Powered Two Wheelers compared with cars:

Driving dynamics, fuel consumption and exhaust emissions in daily use

Bertrand-Olivier DUCREUX

DATA AND REFERENCES
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Since 2000 and the first Euro regulation applying to powered two wheelers, ADEME (French Environment and Energy Management Agency) has been working to assess the PTW exhaust emissions. Older PTW (Euro1, Euro2) were thus studied in some former work released in 2000 and 2005[1].

As of 1 January 2007, all PTW of more than 50 cm^3 *(therefore excluding mopeds) sold in Europe have to meet Euro3 emission standards (some derogations remaining in effect until end of 2007). This new step requires that manufacturers implement technical solutions (which have been proven in passenger car use), including fuel injection in most models, fuel mix regulators and three-way catalytic converters in exhaust systems.*

Therefore, the implementation of Euro3, leading to deep changes in engine control features, justified resuming ADEME evaluations of the environmental performance of this category of vehicles.

Moreover, at the same time, the Paris City Hall got in contact with ADEME to join a workgroup about PTW emissions. This group brought together representatives of the municipality and from the world of two-wheel vehicles. The focus of the workgroup was not only to assess new Euro3 PTW emission levels, but also to quantify the differences in emissions and fuel consumption with cars, taking into account the peculiarities of PTW driving in the traffic. These expectations were asking for updates in current knowledge in PTW emissions compared to cars, as described in former articles[2].

The test program described below was created through exchanges with this work group. This ensured that it was representative and realistic from the riders' point of view.

1. See on ADEME website:
http://www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=23210&p1=02&p2=12&ref=17597
http://www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=28529&p1=02&p2=12&ref=17597
2. For interesting examples see: *"The rising importance of two-wheelers emissions –a comparison to cars"*, M. Weilenmann & P. Novak, EMPA and *"Comparison of real-world emissions from two-wheelers and passenger cas"*, A-M. Vasic & M. Weilenmann, EMPA.

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Building the detailed study

The test program therefore seeks both to evaluate the environmental progress made by PTW after Euro3 implementation and to compare the results with those obtained by recent model passenger cars (Euro4 compliant). However, as it had been done formerly in ADEME's PTW studies and as it was discussed with the PTW workgroup, the assessment was to be made in conditions as close as possible to the real use of cars and motorbikes, and not only on mandatory test cycle.

It was decided to compare the two families of vehicles under similar operating conditions from the driver's point of view: a home-to-office trip between the suburbs (Linas) and downtown Paris (Musée d'Orsay) at rush hour (arrival time in Paris: 8.30 am).

This path includes highways, wide roads and urban streets with a wide range of congestion level along the way. The total distance is 31 km long and the trip should represent what a driver encounters as driving conditions when commuting to a big city.

As mobile emission measuring devices still cannot be embedded on PTW (too large, too heavy), the emission assessment had to be made on a roller test bench. A secondary advantage of this testing strategy is that it is then possible to "re-play" any test cycle on any vehicle if needed, remaining exactly in the same conditions (on the contrary, if measured "online" on the road, the results would become date-dependant because of traffic variations).

The next issue was therefore to build a sufficient knowledge of the driving dynamics of cars, small and bigger PTW (including both scooters with automatic transmission and motorbikes with clutch and gearbox), so that various test cycles can be built for the test bench.

"Real use" of motorcycles, scooters and passenger cars in the traffic

To build the test cycles, several trips were recorded simultaneously on the reference route for a car, a 600 cm^3 motorcycle and a 125 cm^3 scooter. For each of them, a skilled driver or rider familiar with his vehicle in the urban traffic was aiming at an arrival time of 8.30 am. Thus, the car and the two PTW were driving in the same traffic condition.

The vehicles had to adhere to speed limits, but the PTW were allowed to drive between lines of slow or stopped cars, as they usually do under normal driving conditions in France.

These simultaneous recordings were repeated five times, on successive days. The stored datas included time, speed, distance, engine rpm, throttle position and driver's comments about traffic congestion.

The speed profiles were then analysed (versus time and versus distance) to split them depending on the type of road and congestion level and the behaviour of every vehicle was studied. The comparison of each single vehicle, from one day to the others, showed a good consistency (average speeds, stops, congestion). Then, when compared to the other vehicles, it allowed us to extract a dynamics structure for each of the three vehicle types.

In particular, when analysing the average speeds of both PTW on every sector of the route, we noticed that they were quite close to each other. This result led to an average travel time of 43 minutes for the 600 motorbike, versus 44 minutes for the 125 cm^3 scooter.

We can see on fig.1 that it's only on the faster sectors (average speed over 65 km/h) that the bigger motorbike took a slight advantage of its higher performance potential. As this type of traffic only represent a minor part of the total distance, the global travel time does not really benefit from this.

The small difference in driving dynamics between the two PTW is also noticeable on fig.2.

The average acceleration levels of both PTW do not appear to be as different as their engine's maximum power outputs are. This demonstrates that in urban and sub-urban traffic, the performance potential of bigger PTW is rapidly useless when congestion increases.

From this result, it was decided to consider all types of PTW as a single type of vehicle and therefore to build only one set of test cycles dedicated to PTW,

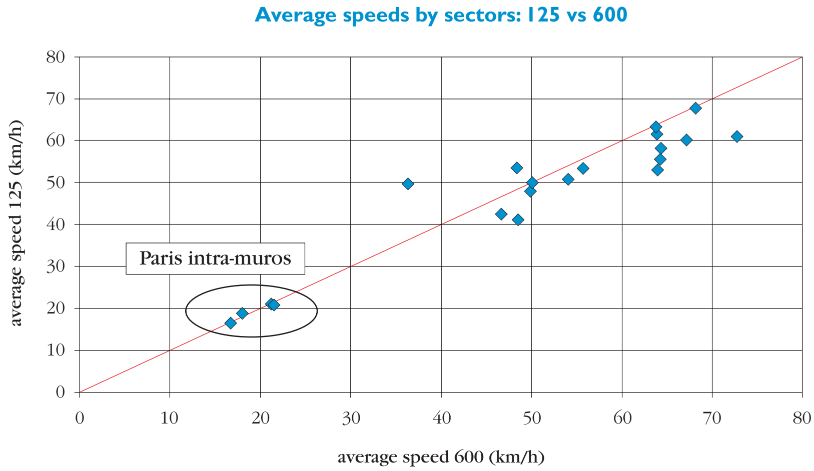

Fig.1: 125 scooter and 600 motorbike average speeds.

