Study on possible new measures concerning motorcycle emissions

Final Report – Revised Version

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Summary

This report is a revised version of the final report on new measures concerning motorcycle emissions, submitted to the European Commission in October 2008 (http://ec.europa.eu/enterprise/automotive/projects/report_measures_motorcycle_emissions.pdf). A thorough review took place in this period and new scenarios were requested to be performed. Also, a Motorcycle Working Group meeting took place on June 29, 2009 where a discussion on the different regulatory approaches were discussed. This report includes all this new information that became available in the period Oct.2008 to June 2009.

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List of abbreviations

2S	2 Stroke
4S	4 Stroke
ACEM	Association of European Motorcycle Manufacturers
AECC	Association for Emissions Control by Catalyst
ATV	All Terrain Vehicle
ATVEA	All Terrain Vehicle industry European Association
BASt	Federal Highway Research Institute (Germany)
BAT	Best Available Technology
CB	Carburettor
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of Production
COPERT	Computer Programme to Calculate Emissions from Road Transport
DeNOx	NOx emission control devices
DPF	Diesel Particle Filter
DI	Direct Injection
EC	European Commission
ECE-R40	Economic Commission for Europe Regulation 40 driving cycle
ECE-R47	Economic Commission for Europe Regulation 47 driving cycle
EDC	European Driving Cycle
EUDC	Extra Urban Driving Cycle
EFI	Electronic Fuel Injection
EMPA	Federal Laboratories for Materials Testing and Research (Switzerland)
EOBD	European On Board Diagnostics
EQUAL	European Quadricycle League
FC	Fuel Consumption
FI	Fuel Injection
GDi	Gasoline Direct Injection
GHG	GreenHouse Gas
HC	Hydrocarbons
IES	Institute for Environment and Sustainability (European Commission)
IMMA	International Motorcycle Manufacturers Association
IUC	In-Use Compliance
IUPR	In Use Performance Ratio
JRC	Joint Research Centre (European Commission)
LAT	Laboratory of Applied Thermodynamics (Aristotle University, Greece)
MIL	Malfunction Indicator Lamp
MC	Motorcycle
MCWG	Motorcycle working group
MVEG	Motor Vehicle Emissions Group
MY	Model Year
NEDC	New European Driving Cycle
NO_x	Nitrogen Oxides

OBD	On Board Diagnostics
OEM	Original Equipment Manufacturer
OxCat	Oxidation Catalyst
PTW	Powered Two Wheelers
RW	Road Worthiness
SME	Small Medium Enterprise
TA	Type-Approval
TNO	Netherlands Organization for Applied Scientific Research
TÜV	Technical Inspection Agency (Germany)
TWC	Three Way Catalyst
UDC	Urban driving Cycle
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds
WMTC	Worldwide Motorcycle Test Cycle

Executive summary

Background

The current study largely follows up on an earlier (2004) study conducted by the LAT/AUTh (Final Report on: "Impact assessment/Package of New Requirements Relating to the Emissions from Two and Three-Wheel Motor Vehicles") which aimed at evaluating potential measures for the regulation of mopeds at a Euro 3 level and the more efficient control of in-use motorcycles, as requested by Directive 2002/51/EC. The current study offers an updated version of the calculations, using new experimental information that became available over the last four years. It also extends the time horizon of the calculations to 2020, instead of 2012 which was the target in the previous study. This allows a more realistic calculation of the cost-effectiveness of the various measures proposed. The current report is the July 2009 revised version of the report submitted to the European Commission (EC) in October 2008. It responds to a number of issues raised by the EC and discussed in the Motorcycle Working Group (MCWG) in the meantime.

The boundary conditions for the cost-effectiveness calculation of PTW emissions have somehow changed since 2004. The most important changes can be summarized in the following list:

- The introduction of Euro 5-6 passenger car emission standards and Euro VI heavy duty emission standards means that the contribution of power two wheelers (PTWs) will become increasingly important, if no additional regulations are brought forward. Therefore, the reduction in emissions from other road vehicle categories in the future should be taken into account when calculating the contribution from PTWs.
- The long-term motorcycle market seems to increase in European countries and the projection of the industry is that this will more or less continue into the future. This has to be reflected to the calculations. On the other hand, the mopeds market decreases as it was also earlier projected. The current sales' plunge due to the 2008-2009 financial turmoil is not modelled because this is still considered as a short-term effect.
- The market of PTWs becomes more diverse in model types and versions. In particular, the market of three-wheelers and four-wheelers is growing with a large variety of models. The engine types of these models vary from spark ignition to compression-ignition ones.
- UNECE has further advanced with the development of the World Motorcycle Test Cycle (WMTC) and a second version of the cycle is currently available. As the European regulations offer the first version of the cycle as an alternative for type approval (2006/72/EC), it is necessary to review what the implications of introducing the second version of the cycle will be on the type approval procedure.

A number of specific objectives were set in the service request for the particular project. In particular, the report should assess the cost-effectiveness of the following regulation elements:

1. Durability of anti-pollution devices
2. In-Use conformity
3. CO_2 emissions and fuel consumption
4. New set of pollutant emission limit values for tricycles and quadricycles
5. New set of pollutant emission limit values for mopeds
6. OBD systems on two and three-wheel motor vehicles
7. Evaporative emissions on two and three-wheel motor vehicles
8. Impacts of the mandatory use of the new WMTC

In order to consider the impact of different policy options, the following five approaches were modelled:

- Baseline: No policy change, in principle continue with directives 2002/51/EC & 2006/72/EC.
- Scenario 1: Introduction of the bundle of measures initially proposed by the European Commission to their preliminary draft proposal (document *Moto_105* [14]). This is basically introduction of a Euro 3 mopeds limit.
- Scenario 2: Emission limits for motorcycles that would approach technical equivalency to Euro 5 passenger cars plus an additional step over scenario 1 for mopeds (Euro 4).
- Scenario 3: Introduction of measures that are today considered as best-available technology for PTWs.
- Scenario 4: Introduction of the same emission limit values of Euro 5 cars to all PTWs, with distinction to combustion concept (positive ignition or compression ignition).

Methodology and input data used

The methodology used to calculate the cost-effectiveness was revised over 2004 by using updated information as much as possible, compared to the earlier study. Eventually, this has been made possible for most of the technical aspects of the work. The emission factors for both exhaust and evaporation emissions have been revised based on new experimental information. The vehicle stock of mopeds, motorcycles, and other road vehicles has been updated. New estimates for costs for aftertreatment systems have been also considered.

Scenarios were then executed by introducing all available technical and cost information in a computer model, which was developed in the framework of the 2004 report. The model was updated with all new data (improvement of emission factors, PTW fleets etc.) and new methodologies (addition of tricycles and quadricycles, new evaporative emissions methodology, etc). The simulations provided the effectiveness (i.e. emission reduction) and the additional cost of the different measures for the fleet of PTWs. The two values are then combined to calculate the cost-effectiveness of the different measures.

With regard to the assessment of measures where no cost-effectiveness was necessary, this was done by collecting information from the public domain and emission databases which were available to the project partners.

Results of the scenario calculations

PTW share of total road-transport emissions

Compared to the 2004 report, the extension of the projection to 2020 reveals the following differences, if one assumes no further PTW measures considered to what has already been decided today:

- The contribution of PTWs to total HC emissions becomes even more important, emitting in absolute terms more than all other vehicle categories by 2020. This clearly shows the need to better control HC emissions from mopeds and motorcycles
- PTWs also become much more important relevant contributors of CO emissions by 2020. However, there are limited CO-related air-quality issues today in Europe and the emissions of CO are further assumed to decrease in the future due to normal technological development. Hence, the high contribution of motorcycles and mopeds to total CO emissions is not considered such a significant environmental problem.
- The contribution of PTWs to NO_x and PM emissions seems to increase after 2013, due to the introduction of DeNOx and DPF aftertreatment systems in both passenger cars and heavy duty vehicles at Euro 5/V and particularly in Euro 6/VI level, that significantly decrease emissions from these vehicle categories. Although, the contribution of PTWs remains small (at ~2% and ~5% respectively) by 2020, there seems to be a need to further control emissions in particular when focussing on urban emissions. In this case, the contribution of PTWs increases to ~10% and 20% of total road transport NOx and PM emissions respectively by 2020.
- CO_2 emissions from PTWs are overall a very small share of total emissions. Given the fact of much lower CO_2 emissions of PTWs per passenger, compared to passenger cars, the increase in trips conducted by PTWs will actually have a positive effect in the overall reduction of CO_2 emissions from road transport.

Tri- and quadricycle share of total road transport emissions

As a result of the new estimate, the contribution of such vehicles cannot be considered negligible, within the PTW sector. In particular, quadricycles will be responsible for more than 35% of total PM from the sector in 2020. This corresponds to almost 2% of the total PM emitted from all road transport sectors. Given the facts that the evolution of the mini-cars stock is quite conservative and that their operation mainly occurs in urban or tourist areas where air quality is of a high importance, this relatively high share of PM emissions is an issue that needs to be addressed.

The evolution of NO_x emissions from such vehicles is also an issue that needs to be looked at with some attention. The contribution of such vehicles is currently some 7% of the total PTW emissions. Due to the introduction of more Euro 3 motorcycles in the future years, which may actually have higher NOx emissions than conventional motorcycles, share of tricycles and quadricycles to total emissions is not expected to significantly change in the future. As a matter of fact, quadricycles are projected to contribute to only about 0.15% of total road transport emissions. Attention however should be given to local environments (hotspots) with high concentrations of such vehicles.

The contribution of quadricycles in HC emissions is dominated by ATVs and their gasoline engines. While ATVs were about 1.5% of total PTW emissions in 2007, this is projected to more than double in the future, as emissions from PTWs drop with the improvement in technology. As a result, ATVs alone will be some 2% of total HC emissions emitted by road vehicles. Again, this is an issue that will have to be addressed by the regulations.

Emission limit related scenarios

The cost, emission benefits and the cost-effectiveness of the different policy measures, related to the formulation of new emission standard values were assessed in this study. A set of alternative scenarios and a baseline were developed in order to evaluate different policy options as regards possible future emission limits.

1. "Baseline": This considers the emission evolution assuming no legislative step beyond 2002/51/EC and 2006/72/EC. The cost of the baseline is assumed zero.
2. Scenario 1: This corresponds to the "Initial Commission Proposal" related to update of emission standards, as reflected in the "Status Report Emissions" (Moto 105 [14]). This assumes introduction of Euro 3 mopeds in 2010 with numerical emission limit values equal to Euro 2, but a type-approval method which consists of a cold-start ECE-R47 and a 30% weighing factor for the cold start. In this package of measures, no emission control of motorcycles further to Euro 3 is included.
3. Scenario 2: This scenario assumes a Euro 4 stage for motorcycles in 2012, with a reduction of 25% in all pollutants relative to Euro 3 standards. Euro 5 is then introduced

in 2015 with emission standards which lead to the same Euro 5/Euro 3 ratio with gasoline passenger cars. For mopeds, this scenario assumes introduction of Euro 3 in 2012, with emission standards similar to Scenario 1. Finally, a further Euro 4 stage for mopeds in 2015 assumes a 33% reduction in THC+NO_x.

