for Emissions Control by Catalyst, AiSBL
ASDI: Air-Supported Direct Injection
CO: Carbon monoxide

CPC: Continuous Particle Counter
CVS: Constant Volume Sampling
CVT: Continuous Variable Transmission
EC: Elemental Carbon
EFI: Electronic Fuel Injection
FTIR: Fourier-Transformed Infra-Red analyser
gtr: Global Technical Regulation
HC: Hydrocarbons
IVT: Institute for Internal Combustion Engines and Thermodynamics of Graz University of Technology
LPDI: Low Pressure Direct Injection
NO_x: Nitrogen Oxide
OC: Organic Carbon
PM: Particulate Matter / Particulate Mass
PMP: Particulate Measurement Program
PN: Particle Number
PTFE: Polytetrafluoroethylene
TGA: Thermo Gravimetric Analyser
UNECE: United Nations Economic Commission for Europe
WMTC: World-wide Motorcycle Test Cycle