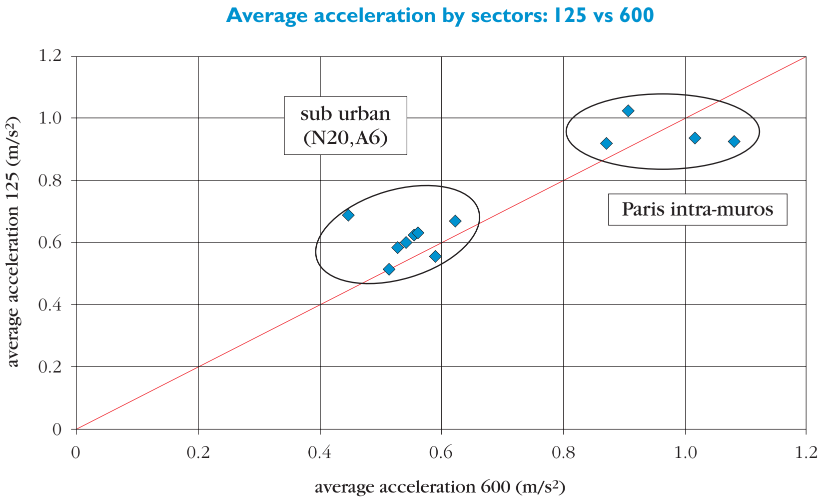

Fig.2: 125 scooter and 600 motorbike mean positive acceleration.

regardless to their power output. It was considered that a cycle possibly leading to wide open throttle operation for smaller PTW was reflecting the real use.

Next to this PTW comparison, the same analysis was made on the car's recordings, resulting in an average travel time being twice the time for PTW: 88 minutes were needed on the road to reach the arrival point. PTW take a clear benefit of their lower size: riding between the car lanes they have to stop less often in the traffic jams. The car travel reflects the high congestion level along the way, due to the chosen peak hour.

Finally, extracting datas from the on-road recordings, two sets of test cycles were built, one for powered two wheelers and the other for cars. Each of these sets is describing the whole path, split in the following six phases: urban (with cold start 20°), "Nationale" road, fluid highway, congested highway, traffic jam and hot urban. The duration of some phases had to be adapted compared to real driving time, because of testing installation needs (limitation due to sampling bags volume, or requirement of sufficient sample size to ensure accuracy of analysis with CVS system). These slight modifications are later corrected to calculate the actual results on the real route.

The key feature of these cycles is that they describe the driving dynamics of both PTW and cars, while driving in parallel in the same conditions (traffic congestion, type of road, weather).

The main characteristics of these cycles are summarised in the following table:

	average speed (km/h)		duration (s)		distance (m)		average accel (m/s²)		maxspeed (km/h)		nb stop / km		stop time / km	
	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW	car	PTW
urban cold	19.1	24.0	889	706	4 706	4 705	0.672	1.092	50.8	52.7	3.0	2.3	41	38
"Nationale" road	41.0	60.6	914	618	10 408	10 407	0.536	0.613	93.0	91.5	1.0	0.3	10	2
fluid highway	70.4	81.8	529	455	10 341	10 335	0.460	0.552	108.9	111.7	0.1	0.1	0	0
congested highway	12.1	44.0	994	466	3 340	5 700	0.626	0.388	48.6	57.4	6.6	0.2	75	1
traffic jam	4.3	7.5	820	472	989	988	0.625	0.641	31.0	37.8	18.2	10.1	433	103
urban hot	19.1	24.0	889	706	4 706	4 705	0.672	1.092	50.8	52.7	3.0	2.3	41	38

Table 1: test cycles characteristics.

The cold and hot "urban" phases describe the same "speed vs time" profile.

The "traffic jam" is a very severe congestion due to road works, which we decided to keep in order to evaluate the emission control systems in such extreme conditions.

For practical reasons, cold urban + "Nationale" road + fluid highway are gathered in one single cycle called "Suburbs" and the three other phases build a second cycle called "City".

We can make a few comments on the dynamics of these cycles, compared to the homologation cycles being in use in European homologation tests. As shown on fig.3, where average speed and acceleration are plotted, we can notice that ECE cycle is quite similar to urban real driving for cars and EUDC cycle is close to highway real driving for cars. However, as far as PTW are concerned, we clearly see that their behaviour in the traffic induces some important difference with cars and therefore with regulatory cycles.

The same figure also highlights the main differences between car and PTW "real-world" driving: average speeds are higher for PTW, whatever the context, but the average acceleration is more specific. The average acceleration for the PTW is much higher in urban cycle, whereas a bit closer to cars on roads, highway and in the heavy traffic jam. On the congested highway, PTW show a very low rate of acceleration. This is due to a typical traffic mode (in France) where cars are nearly stopped, moving with slow "stop-and-go" pattern, while PTW ride quite smoothly between the slow car lines, hardly braking and not often stopping.

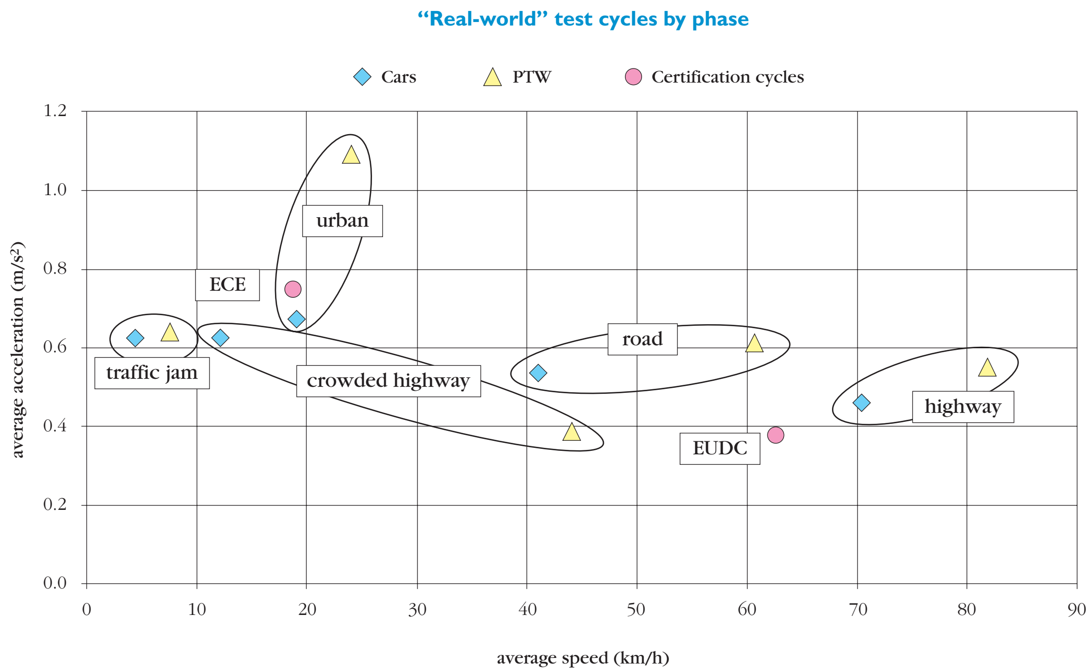

Fig.3: "real world" test cycles dynamics compared to homologation cycles.