4. Scenario 3: Introduction of a Euro 4 emission standard for motorcycles in 2010 that will introduce reductions already achievable by the 20th percentile of the current motorcycle fleet (best available technology, BAT). The emission factors for CO, HC, NO_x and CO_2 utilized in this scenario, the data sources and the assumptions are described in section 0 of this report. We were not able to introduce any reduction to PM emission factors in this scenario, due to the lack of available experimental information.
5. Scenario 4: Introduction of emission limits equal to Euro 5 passenger car limits for all PTWs (mopeds, motorcycles, tricycles and quadricycles) in 2016 with an intermediate Euro 4 step in 2013. This scenario has been a request for a numerical simulation by the European Commission. The technology required and the feasibility to meet the strict emission limits imposed have not been assessed in this study.

Based on the simulation, the scenarios achieve the following reductions over the baseline in 2020:

- Scenario 1 achieves 1.5%, 6.5%, and 27% reduction in CO, HC, PM, and CO_2 respectively. NOx marginally increases (by +0.24%).
- Scenario 2 leads to 16.3%, 15.3%, 37%, 1.77%, and 26.9% reductions in CO, HC, PM, CO_2, and NOx, respectively.
- Scenario 3 achieves reductions of 15%, 2.3%, 9.7%, and 22% for CO, HC, CO_2 and NO_x, respectively. No PM reduction could be assessed based on the available experimental data.
- Finally, Scenario 4 achieves 18.5%, 28.2%, 40.1%, 0.88%, and 36.7% reductions in CO, HC, PM, CO2, and NOx, respectively.

The cost-effectiveness of the introduction of the different technical measures in each scenario has been assessed until 2020, regardless of the date of introduction of each emission standard. This has led to the following conclusions:

- With regard to HC and PM Scenario 1 appears as the most cost-effective one, followed by Scenario 2 and 4. Scenario 3 appears much less cost-effective for HC as it practically requires the same technology with Scenario 2 but with more relaxed emission limits. No effectiveness could be calculated for Scenario 3 and PM.
- Scenario 1 achieves no NOx reductions and therefore no cost-effectiveness could be assessed. From the remaining scenarios, Scenario 3 appears as the most cost-effective demonstrating the potential of the best available technology to reduce NOx.
- With regard to CO_2, cost-effectiveness is not a direct product of technology introduced specifically to decrease CO_2, as no CO_2 emission limits were introduced by any scenario. However, CO_2 benefits occur as a positive side-effect of the technology introduced to limit

other pollutants. In this respect, Scenario 3 appears as the most cost-effective one, followed by Scenario 1, 2, and 4 in degrading order, in terms of cost-effectiveness.

Durability of Emission Control Systems

The need to introduce an emission control durability regulation was examined. It was not possible to estimate the cost to develop emission control devices that would be necessary to achieve a longer useful life. The simulations for the effectiveness of the different options led to the following conclusions:

1. The actual degradation of current stock motorcycles is largely unknown as two experimental campaigns available to the study team led to distinctly different behaviour.

2. The 20% degradation over the useful life considered in the baseline, rather appears at the low range of expected values.

3. It is absolutely critical that a durability regulation is introduced for PTWs, otherwise significant departures from the emission standard may occur at rather short distances (i.e. less than 5000 km). It is impossible to quantify the extent of this phenomenon without a durability regulation in place.

Once a durability regulation has been decided, the actual useful life is not a critical parameter. Increase of the useful life by 60%, to simulate the Euro 5 passenger car equivalent useful life, led to additional reductions in emission levels by 2020 in the order of 4 ktn of HC (out of 220 ktn total emissions), 30 ktn of CO (out of 900 ktn of emissions) and 1.1 ktn of NO_x (out of 37 ktn of emissions).

In-Use Compliance (IUC)

There are no different conclusions reached for the effectiveness of IUC over the 2004 report. IUC is considered as one of the no-regret measures, in the sense that an IUC procedure works as a reminder that any vehicle can be potentially subjected to an emission test, even after leaving the manufacturer's facility. In that sense, the manufacturer rather adopts the precautionary principle that all products leaving the production line should be compliant with their type approval limits. This allows limited – if any – space for a direct IUC effect, i.e. the actual discovery of a vehicle family which does not comply with its type approval and the initiation of a remedial process, including the recall, the repair of the defected component, etc. This is the experience gained with the IUC procedure for passenger cars in Europe. In a report, summarizing experience from passenger car IUC in Germany before 2000, no vehicle type of German specifications was found to exceed the type-approval limits. Out of the nine car types admitted for IUC tests, only one direct injection car (an innovative technology at the time of executing the IUC tests) of Dutch specifications was found not to comply with the IUC limits but a condition specific to German type of driving was deemed responsible for this behaviour. Although passenger car conclusions are not necessarily directly transferable to motorcycles, due to the differences in emission control systems utilized, this report at least gives an indication of the direct IUC effect expected.

Modelling of IUC effect by introducing certain assumptions indicates a better cost-effectiveness compared to the 2004 study, as the extended time horizon in the current study (2020 instead of 2012) means that a vehicle that would not attain the emission standard is now considered to circulate for a larger time frame. Still, the emission reductions achievable are marginal (180 tn of HC to a total of ~220 ktn by 2020). The actual cost of implementing the measure is also not too high. However the difficulty to locate vehicles at an appropriate condition and willing users to provide them for a test may be a significant limiting parameter. This is even more so in countries with low quality fuel (e.g. Asia), but poor fuel quality is not expected to be an issue in Europe. Another issue that needs to be addressed when considering the real-world effect of an IUC procedure is the competition between the certification authorities. This means in practice that none of them wants to blame their customers (the motorcycle manufacturers) in case of non-compliance. Therefore remedial measures (additional tests, vehicle replacement, etc.) may be taking place to avoid reporting of non-compliance. Although the extent of this procedure cannot be quantified, it is a frequent rumour which has to be considered in efficient policy making.

The current analysis confirms the decision reached in the Moto_105 proposal [14] not to introduce an IUC procedure for power two wheelers. The reason is the limited effect this is expected to have, compared to the difficulty in locating representative vehicles.

Type approval for CO_2 and fuel consumption

The proposal for CO_2 and fuel consumption measurement in document Moto_105 represents the conclusions from the earlier (2004) LAT/AUTh study and, therefore, there is not much new technical information to be added in this report.

However, the formation of the regulation should allow for a uniform characterisation of PTWs with respect to their energy consumption. The risk is that countries will come up with their own labelling system based on the internal structure market. This increases the risk of adding confusion to the customers and the manufacturers with respect to evaluation of their different products. For example, using a national instead of a uniform international system to classify vehicles would mean that a vehicle model would be differently scored in different countries. This is confusing and does not assist in the boundary-free market integration within EU.

One way of limiting the risk of unequal and ambiguous characterization is to label the energy efficiency within certain categories. One could propose a classification based on capacity, market segment (e.g. scooter, enduro, super-sport, etc.). In any case, as in the case of passenger cars, this measure is more relevant for small, low cost motorcycles. In high-capacity sport models, used mostly for recreation, fuel economy is a rather lower priority compared to absolute performance.

OBD introduction

Using the 2020 as a time horizon compared to the 2012, which was used in the earlier study (2004), improves the cost-effectiveness of the OBD introduction. The reason is that the probability of severe malfunctions increases with age and, therefore, the emission benefit of a system that could diagnose these malfunctions increases. However, there are significant uncertainties in this calculation as it largely depends on a scenario of emission malfunction probability and not solid experimental data on the behaviour of actual motorcycles. There also continues to be a difficulty in the technical implementation of catalyst efficiency monitoring in motorcycles because the knowledge from passenger cars is not directly transferable to motorcycles. Motorcycles have a wider engine speed range, the catalyst thermal gradients are larger due both the operation of the engine and the position of the catalyst, while the WMTC driving cycle does not include steady-speed modes that would enable the same OBD monitoring strategy with passenger cars. This does not mean that OBD monitoring is technically impossible but extensive calibration will be required to introduce OBD for motorcycles at this stage.

The recommendation from the current study is, again, that other measures have a higher priority than the introduction of OBD. This means that durability regulations and roadworthiness procedures need to be first established. These will provide better information on the actual degradation and malfunction probability of motorcycles. After such information becomes available, one would be in better position to reassess the introduction of OBD for motorcycles.

Evaporative emissions

Two options were considered for evaporation control of PTWs. The first measure was the mandatory introduction of fuel injection for mopeds. Fuel injection results to lower evaporative emissions due to its sealed construction, compared to the open bowl of the carburettor. The option of introducing fuel injection to all new models appears a very expensive measure, if all the additional cost for the fuel injection system is allocated to the control of moped evaporation. As a result, introducing fuel injection with the purpose to control moped evaporation emissions appears as a non realistic approach from a cost-effectiveness perspective.

The second measure addressed was the evaporation control of motorcycles, using a canister to vent the fuel tank. This appears as a much more cost effective solution. An updated methodology, based on many more experimental data was used in this study, compared to the 2004 report. As a result of the new methodology, the cost-effectiveness appears worse due to the lower evaporation emissions of motorcycles equipped with fuel injection, than what was earlier considered. In the past, all motorcycle types were assumed to emit about 1.2-1.3 kg HC/year/vehicle. The new experimental information shows that this is rather true for large motorcycles equipped with carburettor. The introduction of fuel injection already significantly reduces evaporation emissions by ~60%; a benefit not considered in the 2004 report. In addition, the actual emission evaporation level is lower for smaller vehicles, due to the smaller tank capacity. The effect of the tank size was also not addressed in the 2004 study.

However, despite the lower benefit than earlier assessed, we continue to consider evaporation control as one of the technically and socially mature measures for the further control of hydrocarbon emissions. Also, the corrected cost-effectiveness calculation still results to quite reasonable values for cost-effectiveness. Therefore, the proposal for introduction of evaporation control in Document Moto_87 is still considered a reasonable approach in controlling emissions.

Tricycles and quadricycles

No cost-calculation has been performed for the emission control of these vehicles. The reason is that they are produced in small series and it is difficult to collect information on the cost of individual component. However, the emission evolution leads to some solid conclusions with regard to the regulation of PTWs:

1. The stock size of these vehicles increases and their emission control needs to be given more attention compared to what thought in the past.

2. If no additional measures will be taken, the contribution of such vehicles in all pollutants (CO, HC, NO_x, PM) will significantly increase in the future. With no additional measures, it is projected that quadricycles will be responsible for ~1.75% of total road transport PM emissions, despite they represent only ~0.09% of total activity. The contribution becomes even more important as several of these vehicles (in particular mini-cars) operate in areas where the population is highly exposed to their emissions (e.g. tourist areas, parks, schools, etc.).

3. An effective regulation should also cover ATVs, as there is no other regulation addressing the emissions of such vehicles. Therefore, an explicit statement to include "four-wheelers designed primarily for use in non-paved streets" should also be included in the regulation.

4. Selecting emission standards based on the scenarios performed depends on the target that one needs to fulfil. All Scenarios achieve quite substantial reductions of total emissions from such vehicles in 2020 in absolute terms, assuming that their stock does not evolve differently than projected in this report. If the criterion is to keep the relative contribution of these vehicles to levels equal to 2009, then the following can be said: Scenario 1 leads to marginal increases in HC and CO and substantial increases to PM and NOx. Scenario 2 decreases the relative contribution to CO and HC and leads to only marginal increases in NOx and PM. Scenario 3 leads to slight reduction of CO, slight increase in HC and roughly doubles the contribution in NOx and PM. Scenario 4 reduces the relative contribution in CO by 2.4 times, the HC contribution by 4.8 times, and leads to 1.5 and 1.2 times increase in the relative contribution of NOx and PM respectively.