In order for the travel time of cars to be representative of real commuting use, time spent looking for a parking spot is later added to the actual trip time (by a slight increase of cars "traffic jam" and "hot urban" phases distance). For this study and as it is usually the case in France, PTW were allowed to park on wide sidewalks: this enabled quasi-local and very quick parking. A recent PREDIT-ADEME research(3) showed that the average time spent looking for car parking (for commuters working in the "Musée d'Orsay" area) was 16 minutes at that time of the day. This still increases the time savings for the PTW user.

Homologation test cycles reminder

The current European homologation process includes, for motor vehicles, average exhaust emission measurements (type I tests).
Euro4 compliant cars are tested with cold start (20°C) on the NEDC cycle, built with 4 elementary ECE and one EUDC cycle.
Euro3 PTW under 150 cm^3 (and over 50 cm^3) are tested with cold start (20°C) on 6 elementary ECE cycles.
Euro3 PTW over 150 cm^3 are tested with cold start (20°C) on 6 elementary ECE cycles and one EUDC cycle.
Euro2 PTW were tested with hot start and on ECE cycle only (maximum speed = 50 km/h).
It might be reminded that Euro3 does not imply any durability requirement for emission control.

An harmonised test cycle for PTW has been defined by European WP 29 and is part of the next evolutions planned for Euro regulation: the WMTC is also part of the present study.

Description of the test vehicles

For this program, 15 PTW and three cars have been measured. Their main characteristics are summarised in table 2. All the vehicles were lent by the manufacturers or their sales departments in France and the bigger motorbikes were complying with the maximum power limitation of the country (78 kW).

Different categories of PTW have been tested, from 125 cm^3 to more than 1 000 cm^3 engines, and both motorbikes (with gearbox and clutch lever) and scooters (with CVT transmission) were included.

As far as cars are concerned, the choice was to pick up 2 gasoline cars (gasoline being the usual fuel for PTW) and one diesel car (without Diesel Particulate Filter) because of the diesel share in French cars sales (75% in 2007). As the study is aiming at daily use, the diesel car and one gasoline car were chosen from urban size with reasonable engine power. However, as some of the PTW are ranging up to 78 kW and therefore to high performance, the second gasoline car is fitted with a bigger 6 cylinder engine with 155 kW output and automatic gearbox. None of these latter vehicles can be quoted as optimised for urban driving, but all of them actually can be found inside French big cities…

category	engine power	mileage (km)	fuel system	test inertia	Euro level
trail 125	8 kW	507	carb	190 kg	Euro3
scooter 125	11 kW	1 359	inj	190 kg	Euro3
scooter 125	11 kW	3 000	inj	240 kg	Euro3
scooter 125	10 kW	1 566	inj	240 kg	Euro3
scooter 125	8 kW	4	carb	190 kg	Euro2
scooter 250	16 kW	4 013	inj	230 kg	Euro3
scooter 400	25 kW	4 255	inj	270 kg	Euro2
scooter 400	29 kW	1 585	inj	310 kg	Euro3
roadster 600	72 kW	4 259	inj	270 kg	Euro2
roadster 600	72 kW	3 321	inj	270 kg	Euro3
roadster 600	53 kW	3 750	inj	270 kg	Euro3
sport/GT >=950	78 kW	1 623	inj	270 kg	Euro2
sport/GT >=950	78 kW	912	inj	270 kg	Euro3
sport/GT >=950	78 kW	209	inj	270 kg	Euro3
sport/GT >=950	74 kW	6 111	inj	320 kg	Euro3
urban gasoline	55 kW	1 900	inj	1 130 kg	Euro4
urban diesel w/o DPF	66 kW	3 643	inj	1 250 kg	Euro4
sedan V6 gasoline auto	155 kW	10 353	inj	1 700 kg	Euro4

Table 2: main characteristics of vehicles.

3. PREDIT-ADEME *"Le temps de recherche d'une place de stationnement"*, SARECO, February 2005.

Taken from the manufacturer's press fleets, there is no reason to think that the test vehicles were specially tuned for our tests. Some mileages may appear quite low: this is due to the fact that most of them being Euro3 compliant, they were new models at the time of our tests, leading to short availability duration for each user (the Press and our test lab). It can be noticed that 4 Euro2 PTW were included to verify the consistency of emission results when compared to our former studies.

Laboratory measurement and tests performed

All measurements have been performed at the UTAC lab, where both PTW and cars emission test facilities are used for official European homologation. This was a guarantee for reproducible and calibrated measurements of regulated pollutants (CO, HC and NO_x), of CO_2 emissions and of fuel mileage. Only the averaged results using the classical CVS system were recorded with no continuous online sampling.

Roller bench setting was made in accordance with the homologation files, for cars and for all the powered two wheelers (a few coast-down tests have also been made to check for consistency between these official settings and actual measured rolling resistance).

Every vehicle has been tested on several cycles:

For PTW:
- Euro3 test cycle (the whole cycle was measured including EUDC, even for PTW under 150 cm^3), with preconditioning and "ambient start" (20°C) as in the European Directive,
- "real-use" PTW cycles (Suburbs and City) beginning with a 20°C start,
- WMTC cycle (here we made the difference between the PTW categories, not measuring the 3^{rd} phase for small PTW unable to reach 130 km/h).

For cars:
- Euro4 test cycle (20°C start),
- "real-use" cars cycles (Suburbs and City) beginning with a 20°C start,
- The "urban" part of CADC cycle was measured for further reference.

Every measurement has been repeated at least twice and sometimes more when the results were showing a high dispersion or considered as surprising.

Considering PTW gear shifting strategies, for "real-use" cycles it was left to the test operator practice, as it is the case for the Euro3 homologation procedure. For WMTC cycles, the shifting diagrams from available "version 9" Excel file was used. Scooters were driven with no specific strategy: the CVT was controlling the transmission ratio on every cycle.

Cars shifting strategy was taken from the NEDC cycle for Euro4 compliance verification, and had been specified from the on-road recordings analysis for the real-use cycles.

The big 6 cylinder car with automatic transmission was tested in "Drive" mode.

First results: progress from Euro2 to Euro3

For each vehicle, its "Euro level homologation" compliance was assessed. The situation would not have been perfectly satisfactory for some PTW if they had been brand new; however due to the lack of durability requirement for Euro3 level, all vehicles were qualified as correct for the test campaign.

A quick overview of PTW progress between Euro2 and Euro3 on the real-world cycles is presented on fig.4, using their average emission factors on the whole path (in g/km):

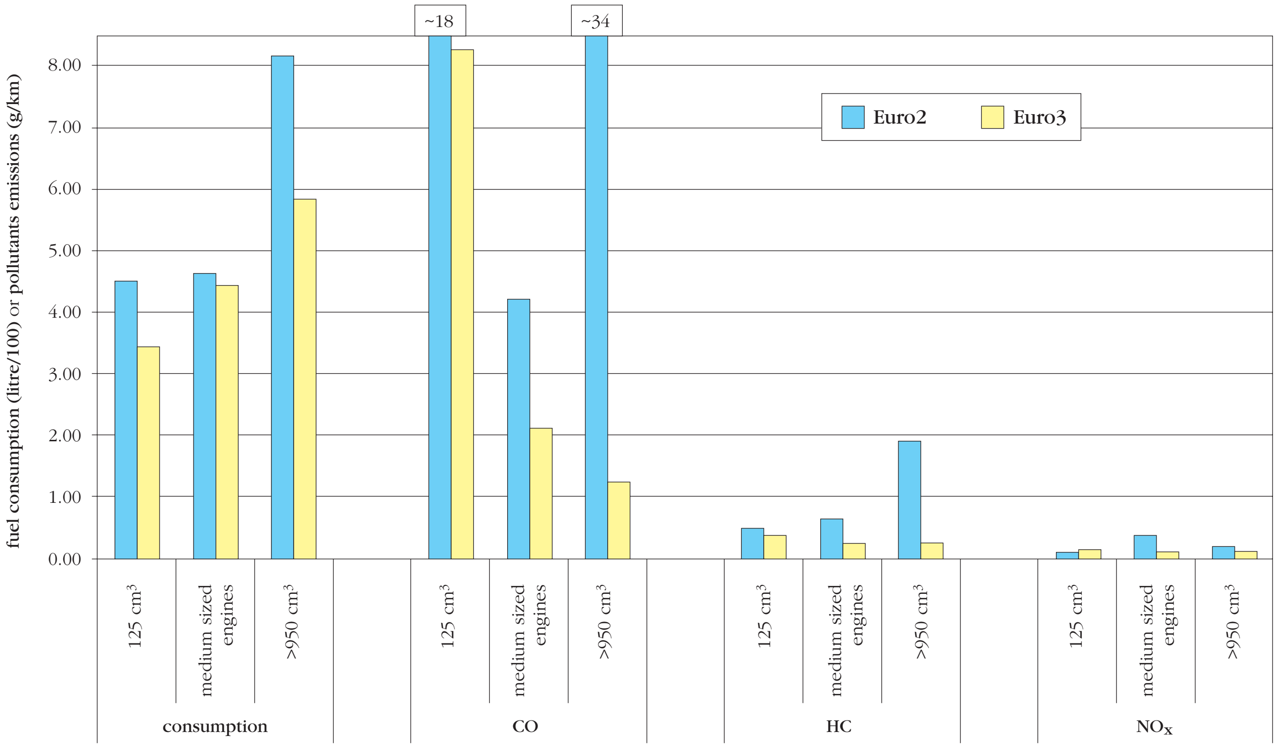

Fig4: comparison of exhaust emissions and fuel consumption between Euro2 and Euro3 PTW.

The four Euro2 PTW measured during the study had emission levels in line with (or slightly better than) previous ADEME studies (S. Barbusse, 2000 and 2005).

Euro3 PTW results, all of which were measured over the same real use cycle, showed clear improvements in pollutant emissions and fuel mileage for all categories:

- NO_x emissions are below 0.16 g/km for 125 cm^3 and 0.12 g/km for larger engines (Euro3 limit is 0.15).
- HC emissions fall significantly, to less than 0.4 g/km for 125 cm^3 (Euro3 limit is 0.8 under 150 cm^3) and 0.26 g/km for larger engines (Euro3 limit is 0.3).

Note that our former 2005 results showed a level of (HC + NO_x) of 1.5 g/km on average for 125 cm^3, and more than 5 g/km for some larger engines.

- CO emissions for motorcycles “>125 cm^3” are below 2.1 g/km and are even better managed as engine size increased (average of 1.25 g/km for 1 000 cm^3 and over; Euro3 limit is 2.0).
- On the other hand, CO emissions for 125 cm^3 remain high (up to 8.3 g/km), particularly during extra-urban driving.

Note that 2005 results showed CO emission levels above 30 g/km for large engines and 12 g/km on average for 125 cm^3.

These values show that the PTW market has responded well to stricter regulations, since homologation thresholds are nearly met (with the noticeable exception of 125 cm^3 CO emissions) for the “real-use” cycles, which are stricter than current legislation.

Moreover, the reduction in CO and HC emissions after implementation of Euro3 has resulted in better fuel efficiency:

- A reduction in greenhouse gases (CO_2, HC, CO), from –7 to –25% depending on the engine size, *(82 to 140 g eqCO_2/km, for engine between 125 cm^3 and more than 1 000 cm^3).*
- An improvement in fuel efficiency (l/100) of 20% for 125 cm^3 PTW *(Euro3 average: 3.5 l/100)*, reaching 25% for engines greater than 950 cm^3 *(Euro3 average: 5.8 l/100).*
- A lower improvement in fuel efficiency (about 5 to 10%) for PTW of average engine size, especially since Euro2 references measured for the present study were already quite efficient (injection) *(Euro3 scooter average: 4.1 l/100 and roadsters 600: 4.8 l/100).*

These results, though globally positive, highlight some weakness in present Euro regulation, in particular for smaller capacities being homologated on the urban ECE cycle (max speed = 50 km/h). This leads to high CO level when driven on suburban roads, over 50 km/h.

Euro4 cars and Euro3 PTW comparison: exhaust emissions

Here we compare the total absolute quantity of pollutants emitted into the atmosphere (and of fuel used by the engine) during the complete trip (31.015 km for PTW), taking into account the car's specific driving profile and the time spent looking for parking (due to this added "parking search", the distance travelled by cars is higher than that of PTW; therefore average emission factors are not convenient indicators).

The average number of passenger per vehicle in Paris area has been evaluated to 1.1 for PTW and 1.18 for cars. Therefore, these values being quite close to each other, the following analysis is presented for one single vehicle and no correction is taken into account considering the occupancy rate of vehicles.

These results are representative of reasonable driving style in heavy traffic conditions.