Social Impacts and Impacts to SMEs

The obvious social impact in introducing an emission control scenario is the reduction of pollutants concentration in the atmosphere. In particular for PTWs, this becomes increasingly important since the operation of many of them is limited only to the urban road network. The emission limit scenarios and the additional measures proposed offer significant reductions to pollutant emissions, especially for HC and CO where motorcycles, mopeds, and tricycles and quadricycles are the most significant contributors of road vehicles.

Based on information received from the motorcycle industry (ACEM) "Eurostat recorded 870 powered two-wheeler companies as manufacturers in 2006, and their average yearly turnover of Euro 8 million suggests a significant proportion of SMEs. The downstream sector depending on the PTW industry is represented by a network of over 37,000 dealers and independent repair shops". This information points towards a large number of SMEs directly or indirectly involved in the PTW business.

In general, and by repeating conclusions from the 2004 report, each policy option that will be adopted by the Commission to formulate a new legislation, contributes uniquely to a "common purpose", which is the reduction of pollutant emissions from PTWs. All policies related to pollutant emission reduction are associated with "*General Social Impacts*", which can be described by the following "chain reaction": Any regulation/implementation of a policy option most probably leads to an upward pressure on the PTWs' direct costs (i.e. purchase price) or associated costs (i.e. maintenance, periodically scheduled checks, etc.). This cost increase may cause a decline in new PTWs sales and especially in these categories that are popular to youngsters or low income consumers in general. Therefore, a stringent emissions policy may result to environmental benefits from new motorcycles, but on the other hand it may shift the market towards cheaper second-hand vehicles and/or increase in the lifetime of all vehicles, which may result even to an increase in pollution and congestion. Furthermore, a stringent emission policy may lead small vehicle fleets to their extinction, introducing an economic burden to small companies and SMEs.

It is difficult to estimate in absolute terms what will be the effect of each policy on SMEs employment and on the market structure. Most of the data available are empirical and originate from one source only (industrial associations) so it is not easy to draw solid conclusions. However, it seems that the PTW market is much more volatile than the passenger cars one, as revealed by the current economic turmoil. The Q1/2009 sales of motorcycles dropped by 35% over Q1/2008 compared to 17% of passenger cars over the same periods. This may be due to a larger share of motorcycles used for recreation rather than basic transportation, compared to passenger cars. Recreation use is much more elastic to cost increases than transportation needs. It is not known whether the reaction of the market to individual cost increase of motorcycles and mopeds, due to emission control measures, will be similar to what observed during the turmoil. In any case, emission control measures add relatively more to motorcycle price than passenger cars, and this should be taken into account when developing the regulations.

Assessment of additional measures and policies

Impact of European regulation in other parts of the world

The conclusions that can be reached from a look on global developments of PTW regulation and the impact of the European on global regulation may be summarized in the following points:

- European motorcycle legislation has strong impacts on Asian markets with respect to emission standard values and procedures
- Delays in integrating additional measures leads Europe in loosing the lead of emission regulation
- Complicated / advanced measures may not work in Asian countries due to organisation and mentality particularities. This refers in particular to:
  - OBD effectiveness, as limited respect to MIL warnings is expected, as long as the vehicle is fully operational. Therefore the effectiveness of OBD to identify malfunctions will not be followed by an effective procedure to repair these malfunctions.
  - In-use conformity will be difficult to enforce as several vehicles are expected to operate on various fuels after their registration. For example, it is known that lube oil or other hydrocarbon sources of poor quality are used as fuels in these countries. These fuels may have an irreversible effect on the emission control system (poisoning by ash or sulphur). Hence, collecting a sample which is within the manufacturer specifications may be difficult to achieve.
- Measures at manufacturer-level which require minimum user intervention (e.g. durability requirements) are expected to be more effective from a practical (real-world) point of view.

Based on the history of global emission regulation evolvement, complementation of the current Euro 3 emission standards with additional measures but also proposal of standards at Euro 4 level are expected to also exert more pressure on Asian authorities to control national fleets.

WMTC correlation

A revision of the equivalent EURO 3 limits based on the WMTC cycles was performed. In a first step the European vehicle classification and driving cycles (EDC) as defined in 2002/51/EC were compared with the WMTC vehicle classification and cycles as defined in GTR 2 of August 2005. It can easily be concluded that the WMTC cycles are much more in line with real world motorcycle driving than the EDC.

In a second step the amendments on GTR 2 from January 2008 were introduced and their influence on the correlation factors is discussed. These amendments are mainly related to WMTC class 1 and 2 vehicles. For class 3 vehicles only the amendments on the gearshift prescriptions are applied. They are intended to improve driveability and do not significantly influence the emissions results. In this context also the differences in the vehicle classification between 2002/51/EC and WMTC were considered. It could be concluded that at least for countries having a similar stock distribution as Germany the overlap is quite low.

In a third step an assessment of the influence of the amendments of GTR 2 on the correlation factors to the limit values of 2002/51/EC was performed, based on the IMMA database for the limit value discussions within the ECE WMTC group. This database consists of the data already used in JRC's correlation study and a lot of new data from 2007, where measurements are based on the amended cycles and vehicle classification. This database was further enriched by the results of 10 vehicles measured in 2007 at EMPA in Switzerland and 4 vehicles from the AECC EURO 3 motorcycle test program. For all these measurements the new WMTC cycles were used.

The results of the correlation analysis between the Euro 3 ECE40+EUDC (2002/51/EC) and the WMTC (2006/72/EC) driving cycles, based on the new experimental information, are summarized in the following table:

	Correlation factors for		
v_max	**CO**	**HC**	**NOx**
< 130 km/h	1.1	0.9	1.1
>= 130 km/h	1.2	1.0	1.4

The differences to the factors resulting from the limit values laid down in 2006/72/EC are not so big.

Impact of PTWs on local air-quality

Taking into account several recent studies on urban air quality assessment, it can be concluded that PTWs and mopeds in particular are important contributors to local air pollution, in particular as regards HC and PM emissions. Top down and bottom up approximations indicate that this contribution is in the range of up to 20% or more. Since the emissions of passenger cars are expected to decrease substantially, it is expected that mopeds and PTWs contribution will rise even further. Public awareness also rises, since a number of studies are commissioned that look closely to the issue of street level air quality and identify PTWs as an important source at his scale. Evidently, the recent developments at regulatory level with emission standards limiting not only the mass but also the number of particles and addressing also some categories of gasoline powered vehicles introduce new directions and boundary conditions in the PTWs regulations as well.

Nevertheless, it should be reminded that it is not clear whether PM emissions from PTWs and in particular two-stroke mopeds pose equivalent health risks to the diesel PM emissions, due to the different particle nature.

Type-approval based on the engine-family concept

The type-approval of PTWs on the basis of the "family concept" is a potential beneficial approach for certification of vehicles. For this reason the GTR No 2 initially endorsed the idea, because it would allow extension of conformity to vehicles with similar characteristics and thus reduce the cost and time demand for type approval. Nevertheless, the discussions on this issue were not fruitful and no family concept was incorporated. However in order to provide insight to the Commission on this issue, a brief review was conducted regarding similar approaches within the EU and US regulatory framework. Additionally a family concept proposed by the manufacturers in Moto 105 was analyzed and commented as a potential future development of the legislation.

Based on the analysis, it can be said that either vehicles or engines families can be given certification according to a "family" type-approval concept. There is a distinctive character between the requirements to group vehicles or engines within a family concept. Therefore, the two terms should not be used interchangeably within the regulatory framework, as this may lead to confusion and regulation gaps. In the same direction, any future regulations should be clear as to whether the scope of a family approach is to ensure conformity with respect to pollutant emissions or simplification of the CO_2 and fuel consumption monitoring procedure.

If aim of the regulation is to simplify the type-approval procedure with regard to conventional pollutants, then the "engine family" concept should be adopted, which is reflected by both the US regulations and the European Industry proposal in Moto 105. It is proposed that the industry comes up with typical examples of similar engine and aftertreatment realisations used in different models, together with the type-approval values of these motorcycles.

If the simplification of the CO_2 emissions monitoring procedure is sought, a broader approach should be investigated taking into account vehicle related criteria, at least:

- Vehicle mass
- Number of wheels
- Power output
- Transmission type

Final Evaluation of available options

A number of measures were examined in this study with respect to their effectiveness in reducing emissions and the associated costs. Based on this analysis, the final conclusions can be drawn:

1. Regulations for durability need to be introduced to effectively control emissions over the useful life of the vehicle. It is today very difficult to estimate the current degradation level of motorcycles but there is evidence that certain models may emit much beyond the emission limits at relatively short mileage after their type-approval. This situation needs to be remedied. As long as durability requirements have been introduced, the actual distance that will be used as a useful life is of secondary importance.

2. Regulations to monitor the CO_2 and energy consumption of PTWs can be put in place to monitor the performance of such vehicles. PTWs appear as much more energy efficient means of transportation than passenger cars and their activity should be promoted as a measure to further control GHG emissions from road transport. The energy efficiency labelling regulation should be formulated in a way that will not affect the sensitive PTW market. A solution would be to classify vehicles within the same market segment.

3. One measure that was found very cost-effective in the previous LAT/AUTh study was the establishment of a periodic road-worthiness test. Although this was not reassessed in the current study, it is repeated that road-worthiness testing is a very suitable measure in controlling emissions from motorcycles. This can become even more effective if it is linked to roadside emission checks, as vehicles will be checked without previous notice. Road-worthiness procedure effectiveness is enhanced if combined with the benefit this is expected to have on safety-related issues as well.

4. With respect to HC emissions, a number of measures can be classified with respect to the effectiveness and cost. IUC is both low cost and a low effectiveness measure that rather has a precautionary character. From the other measures, the evaporation control of motorcycles appears as the most cost-effective solution, while the Euro 3 mopeds as the most effective one. Interestingly, OBD measures appear more cost-effective than the BAT for motorcycle emission control. In general, OBD appears more cost-effective than what was presented in the earlier report. However, OBD technology is not yet mature for immediate introduction. A technical committee for discussing options of introducing OBD to motorcycles should however be formulated, in preparing the OBD introduction in the future.

5. For NO_x emission control, the available options are located along a straight line on a log-log scale, when their cost-effectiveness is concerned. Again, IUC appears as a low-cost, low-effectiveness measure. Then OBD options appear more costly and more effective. Finally, the higher effectiveness, but also cost, appears from the further tightening of the emission standards. Therefore, with regard to NOx high-cost measures are also the ones which can provide high effectiveness.

1 Introduction

1.1 Project identification

This is a revised version of the final report of the project entitled: *"Study on possible new measures concerning motorcycle emissions"* (ref. ENTR/15/18) awarded by the European Commission/ Directorate General Enterprise and Industry to a consortium led by the Laboratory of Applied Thermodynamics / Aristotle University Thessaloniki (LAT/AUTh - GR) and consisting of the German Federal Highway Research Institute (BASt - DE), EMPA Swiss Federal Laboratories for Materials Testing and Research (CH), TÜV-Nord Mobilität (DE), and TNO-Automotive (NL). The project was initiated in February, 2008 and finished in October of the same year. The final report of this project was presented in the Motorcycle MVEG meeting on October 20, 2008. However, a number of questions were raised by the Commission and the execution of a revised scenario was requested. Therefore, this revised version of the report tries to address these new issues raised. In addition, a new partner was added – Emisia SA – who performed the emission limit scenarios in this revised version of the report.