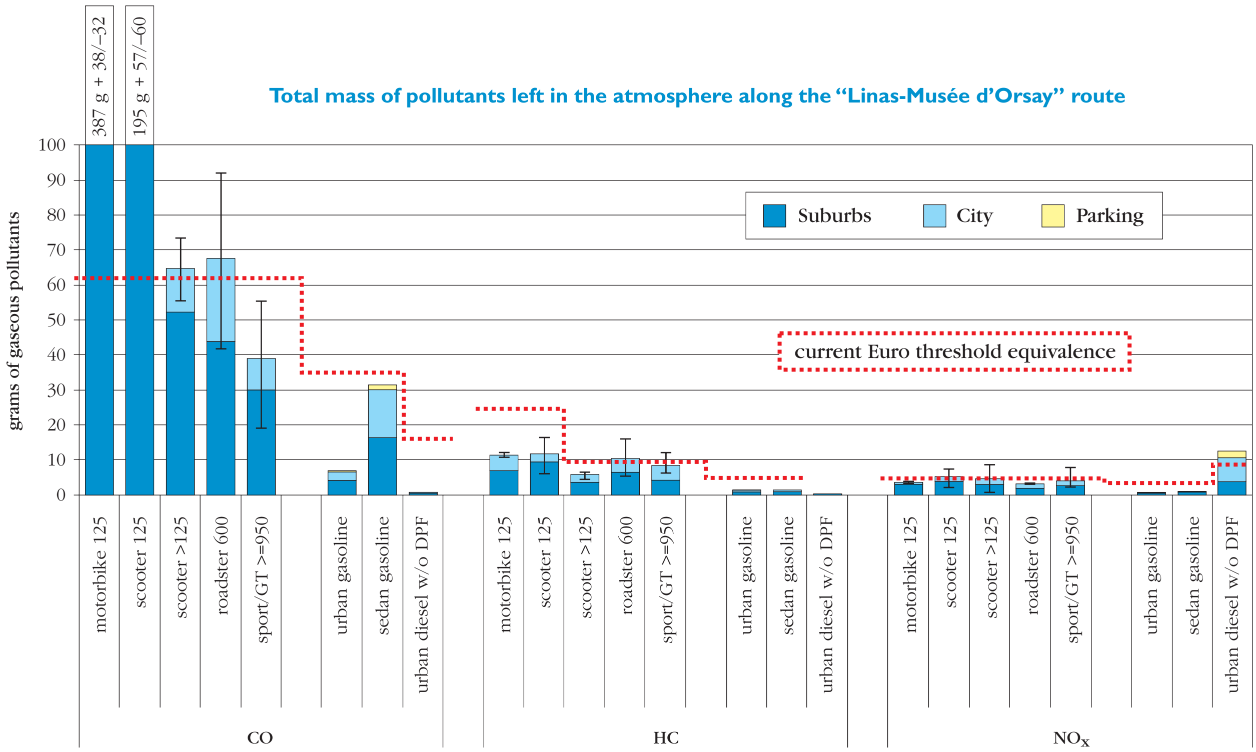

Fig5: comparison of absolute pollutants mass emissions between Euro3 PTW and Euro4 cars.

On fig.5, total amounts of pollutants along the way are plotted for every phase of the real use (Suburbs, City, and parking for the cars). Only Euro3 PTW are considered, the study aiming at "up-to-date" vehicles.

The dotted red lines correspond to the equivalence of the emission factors threshold of current Euro standards for every pollutant and for each vehicle category on its "real-use" cycle.

The dispersion bars show the measured fluctuations between the different tests and between the different PTW of each category (see table 2). The dispersion is mainly due to the differences between the various vehicles inside categories including more than one model.

- For 125 cm^3 vehicles, emissions of CO and HC remain 10 to 20 times higher than the average for Euro4 gasoline cars. Besides, it must be quoted that the 125 motorbike was equipped with a carburettor-fed engine, whereas all the 125 scooters where fuel injected.
- For larger engines:
  - CO emissions are two to three times higher than the average for Euro4 gasoline cars.
  - HC emissions are six times greater than those of Euro4 gasoline cars.

The difference between 125 cm^3 and larger engines is the consequence of lighter regulations for motorcycles under 150 cm^3 than for motorcycles with larger engines (the 125 cm^3 standard measures emissions based on the ECE cycle only). Hence, the 125 cm^3 PTW demonstrate CO emission factors being 2 to 4 times higher on the "Suburbs" than on the "City" real-use cycle.

- PTW NO_x emissions are on average six times higher than those of Euro4 gasoline-powered cars. They are, however, less than half those of Euro4 diesel cars. Relatively low NO_x emissions remain a noticeable performance of "4 stroke" PTW, despite the introduction of lambda regulation on Euro3 engines above 150 cm^3: increasing the air-fuel ratio from former rich mixture did not lead to a big increase of NO_x. This might be due to the fact that high load phases (often the most NO_x generating) for PTW engines, which correspond to acceleration phases in the context of our study, do not last long since average inertia of PTW remains quite low.

In order to complete this comparison, some simple calculations have been processed using the database of the Artemis project and the numerous car exhaust emission results on elementary cycles. Extracting emission factors on sub-cycles close to the different phases of our real-use cycles, it has been possible to obtain an estimation of the exhaust emission of older cars.

A Euro1 gasoline car would have emitted approximately 130 g of CO and 45 g of HC.
A Euro2 gasoline car would have emitted about 42 g of CO, 2.5 g of HC and 11.4 g of NO_x.
A Euro2 diesel car would have emitted around 36 g of NO_x.

It can be reminded that Euro1 for cars (1993) was the step justifying the fuel injection generalisation for gasoline cars, with 3 way catalysts and lambda regulation, thus corresponding quite well to the PTW Euro3 effect on big motorcycles.

The above estimations allow to position PTW exhaust emissions relatively to cars, as follows:
- 125 cm^3 Euro3 PTW are worse CO emitters than Euro1 cars (1993), especially the carb-fed motorbike, but HC emissions are 4 times lower than Euro1 cars.
- Intermediate capacities PTW show better CO results, about half that of Euro1 gasoline cars (still 50% higher than Euro2), and HC 5 times lower than Euro1 cars (still 3 times higher than Euro2 cars).
- Bigger capacities PTW show CO emissions equivalent to that estimated for Euro 2 gasoline cars, and the same HC level than intermediate capacities (between Euro1 and Euro2 cars).
- For all Euro3 PTW, their NO_x emission level is nearly half the one estimated for Euro2 gasoline cars, being therefore much better than that of diesel cars of any generation.

The shift in time between PTW and cars Euro regulation is here clearly highlighted. Nevertheless, all PTW have followed their regulation strengthening, as already demonstrated in the above Euro2/Euro3 comparison.

It also appears that taking into account the parking phase for cars is not an important penalty to their emission control performance: while the parking phase represents approximately 10% of the total distance, it represents about 6% of CO emissions and 3.6% of HC emissions. Only for the two urban cars did the parking phase represent 14% of NO_x emissions with a high absolute level for the diesel car (average of 0.4 g/km).

Euro4 cars and Euro3 PTW comparison: fuel consumption and greenhouse gases emission

In accordance with former assessments of PTW exhaust emissions published by ADEME, the greenhouse effect of exhaust pollutant emissions is taken into account using Global Warming Potential values proposed by IPCC in 2001 (considered here are the minimum values of the proposal, i.e. GWP = 1.15 for CO, 11 for HC, and 0 for NO_x). This leads to a correction added to pure CO_2 emission, that could be considered as negligible for cars (due to very low CO and HC emissions when Euro4) but is still not so low for PTW. Emissions of greenhouses gases found on the chart (as "CO_2equ") includes CO and HC contribution to greenhouse effect.

Total volume of consumed fuel and total mass of greenhouse gases left in the atmosphere along the "Linas-Musée d'Orsay" route

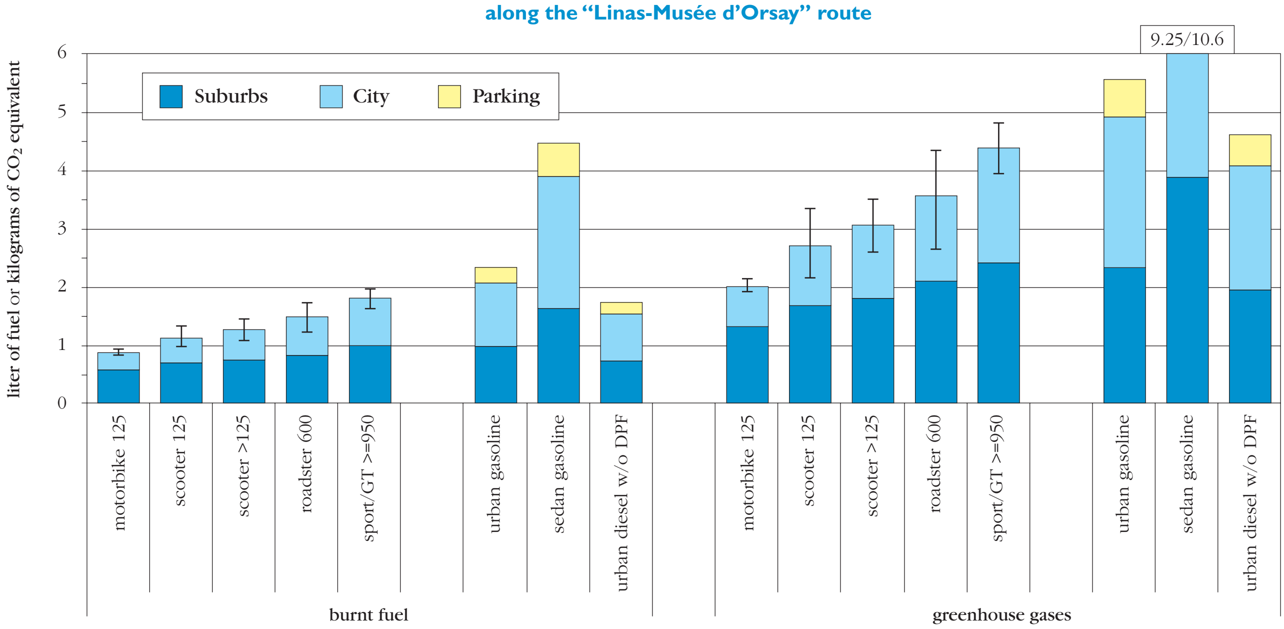

Fig.6: comparison of total consumed fuel and emitted greenhouse gases.

- Globally, fuel consumption for Euro3 PTW is lower than that of the two gasoline-powered cars. Only the compact diesel car is a bit more fuel efficient than motorcycles with engines larger than 950 cm^3.
- The latter PTW (the most powerful of our test range) demonstrate high fuel consumption that can be close to that of small cars: this is confirmed by the feedback from big capacity PTW users.
- It appears clearly that the lower the PTW engine size, the lower the fuel consumption. 125 cm^3 PTW are the more fuel efficient vehicles.

Moreover, a noticeable difference emerges between all the 125 scooters and the 125 motorbike. The possible technical factors are: the maximum output of the motorbike being lower than scooters (8 kW vs 10 to 11 kW), the mass of the vehicle (conditioning the test inertia) of the motorbike being lower than the tested scooters (120 kg vs 135, 155 and 160 kg), but probably the main explanation comes from the gearbox allowing a better optimisation of the fuel consumption than the scooters CVT. This particularly can be noticed in the urban phase where the motorbike consumption shows a much better level than the scooters (gear shifting strategy offers more degrees of freedom there than in faster suburban cycle). The management of 125 cm^3 scooters transmission ratio appears to be tuned for good performance and driveability, but current technology still remains far from basic "eco-driving" behaviour (a CVT seldom leads to high engine load at low revs). Besides, it is well known that basic CVT transmission have a bad efficiency, as can be deduced from their cooling needs when driving.

Greenhouse gases emissions follow the same trend than fuel consumption. The only difference is that the diesel car emits more CO_2 than gasoline engines per liter of consumed fuel, leading to a global emission being slightly over the big capacities PTW average (with the car parking being taken into account).

Euro4 auto and Euro3 PTW comparison: energetic efficiency

In order to better understand the above results concerning fuel consumption, ADEME evaluated the energetic efficiency (conversion of the fuel into mechanical power) of each vehicle. A simple calculation along the real-use cycles, using the settings of the roller bench for each vehicle, gives the mechanical energy provided by their powertrains during each test. This mechanical energy results from the fuel conversion into power at the wheel, through the engine and transmission. Therefore, the ratio between this energy needed for the vehicle travel and the amount of consumed fuel, illustrates the energetic efficiency of the powertrain.

It must be highlighted that despite a false common idea, the energy needed to move a PTW is not only proportional to its mass. The average aerodynamic drag of a PTW is between 50 and 100% of a car's drag (C_d.A order of magnitude between 0.4 and 0.7 m^2) and rolling resistance of PTW tyres is about twice the resistance of car's tyres (about 15 to 20 kg/ton). The lower mass of PTW is a clear benefit for acceleration potential but fuel consumption is not reduced by the same ratio than mass. On the ADEME test cycles, the total average energy needed for PTW is between 50 and 60% of the tested cars.

The classification of the different vehicles according to their efficiency is presented on fig.7. Important factors such as Euro level, engine fuelling system, maximum power output and test inertia (closed to the "real-use" mass including the rider) are also reminded on the graph.