The current study largely follows up on an earlier (2004) study conducted by the LAT/AUTh (Final Report on: "Impact assessment/Package of New Requirements Relating to the Emissions from Two and Three-Wheel Motor Vehicles"[1]) which aimed at evaluating potential measures for the regulation of mopeds at a Euro 3 level and the more efficient control of in-use motorcycles, as requested by Directive 2002/51/EC [1]. The current study offers an updated version of the calculations, using new experimental information that became available over the last four years. It also extends the time horizon of the calculations to 2020, instead of 2012 which was the target in the previous study. This allows a more realistic calculation of the cost-effectiveness of the various measures proposed.

1.2 Background

The emission of powered two-wheelers (PTWs) was first regulated by Directive 97/24/EC which entered into force on June 17, 1999 and introduced two stages for the regulation of new types of mopeds; the first stage (Euro 1) became mandatory concurrently with the implementation of the Directive, while the second one (Euro 2) came into force on June 17, 2002. The same Directive also introduced an emission standard (Euro 1) for new types of motorcycles. The Commission was asked to come forward with proposals for a second stage of emission regulation for motorcycles. Directive 2002/51/EC (July 19, 2002) implemented the proposals of the Commission and introduced this second stage (Euro 2) of emission standards, together with emission standards for a Euro 3 regulation.

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1 Relevant documents of the discussions in the MVEG Motorcycles group may be found at the group's website (http://ec.europa.eu/enterprise/automotive/mveg_meetings/index.htm). By convention, all documents related to the discussion are provided with a "Moto_XXX" index. This convention is also used in the current report.

Directive 2002/51/EC already expressed the need to further control emissions of motorcycles, by introducing measures aiming at the durability of aftertreatment devices, the monitoring of CO_2 emissions, the introduction of roadworthiness testing etc. Indeed, the previous report of LAT/AUTh discussed the cost-effectiveness of the following measures:

- Durability of emission control systems
- In-Use Compliance procedure for PTWs
- Type approval for CO_2 and fuel consumption
- PM regulation from 2-stroke engines
- Euro 3 emission standard for mopeds
- OBD introduction
- Evaporative emissions
- Replacement & retro-fit catalysts
- Time-frame for full introduction of the WMTC
- Emission road-worthiness procedure

In that former study, we concluded that several of these measures may lead to significant reductions of motorcycle emissions, at a reasonable cost. A summary of the assessment is provided in document "Status Report: Emissions of 2- and 3-wheelers" which may be found on the web-site of the 7th meeting of the special MVEG group on Motorcycle emissions (Moto_87).

In particular, the regulation of the durability of emission control systems was considered as an important measure to control emissions over the vehicle life-time. The effect of the in-use compliance was found negligible for all pollutants and a non-practical measure to introduce, due to the many models in small series that exist for power-two-wheelers, compared to passenger cars. The introduction of fuel consumption and CO_2 monitoring was considered beneficial for the PTW market, due to the low CO_2 emissions per passenger-km. One of the measures that was looked into with much detail was the need to introduce a separate regulation on the control of PM. This was deemed not necessary, as measures introduced to reduce gaseous pollutant emissions were also considered effective to reduce emissions of particulate matter, based on the conclusions of the study of Rijkeboer et al. [2]. On the contrary, other measures, such as the promotion of synthetic oil use, were considered more cost-effective as an option to reduce PM emissions from on-road and future PTWs.

The previous study also proposed new emission standards for mopeds at a Euro 3 stage. The proposal was to retain the same numerical values with the Euro 2 regulation, but introduce a cold-start test with a 30% weighing factor of the cold-start part. On the other hand, the introduction of OBD systems was found to be a rather expensive measure for power two wheelers, as it is associated with significant investment and development costs, while the fleet of PTWs is much smaller than the passenger cars one. Contrary to OBD, the control of fuel evaporation by means of a canister to vent the fuel tank was considered effective and relatively economical, as it is based on well-known technology from the passenger car market and more than 90% of evaporation emissions originate from fuel evaporated from the fuel tank. As there was some misunderstanding related to the cost calculation in the earlier report, one should consult document Moto_109 which proves that evaporation is one of the cost-effective measures proposed. Finally, the introduction of a periodical road-worthiness procedure was also considered as a cost-effective measure, which would also have a significant effect on anti-tampering control.

There has been a general positive response within the MVEG motorcycles group, on the conclusions from the earlier report, which formulated the basis for the production of a preliminary draft proposal of a directive (Moto 105 document), already since 2005. However, the European Commission did not further proceed with this directive, as there has been a certain priority first in the regulation of passenger cars (Euro 5-6) and then heavy duty vehicles (Euro VI). However, as both these regulations have now been moved forward, the need to regulate power-two-wheelers has again been prioritised.

Compared to the 2004 report, the boundary conditions for the cost-effectiveness calculation of PTW emissions have somehow changed during the period 2004 to 2008. The most important changes can be summarized in the following list:

- The introduction of Euro 5-6 passenger car emission standards and Euro VI heavy duty emission standards means that the contribution of power two wheelers will become increasingly important, if no additional regulations are brought forward. Therefore, the reduction in emissions from other road vehicle categories in the future should be taken into account when calculating the contribution from PTWs.

- Opposite to what was previously considered, the motorcycle market seems to increase in European countries and the projection of the industry is that this will more or less continue into the future[2,3]. This had to be reflected to the calculations.

[2] Comment introduced in the report version Oct.2008: A major financial turmoil has been taking place at the time that this report is prepared (Oct. 2008), which has already some repercussions on the development of the automotive industry market growth. Our projections in this report do not reflect any potential effects of similar financial incidents, which are considered short-term, for the time being. The projections included in this report rather follow a business-as-usual type of gross domestic product growth in EU.

[3] Comment introduced in the report version Jul.2009: The financial turmoil has had a strong negative impact on the power two wheelers market. During the first quarter of 2009 the European PTW market declined by 35%, compared to 17.2% for the automobile sector, over the same period in 2008. We need to recognise that a permanent shift of the sector to less sales would have significant repercussions to the calculations in this study. Whether this will introduce a relative increase or decrease of the PTWss share to total emissions is difficult to estimate, as both the total number of PTW vehicles will decrease and the replacement rate of older vehicles with new technology ones will also decrease. However, current estimates are that the financial crisis will start to ease by the fourth quarter of 2009. If this proves the case, then the overall effect of the crisis on emissions and the conclusions of this report is expected minimal. The reason is that after periods of decreased demand, usually a boom in sales is expected to make up for the lost ground. This is assisted by policy intervention measures. For example, scrappage schemes adopted in Italy (and Spain) resulted in high sales of particular vehicle classes in June 2009. As it is impossible to predict the final situation, we only need to make clear in this report that no effect of the financial crisis on sales volume and the emissions calculations has been introduced, but we reconfirm that a business as usual scenario with normal growth rates is assumed in the analysis.

- The market of PTWs becomes more diverse in model types and versions. In particular, the market of tricycles and quadricycles is growing with a large variety of models. The engine types of these models vary from spark ignition to compression-ignition ones.

- UNECE has further advanced with the development of the World Motorcycle Test Cycle (WMTC) and a second version of the cycle is currently available. As the European regulations offer the first version of the cycle as an alternative for type approval (2006/72/EC), it is necessary to review what the implications of introducing the second version of the cycle will be on the type approval procedure.

In this framework, the European Commission has requested an update of the earlier LAT/AUTh report, taking into account the new developments in the area. The specific service request was launched within the framework contract ENTR/05/18.

The previous version of the final report (October 2008) summarized these initial requests by the Commission. In the period of November 2008 to May 2009, a thorough review of the previous report version was conduced by the Commission and a list of comments and questions were submitted. This report addresses these issues as well. On top of that, the European Commission and the motorcycle industry (ACEM) requested that some additional scenarios are executed in order to further explore the effect of different emission limits and accelerated replacement schemes on the PTW expected contribution into the future. These scenarios were executed and were presented in the June 29, 2009 meeting of the MCWG group[4]. This report does not include the scenarios requested by ACEM on accelerated replacement of old motorcycles, as it has been beyond the scope of this report to estimate the cost and implications of such no technical measure. Anyone interested should visit the web-site referenced in footnote (4) for more information.

1.3 Objectives

A number of specific objectives were set in the service request for the particular project. In particular, the report should assess the cost-effectiveness of the following regulation elements:

1. Durability of anti-pollution devices
2. In-Use conformity
3. CO_2 emissions and fuel consumption
4. New set of pollutant emission limit values for tricycles and quadricycles
5. New set of pollutant emission limit values for mopeds
6. OBD systems on two and three-wheel motor vehicles
7. Evaporative emissions on two and three-wheel motor vehicles
8. Impacts of the mandatory use of the new WMTC

[4] http://ec.europa.eu/enterprise/automotive/mcwg_meetings/29_06_2009/lat_category_vehicle_5th_emission_scenario_v1.pdf

In order to consider the impact of different policy options, the following four approaches should be modelled for these regulation elements:

- No policy change, in principle continue with directives 2002/51/EC and 2006/72/EC;
- Introduce the bundle of measures proposed by the European Commission on their preliminary draft proposal (Moto 105);
- Introduce emission standards for motorcycles up to a Euro 5 stage;
- Introduce measures that are today considered as best-available technology for PTWs.

In addition, in assessing the cost-effectiveness of different regulation elements, the report should also provide an assessment of the following:

1. Development of the market and the technology in other parts of the world and examination of the impact of European regulation in these regions;
2. WMTC – ECE40+EUDC correlation factors based on new experimental information;
3. Contribution of motorcycles in local hot-spots, including the contribution to CO emissions;
4. Possibility to regulate motorcycles on the basis of the family concept;
5. Anti-tampering effect of new emission control technologies.

The request from the European Commission was to clarify the importance of each of these issues and prioritise accordingly. An additional request expressed at a later stage was to model the effect of introducing to motorcycles equal emission limits to passenger cars Euro 5. This has been included in the current revised version of the report.

1.4 Approach

The methodology used to calculate the cost-effectiveness was revised by using as much as possible updated information, compared to the 2004 study. Eventually, this has been made possible for most of the technical aspects of the work. The emission factors for both exhaust and evaporation emissions have been revised based on new experimental information. The vehicle stock of mopeds, motorcycles, and other road vehicles has been updated. New estimates for costs for aftertreatment systems have also been considered.

This information was then used to update the 'baseline' scenario. Therefore, the contribution of motorcycles has been re-assessed taking into account all known and foreseeable regulatory steps for PTWs and other on-road vehicles. The calculations have been extended to year 2020 in order to allow some 10 years after the introduction of new measures (assumed to take place in 2010).

Scenarios were then executed by introducing all available technical and cost information in a computer model, which was developed in the framework of the earlier report. The simulations provided the effectiveness (i.e. emission reduction) and the additional cost of the different measures for the fleet of PTWs. The two values are then combined to calculate the cost-effectiveness of the different measures.

With regard to the assessment of measures where no cost-effectiveness was necessary, this was done by collecting information from the public domain and emission databases which were available to the project partners.

1.5 Meetings

The following meetings took place between the consultancy team and different stakeholders to clarify different aspects of the project.

- January 24, Brussels: kick-off meeting took place with the participation of the Commission and LAT.
- April 11, Brussels: Meeting with AECC to discuss scenarios and possible data that can be provided for the study.
- May 7, Thessaloniki: Meeting with ACEM to discuss new developments and technology options.
- July 10, Brussels: Meeting with AECC to present the emission measurement test results of phase 1.
- July 11, Brussels: Meeting with ACEM to clarify scenario implementation.
- October 13, Teleconference: Meeting with AECC to present results of the durability testing of phase 2.
- October 20, Brussels: MVEG Motorcycle Meeting, to present the results of the cost-effectiveness calculations.
- June 29 (2009), Brussels: MCWG meeting, to present the results of the updated scenarios executed for this revised version of the final report.

1.6 Structure of the report

The report, further to this introductory chapter, is structured as follows:

Chapter 2 discusses in detail the methodology and the input data used in the analysis.

Chapter 3 presents the results of the baseline calculation and the scenarios considered.

Chapter 4 presents an assessment of a number of additional issues requested by the European Commission.

Chapter 5 makes a summary and a conclusion of this work.

2 Methodology

2.1 Vehicle categories-definitions

The focus of earlier directives on emission regulations (97/24/EC and 2002/51/EC) was primarily on power two wheelers, i.e. mopeds (<50 cc) and motorcycles (>50 cc). This has been a rather straightforward distinction of the two different vehicle classes. Distinct emission standards and driving cycles were proposed for the two classes, in order to account for the difference in engine technology and vehicle usage. The two Directives also regulated emissions of tricycle and quadricycle vehicles. The interest in these two vehicle types was in the past very small, due to their negligible fleet size, compared to PTWs. However, the vehicle stock of such vehicles has been steadily increasing over the last years (see details in section 2.2), while more vehicle types have started to appear in a variable number of configurations and for various applications. Therefore, Directive 2002/24/EC provided a description of which vehicle types are allocated to the different classes, by using limits with regard to the number of wheels and engine performance.

In order to distinguish the different vehicle types discussed in this report, Table 2-1 provides a summary of Directive 2002/24/EC and representative photos of vehicle types in each class. The different vehicle types are distinguished based on their number of wheels, maximum speed, max engine capacity/power, max power of any electrical motor, and max mass of an unladen vehicle. The limits for each of the classification criteria are given on the Table. A special clarification needs to be made for vehicles in classes L6 and L7. The directive 2002/24/EC in principle only addresses vehicles for use in paved roads, such as the ones on the leftmost pictures within each category. These vehicles are regularly termed as mini-cars, as they mainly serve the transportation needs of the elderly, i.e. they serve the same purpose as regular passenger cars albeit in smaller size. However, we have also included vehicles of the type shown in the rightmost pictures in categories L6 and L7, which are typically known as All-Terrain Vehicles (ATVs). These are vehicles primarily used for leisure in non-paved roads. Their specifications, in particular in terms of chassis, suspension and steering, are distinctly different than paved-road vehicles. However, there is no separate directive to control their emissions. As a result, in order for these vehicles to operate on public roads, emission type-approval needs to be given, following the emission standards of directive 2002/51/EC (or any amendments). Therefore, in order to calculate emissions of PTWs, tricyles and quadricycles in this report, the fleet of ATVs has been also included.

On the other hand, Directive 2002/24/EC does not cover the type-approval of vehicles such as the ones presented in Table 2-2**.** The reasons for the exclusion of these vehicles from type-approval are also given on the Table. As a result, the stock of these vehicles has not been included in the subsequent analysis. However, one should point towards a potential complication of the definitions, as 2002/24/EC refers to the type-approval of the vehicles, with reference mostly to safety aspects related to the operation of the vehicle (road, off-road, max speed limitations, etc.). However, from an emission control perspective, there is no reason to exclude some vehicles from type-approval. For example, there is no reason why trikes for off-road use should not be type-approved with regard to emission limits (such as the vehicle shown last in Table 2-2). This is something that needs to be taken into account by an update of the type-approval regulations of the future as many more vehicle versions, intermediate to traditional cars and motorcycles, have started to appear. In principle, all vehicles carrying an internal combustion engine, used for road or off-road use, should be type-approved with respect to their maximum emission limits.

Table 2-1: Vehicle types considered in regulation 2002/24/EC.

Categ.	Vehicle Type	No of Wheels	Max Speed (km/h)	ICE Max Cap (cm3)	ICE Max Power (kW)	Elec Motor (kW)	Max Unl. Mass (kg)	Characteristic Vehicles
L1e	Moped	2	45	50		4		 
L2e	Three-Wheel Moped	3	45	50 (SI)	4 (other ICE)	4		
L3e	Motor-cycle	2	>45	>50				 
L4e	Motor-cycle+ Side Car	3	>45	>50				
L5e	Motor Tri-cycles	3 (symmetrical)	>45	>50				 
L6e	Light Quadri-cycles	4	45	50 (SI)	4 (other ICE)	4	350	 
L7e	Heavy Quadri-cycles	4			15	15	400 (passengers) 550 (goods)	 

Table 2-2: Vehicle types not considered in regulation 2002/24/EC and in the subsequent calculations in the current study.

Speed less than 6 km/h 	Tractors and Machines used for agricultural or similar purposes 
For the physcailly handicapped 	Electric Bicycles 
Used for Competition 	Vehicles designed primarily for off-road leisure use having wheels arranged symmetrically with one wheel at the front of the vehicle and two at the rear 

2.2 Vehicle stock

Based on section 2.1 and the emission performance, the PTW were distinguished in the following classes:

- Mopeds
- 2 stroke motorcycles
- 4 stroke motorcycles
  - Engine capacity <150 cc
  - Engine capacity between 150 cc and 750 cc
  - Engine capacity >750 cc
- Tri- and quadricycles
  - Compression ignition
  - Spark ignition

The population data per year, country, vehicle class and age of the previous PTW study were estimated using the TRENDS model (2003) data refined with data from Eurostat and ACEM. In the current study these data were updated using data from the FLEETS project [3] as well as version 2.52 of the TREMOVE model [4]. FLEETS has been a project concluded in 2008 and funded by the European Commission, aiming at collecting detailed data on the vehicle stock in all European member states and Croatia, Norway, Switzerland and Turkey. The results and the final report of the project are available at http://lat.eng.auth.gr/copert, under the "Data" menu-item.

Some new vehicle types have started recently to appear (e.g. diesel motorcycles) but the volume of these vehicles in the stock is very small to have any measurable effect. It is also not possible to predict future market evolution of such vehicles, as this is a highly volatile market, tied to many boundary conditions. In the past, several vehicles have appeared following fashion patterns and have disappeared without even making any measurable market values (for example mini-motorcycles, or motorcycles with a roof).

In order to extend the projection up to 2020, the fleet increase predicted by TREMOVE 2.52 was applied on the FLEETS data. The resulting evolution of the PTW vehicle population for years 2007 to 2020 is presented in Figure 2-1. Figure 2-2 shows the evolution of new registrations in the same period.

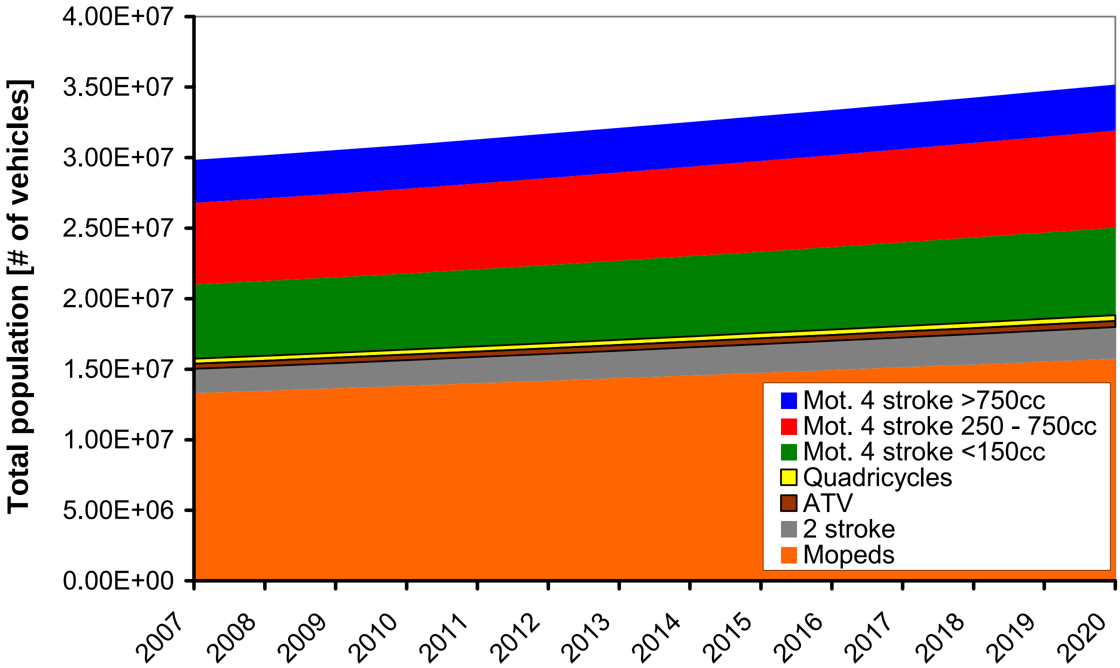


Figure 2-1: Evolution of the PTW vehicle population in the period 2007-2020.

The corresponding age distribution of the resulting fleet and the classification in the corresponding emission standards is presented in Figure 2-3 for mopeds, Figure 2-4 for 2-stroke motorcycles and Figure 2-5 for 4-stroke motorcycles.

It has to be noted that, as is the previous study, all stock and activity data were derived for each EU15 country individually to take into account specific market characteristics as well as activity and climatic data. The stock size was considered to evolve in the same way with the baseline in the different scenarios. That is, any effects of new vehicle technologies (positive or negative) on the market development were considered negligible.