Estimation of powertrain energetic efficiency on "real-use" cycles

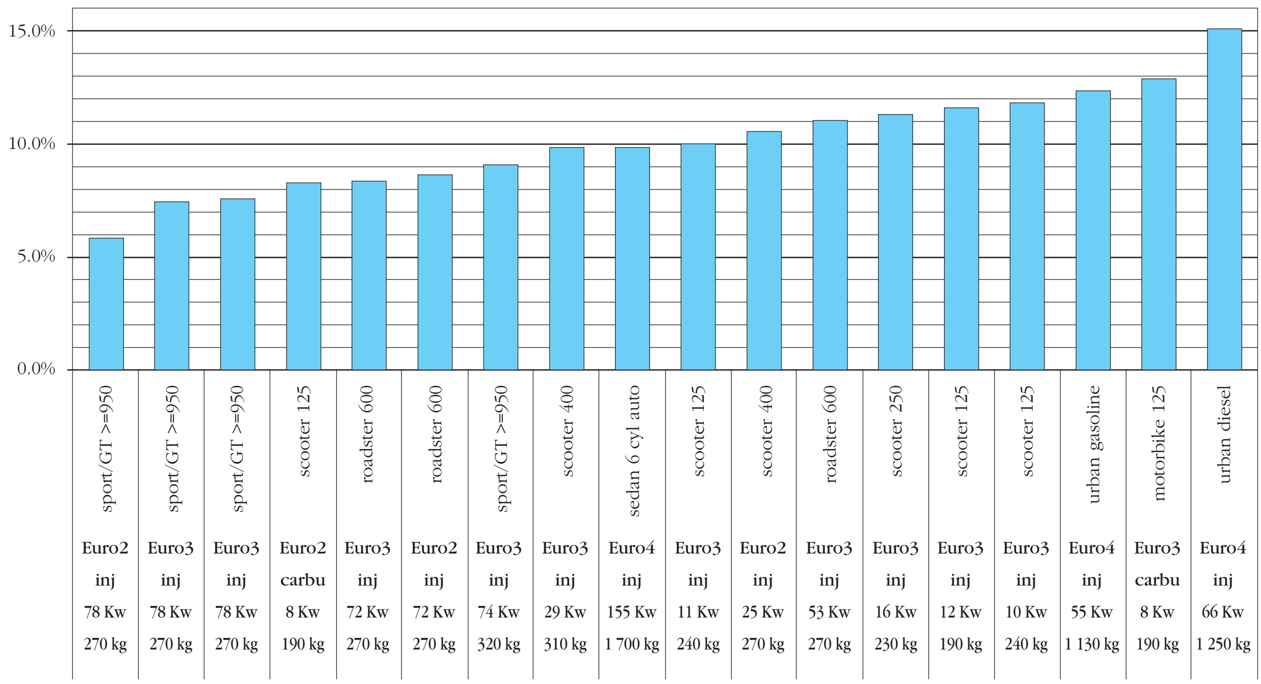

Fig.7: classification of estimated energetic efficiency.

It appears that in daily urban and suburban use:

- The powertrains of small Euro3 PTW have fuel efficiencies comparable to that of compact gasoline car, the 125 motorbike even being slightly better than our reference urban gasoline car. Their light weight provides a significant reduction in fuel consumption as they require less energy than a car to move.
- The improvement of fuel use with Euro3 is also noticeable for all PTW categories, as Euro2 models are less efficient than Euro3 PTW of the same type and with similar power/mass ratio.
- The vehicles with large engines, which are not well-suited to the type of use studied here, are clearly less energy efficient. This is linked to their performance potential: the 210 HP car and the motorcycles with a high power/weight ratio, have significantly lower efficiency under these operating conditions. The strong decrease of engine efficiency when used at low loads is a well-known feature of internal combustion engines. This also explains why some large motorcycles have fuel mileages which are comparable to that of much heavier cars.

A quick look to the future: WMTC cycle

As a final result and to assess the consistency of WMTC with current Euro regulation, emission results and fuel consumption measurements of the Euro3 PTW have been compared on various test cycles: the ADEME "real-use", the WMTC, and the current Euro3 mandatory cycle.

Fuel consumption on various test cycles

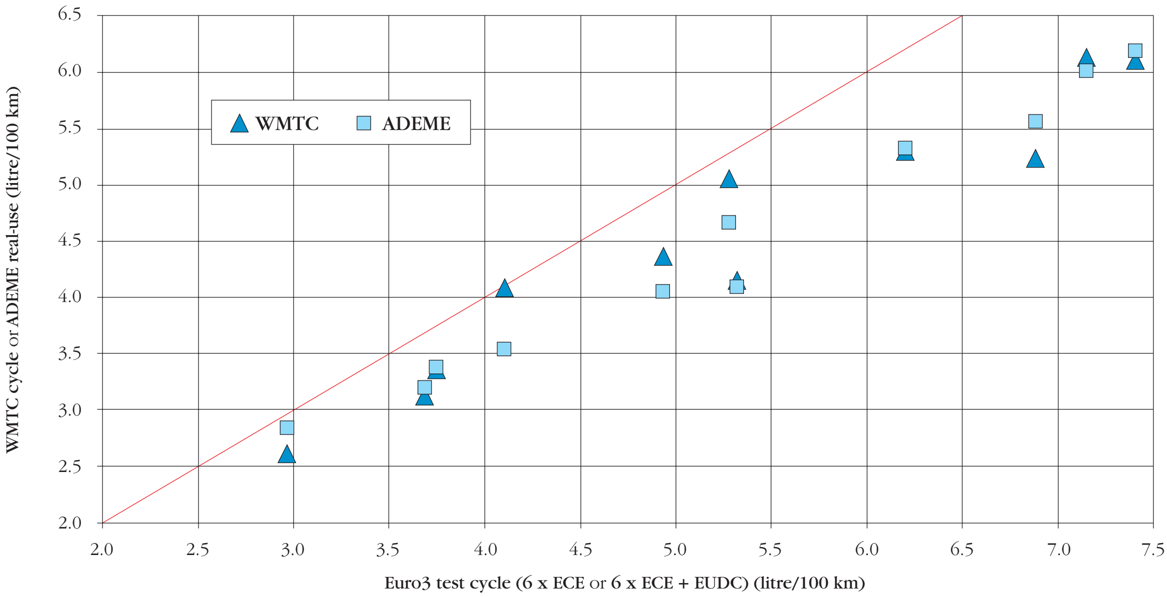

Fig.8: fuel consumption on WMTC, ADEME "real use", and Euro3 test cycles.

Fig.8 clearly shows that fuel consumption on WMTC and ADEME cycles are lower than the values on Euro3 cycle (they are all under the "y = x" red line). As ADEME cycles were built on a "real-use" basis and as WMTC results are globally very closed to ADEME's ones, it can be considered that WMTC introduction would lead to good consumer information with realistic fuel efficiency values measured during homologation.

As far as pollutant emissions are concerned, the situation is not so simple to analyse, as shown on fig.9.