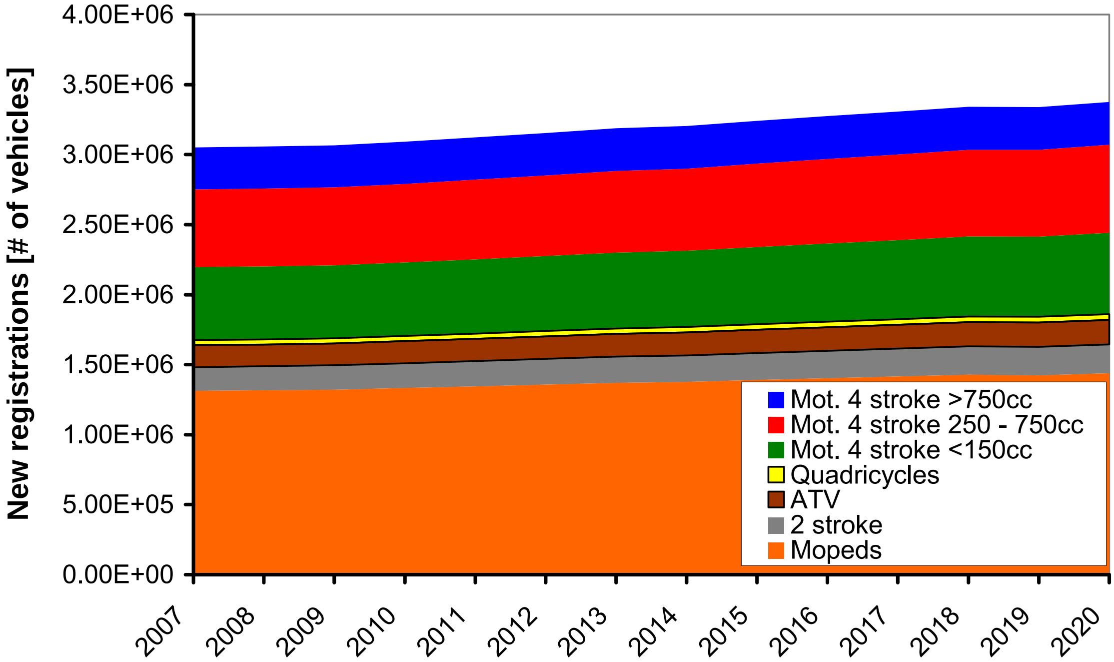


Figure 2-2: Evolution of new PTW registrations for 2007-2020

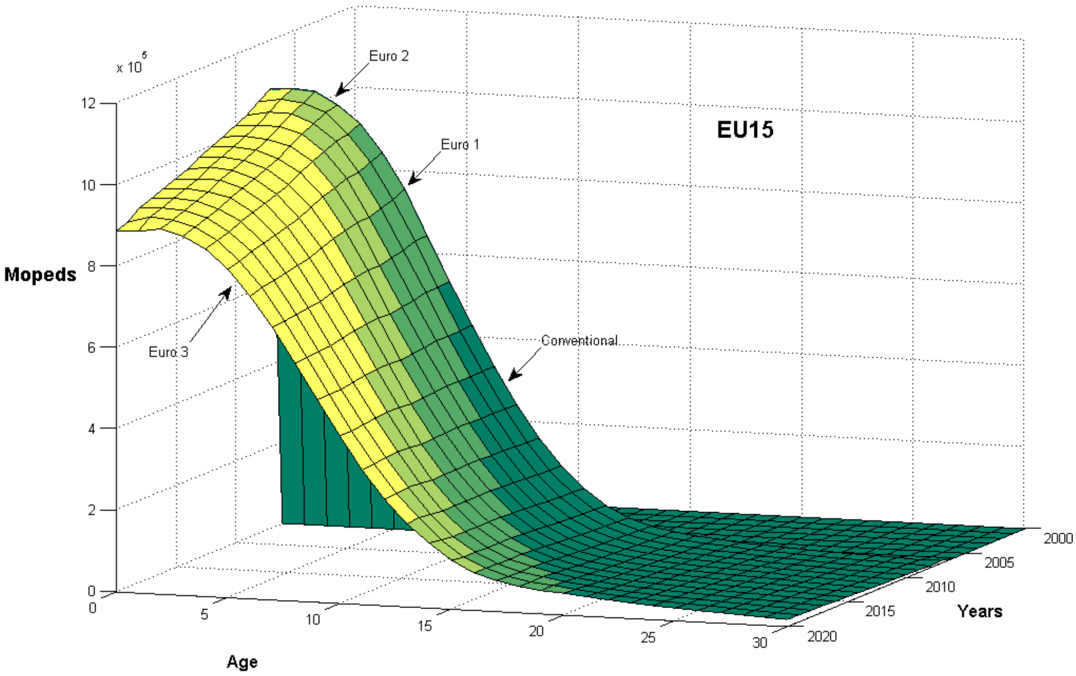


Figure 2-3: Age distribution of the moped fleet in EU15 for years 2007 to 2020 (Note: no modelling prior to 2007, hence the abrupt drop appearing at the background of the figure is an artefact of the three-dimensional presentation of the graph).

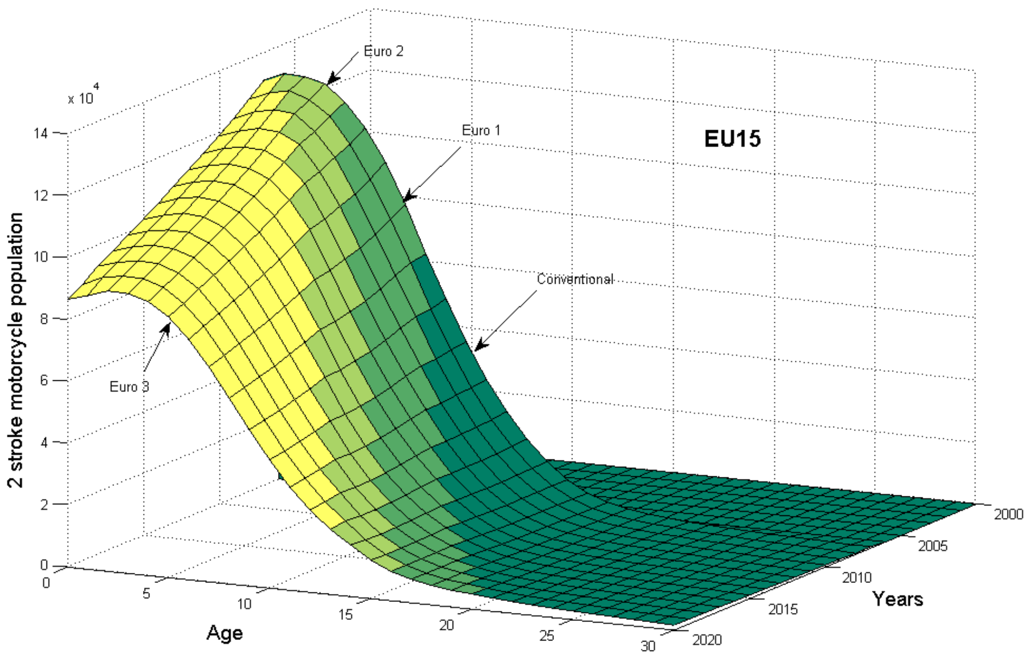


Figure 2-4: Age distribution of the 2 stroke motorcycle fleet in EU15 for years 2007 to 2020

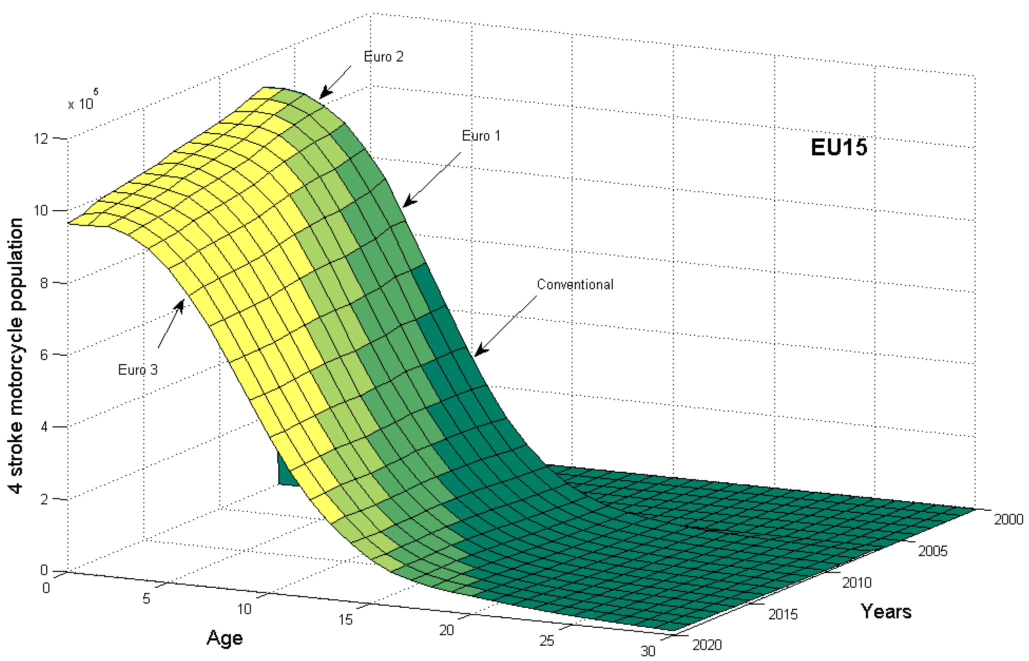


Figure 2-5: Age distribution of the motorcycle fleet in EU15 for years 2007 to 2020. (Note: no modelling prior to 2007, hence the abrupt drop appearing at the background of the figure is an artefact of the three-dimensional presentation of the graph).

In Figure 2-1 and Figure 2-2, tri- and quadricycles appear as a special category corresponding to a relatively small portion of the total vehicle fleet. However, as also mentioned in the introduction, they are becoming increasingly popular and their market share lately exhibits a strong growth. In order to improve the stock estimations for tri- and quadricycles, data from the All Terrain Vehicle Industry European Association (ATVEA) and the European Quadricycle League (EQUAL) were received and used in this study.

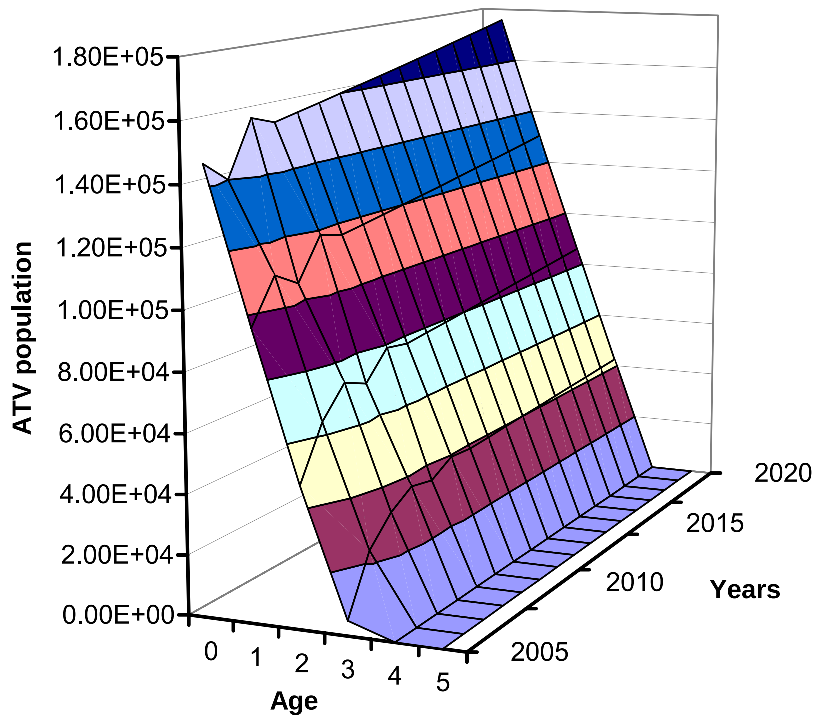


Figure 2-6: Age distribution of the ATV fleet in EU15 for years 2007 to 2020

According to ATVEA, ATVs are vehicles equipped with spark ignition engines to be used mainly for leisure in non-paved roads. ATVEA provided the fleet size of such vehicles for the period 2003 to 2008 (Figure 2-8). Based on their statement that ATVs have an average lifecycle of 5 years, we derived the vehicle age distribution up to 2008 as presented in Figure 2-6. We also assumed that these vehicles are annually driven for 3000 km, at an average. It has to be made clear that the quality of the data and the modelling of the ATV fleet is not as good as the rest of motorcycle vehicles. The reason is that the diverse use of such vehicles, ranging from leisure to agricultural applications and from urban to off-road use complicates the description of their operation. Also, official statistics on the annual activity are missing. As a result, both the fast replacement of these vehicles, but also the annual mileage they are driven (3000 km) are just assumptions. In fact, data of a survey of ATV users conducted by one manufacturer show that the majority of owners operate their vehicles for less than 2000 km per year and the manufacturer estimates that the annual mileage for all registered vehicles should lie in the range of 500 – 750 km per year. As this is only one source of information, it is difficult to accept or reject this conclusion. However, as it will be later shown in section 3.1.1, the contribution of such vehicles to road transport emissions is still too low. Therefore, a further refinement of the data used for their emission estimation is not necessary at this point. However, one should be monitoring the market evolution of such vehicles and reassess this position if the sales volume increases in the future.

In our estimates we assumed that the stock increase of ATVs post 2008 will follow the general trend of motorcycles (Figure 2-8). This may be a rather conservative approach as it results to a significant change in the gradient of increase after 2008. Although we should recognise this, there was no other projection for such vehicles available to the study team. Therefore our conservative approach is equally uncertain to any other projection that we might attempt. Given the relatively small size of these vehicles, slight departures from our projections should not be expected to be visible on either the cost-effectiveness or the share of such vehicles on total emissions. Substantial departures would definitely lead to variations that will have to be calculated and reported. In such a case, and given the uncertainty in the emission type-approval status of such vehicles, it would be proposed that an ad-hoc assessment is carried out, specifically addressing ATVs.

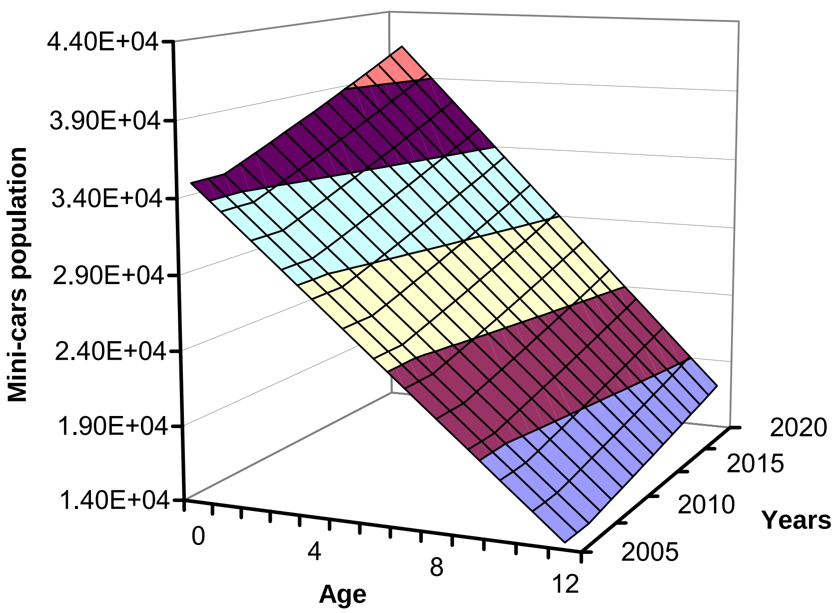


Figure 2-7: Age distribution of the mini-cars fleet in EU15 for years 2007 to 2020

EQUAL provided data for the year 2007 of the other quadricycle category: mini-cars. These vehicles are mainly equipped with compression ignition engines (diesel) of, in average 500 cm^3, originally manufactured for stationary (industrial) applications such as compressors, lifters, etc. The current mini-car fleet is estimated to be about 340,000 vehicles. The age distribution was defined based on assumptions derived form data for large motorcycles and small passenger cars assuming a lifecycle of 12 years and annual mileage of 6,000 km. This is shown in Figure 2-7. In the case mini-cars, the increase of fleet after 2008 was assumed to be proportional to the overall increase of PTW, similar to the approach followed in ATVs (Figure

2-8). The same limitations of the projection, as in the case of ATVs also apply in this case. In fact, only one value for the year 2007 was available by EQUAL and this considered to be steady in the period 2002-2008 and increases thereafter.

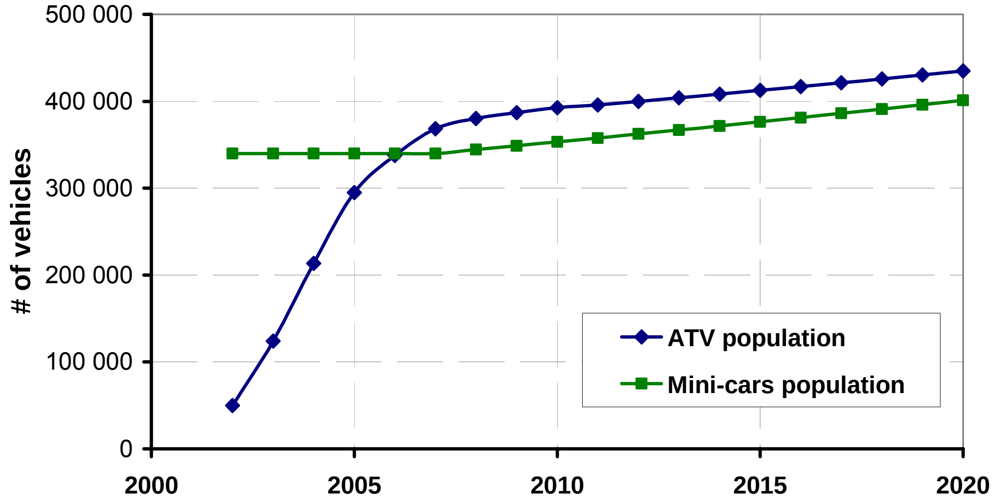


Figure 2-8: Evolution of ATV and mini-cars population

2.2.1 New member states

The data available from FLEETS project covered the PTW population of each EU15 member state up to 2005. The limitation of the analysis only to the EU15 region was made on grounds of data availability when preparing the October 2008 version of the report. In the meantime, the full dataset of FLEETS became available, which includes PTW stock sizes for the new member state (EU12) region. Although it was not possible to repeat all calculations, at least some comparison of the relevant stock sizes is useful to present, in order to implicitly draw some conclusions of the effects of measures presented in this report to the enlarged Europe. Figure 2-9 shows the contribution of power two wheelers to total road transport activity in EU15 and EU12. The absolute activity is about double over EU15, compared to EU12 (~122 bil vehkm, compared to 63 bil veh km in EU12 in 2008). However, the relative contribution of mopeds and motorcycles is only ~ 3% in EU15 and ~11% in EU12. Hence, PTWs constitute a more significant transportation vehicle in EU12 than in the older member states, presumably due to their lower purchase and operation cost than passenger cars.

It is difficult to estimate the relative emission contribution of PTWs in EU12 without detailed emission calculations. The reason is that both the car and motorcycle mean age is higher in the new member states than in EU15. Therefore both the car and motorcycle emission factors will, on average, be higher and it is not possible to estimate whether the relative share of PTWs will be the same, higher or lower compared to EU15. However, the large share of PTWs to total activity means that the impact of measures proposed in this report for emission control will in any case be significant in EU12 as well. Therefore, despite only EU15 is addressed, any findings and conclusions should be relevant for EU12 as well. Where distinct differences are expected, these are clearly outlined when each measure is proposed.

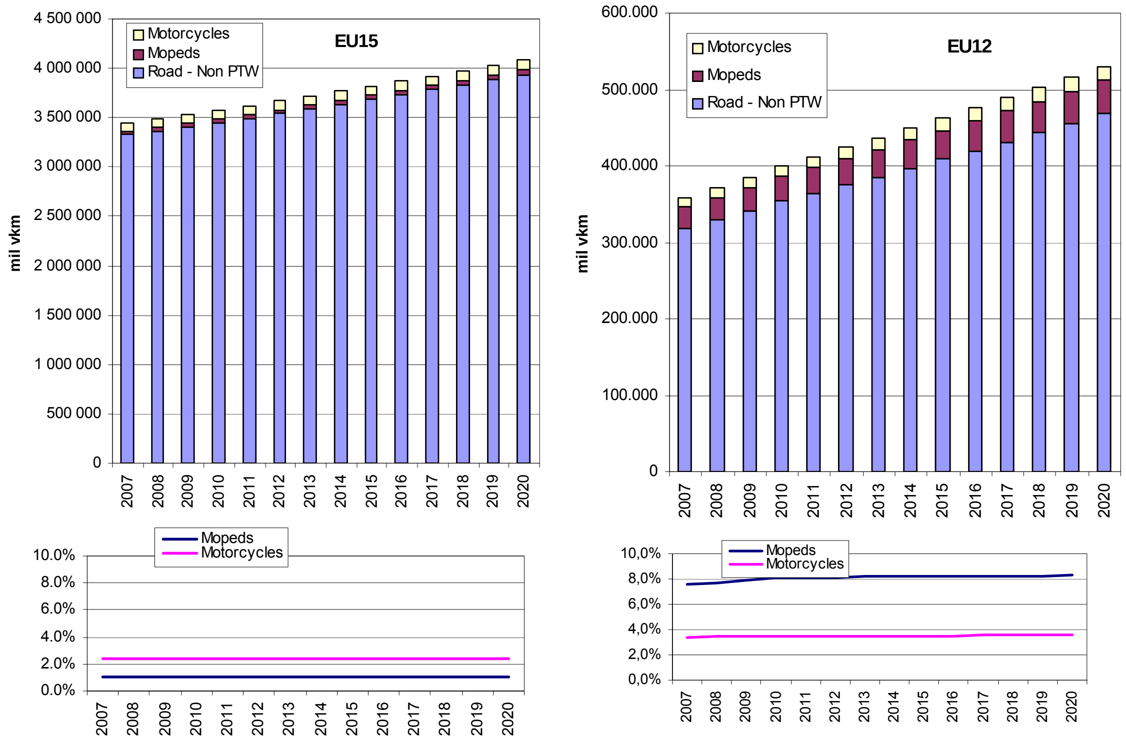


Figure 2-9: Power two wheeler activity compared to road transport. Left: EU15, Right: EU12 new member states, Top: Absolute activity (mil veh.km), Bottom: PTW share to total road transport activity.

2.3 Emission performance

2.3.1 Emission standards

The emission limit values that are currently applicable in EU are shown in Table 2-3. Different driving cycles are applicable for mopeds and motorcycles and a further distinction exists for motorcycles at a Euro 3 level. Figure 2-10 shows the driving pattern of ECE-R47 which is the driving cycle used for the type-approval of mopeds.