Euro3 PTW results on Euro3 and WMTC test cycles

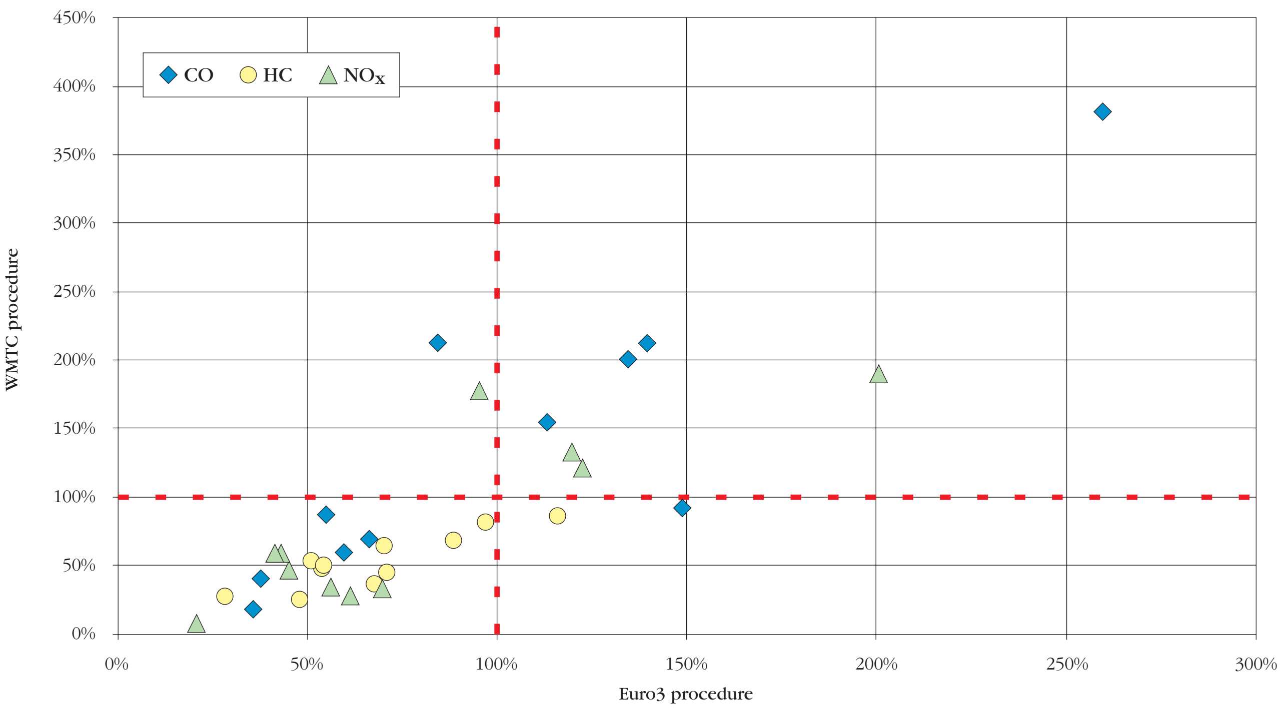

Fig.9: exhaust pollutants on Euro3 and WMTC test cycles.

The tested PTW were tuned for Euro3, certainly not optimised on WMTC cycle. However, it appears that on the PTW of our sample:

- Average CO emissions are 80% higher on WMTC cycle than on Euro3 cycle (remaining globally lower than ADEME cycle results). Nevertheless, some CO values on the WMTC cycle are lower than on the Euro3 cycle.
- HC emissions on WMTC cycle are about 10% lower than on Euro3 (but slightly lower than on ADEME cycle). All the tested PTW emit less HC on WMTC than on Euro3, with none of them failing the WMTC HC limit.
- NO_x emissions do not show any clear trend, being strongly “fine tuning-dependant” (through the accuracy of the lambda regulation).

For 4 out of 11 tested PTW, the results in WMTC conditions and in Euro3 conditions (cycle and emission thresholds) are “homologation compliant”.

2 of the tested PTW are Euro3 compliant but fail in WMTC conditions (because of CO for the first one and NO_x for the other).

One PTW is complying with WMTC procedure, but fails at Euro3 test (it’s the only tested PTW over-emitting HC compared to its corresponding Euro3 limit).

The fact that some of the tested PTW still satisfy Euro3 despite their mileage and are moreover “WMTC compliant” demonstrates that obtaining a robust emission control is possible for PTW.

However, the various PTW complying with only one of the two sets of cycle and limits demonstrate that WMTC can not be described as systematically more severe than Euro3.

Consequently, WMTC must be associated with some durability requirement to ensure that it will lead to an effective further reduction of PTW exhaust emissions compared to Euro3 situation. This is one lack of Euro3 current regulation.

The second “gap in the law” in Euro3 is the non-representative ECE cycle used for PTW under 150 cm^3 (which are commonly used above 50 km/h). It is clear that WMTC cycle (reaching 95 km/h for category 2 PTW) will introduce a strengthening of the emission control requirements for 125 cm^3, as it will be closer to real use. Associated with the durability, it should result in improving smaller PTW exhaust emissions.

Summary of findings

This study provides information on the current environmental status of powered two wheelers:

- Euro3 legislation has resulted in a clear improvement in PTW pollutant emission levels under real operating conditions, especially above 125 cm^3.
- A substantial difference remains between the emissions level of powered two wheelers and those of recent model passenger cars, in real-use.

This is the result of a difference in the severity of automobile and motorcycle regulations: the strength of Euro3 for motorcycles (2007) is comparable to Euro1 (1993) or Euro2 (1997) for cars. The above emission analysis for Euro3 PTW shows results comparable to those of cars between 10 and 15 years old (still quite common on the road today).

- The high performance levels of motorcycles with powerful engines are not in contradiction with good management of pollutant emissions: our measurements show that they have among the best results for Euro3 PTW. However, a high power/mass ratio leads to an efficiency penalty increasing the fuel consumption.
- Euro3 PTW NO_x emissions are significantly lower than those of diesel cars, even of the most recent models.
- The regulation for 125 cm^3 emissions (specific and less severe than that for larger engines) results in levels of CO which are significantly higher during their frequent actual extra-urban use. This particular point deserves special consideration by legislators in the near future given the increasing numbers of this type of PTW in Europe.
- The lack of durability requirements with Euro3 can be noticed with nearly half of the tested PTW not succeeding the homologation test after a few thousand kilometres.
- WMTC could be an efficient improvement of the current situation, provided that it includes a durability requirement. It would also lead to a good tool for consumer information concerning CO_2 emissions and fuel consumption.
- Euro3 PTW greenhouse gas emissions are below those of the average automobile vehicles sold today (an average of 87 g/km for 125 cm^3 scooters compared to more than 130 g/km for a compact diesel car). The best car in the ADEME 2007 ranking (Smart ForTwo diesel) emits 88 g/km over the NEDC homologation cycle (urban and extra-urban cycle).

Future expected regulatory changes will be able to address some of these issues. The introduction of the WMTC measurement cycle (World Motorcycle Test Cycle), the regulation of emission control durability, the reduction of emissions through evaporation and the requirement to measure CO_2 are currently under study by the European Commission. This must be taken as an interesting opportunity for PTW industry to offer greener vehicles, while increasing fuel prices and traffic congestion lead more people to consider PTW as a solution to their mobility needs.

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ADEME
Agence de l'Environnement
et de la Maîtrise de l'Energie

Département Transports et Mobilité
500, route des Lucioles - 06560 Valbonne

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