Table 2-3: European PTW Emission Standards [mg/km]

Stage	Directive	Effective	Category	Driving Cycle	CO	HC	NO_x
Moped							
Euro 1	97/24/EC	17.06.1999	≤ 50 cc	ECE-R47	6 000	3 000	
Euro 2	97/24/EC	17.06.2002	≤ 50 cc	ECE-R47	1 000	1 200	
Motorcycle							
Euro 1	97/24/EC	17.06.1999	2-Stroke	ECE-R40	8 000	4 000	100
			4-Stroke	ECE-R40	13 000	3 000	300
Euro 2	2002/51/EC	01.04.2003	< 150 cc	ECE-R40	5 500	1 200	300
			≥ 150 cc	ECE-R40	5 500	1 000	300
Euro 3	2002/51/EC	01.01.2006	< 150 cc	ECE-R40, cold-start	2 000	800	150
			≥ 150 cc	ECE-R40, cold-start + EUDC	2 000	300	150
Euro 3	2006/72/EC	18.08.2006	V_{max} < 130 km/h	WMTC	2 620	750	170
			V_{max} ≥ 130 km/h	WMTC	2 620	330	220

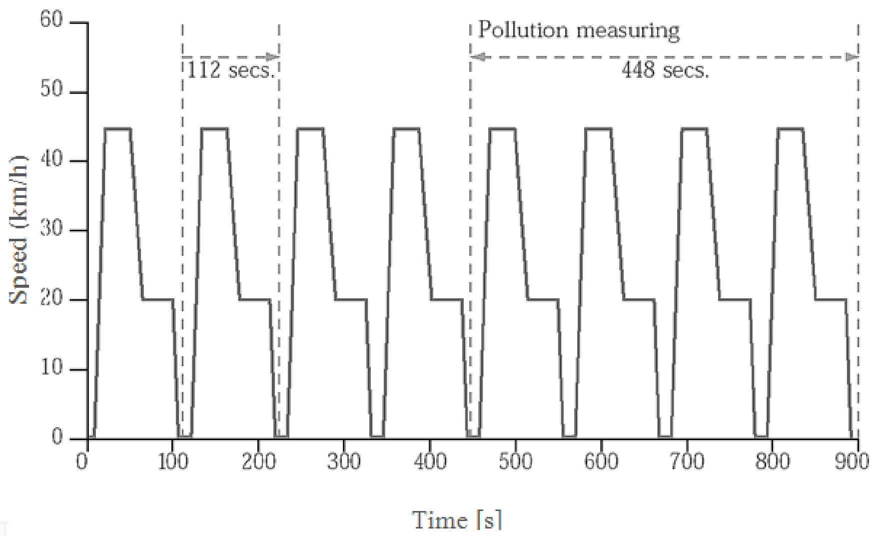


Figure 2-10: ECE-R47, Driving cycle for mopeds (Euro 1 and Euro 2). Pollutant sampling is conducted after the first four subcycle repetitions.

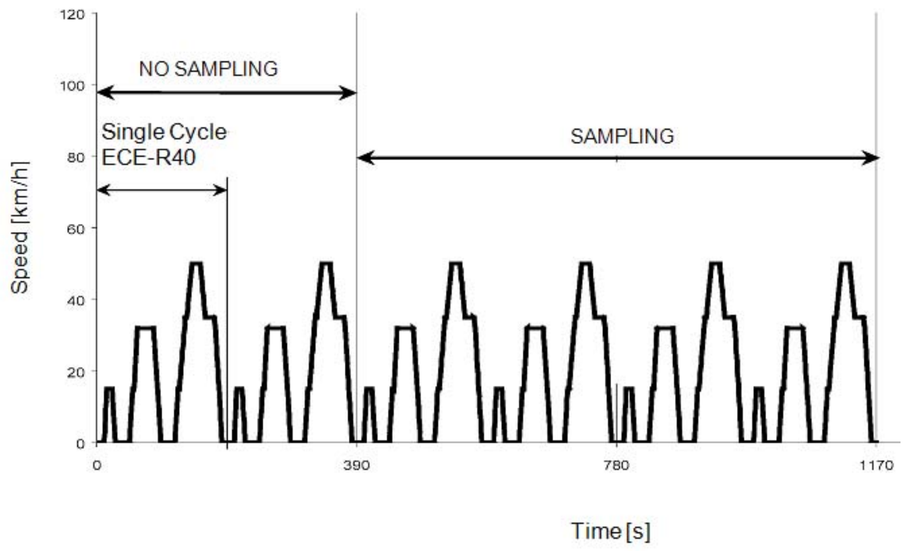


Figure 2-11: ECE-R40, Driving cycle for motorcycles (Euro 1 and Euro 2). Pollutant sampling is conducted after the first two subcycle repetitions

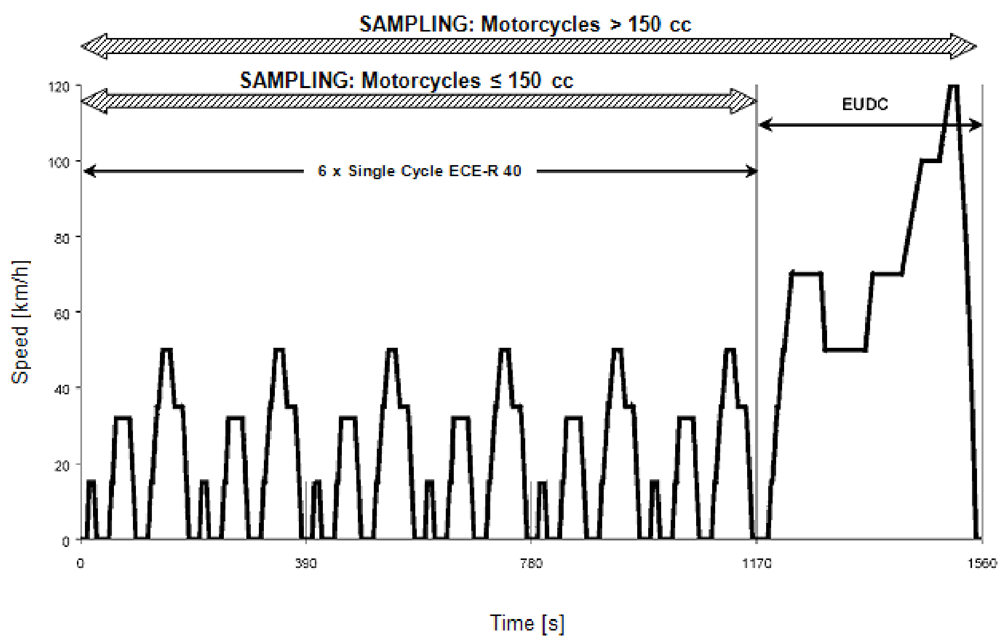


Figure 2-12: ECE-R40, cold (+EUDC) Driving cycle for motorcycles at a Euro 3 level. Only the cold ECE-R40 is used for motorcycles below or equal to 150 cc and the EUDC part is added for motorcycles of over 150 cc.

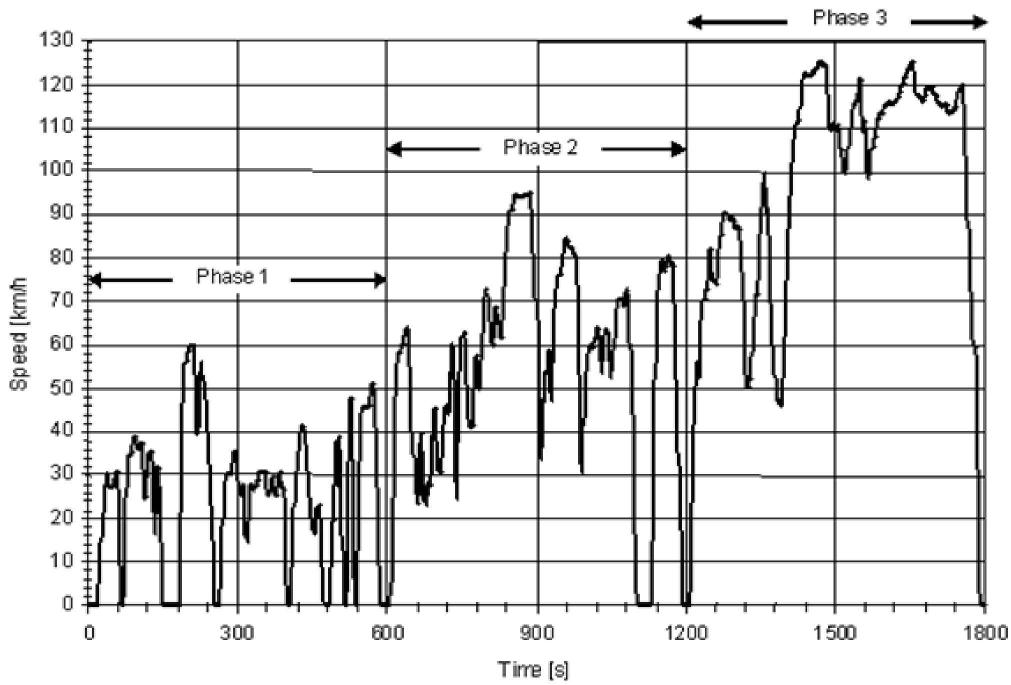


Figure 2-13: WMTC, alternative driving cycle for the type-approval of Euro 3 motorcycles.

In the European Union (EU) the exhaust gas emissions of powered two-wheelers were first regulated with directive 97/24/EC. This directive came into effect on 17 June 1999. At the date of entry into force, Euro 1 standards became mandatory for both mopeds and motorcycles, covering carbon monoxide, hydrocarbons and nitrogen oxides. This directive already contained prescriptions for a second stage of emission standards (Euro 2) for mopeds, entering into force on 17 June 2002.

The corresponding Euro 2 limit values for motorcycles (including light tricycles and light quadricycles) were laid down in directive 2002/51/EC and entered into force on April 1, 2003. Whilst for Euro 1 the emission limits of motorcycles were differentiated between two-stroke and four-stroke engines, this separation was abolished from Euro 2 onwards. Instead, a differentiation was introduced with respect to the engine displacement. Nevertheless Euro 2 resulted in a significant strengthening of the carbon monoxide and hydrocarbon limit values for both mopeds and motorcycles.

Directive 2002/51/EC also introduced a Euro 3 limit from motorcycles, effective since 1 January 2006, which established significantly lower emission limit values compared to Euro 2. With Euro 3 a new set of test cycles became compulsory for motorcycle type-approval. Depending on the engine capacity (the limit being at 150 cc), small motorcycles are type-approved over a cold-start ECE-R40 test, which involves speeds up to 50 km/h. Larger motorcycles though are tested over the cold-start ECE-R40 followed by the extra-urban driving cycle (EUDC). With this procedure, and in particular with the inclusion of a cold-start test, the exhaust emissions of new motorcycles moved towards the emission level of Euro 3 passenger cars.

Due to the objective to have a more realistic test cycle and parallel to the efforts of the European Union, a Global Technical Regulation (GTR) on a Worldwide Motorcycle Test Cycle (WMTC) was discussed under the framework of the UNECE. The European Union was the first of all parties in the UNECE GTR to transpose WMTC into its own legislation. Directive 2006/72/EC introduced WMTC as an alternative to the type-approval of motorcycles. By quoting the relevant excerpt of the directive: "At the choice of the manufacturer the test procedure laid down in UN/ECE Global Technical Regulation (GTR) No 2 [5] may be used for motorcycles as an alternative to the European test cycle for type approval of Euro 3 motorcycles. In case the procedure laid down in GTR No 2 is used, the vehicle shall respect the emission limits provided in the related directive". The new emission limits proposed for this cycle are also shown in Table 2-3 and have been derived from a correlation exercise between WMTC and ECE-R40 or ECE-R40+EUDc, conducted by JRC/IES [6]. It should be noted that the driving cycles considered by the European regulation is the so-called stage 1 WMTC. At stage 2 (Amendment 1 to GTR No. 2 from January 2008 - ECE/TRANS/180/Add.2/Amend.1), a modified WMTC has been proposed which is not transposed to the European regulation yet.

2.3.2 Different emission standards to passenger cars

Power two wheeler emission limits are different to passenger cars. Table 2-4 shows a comparison of the emission limits, expressed per unit of fuel mass consumed for mopeds, motorcycles and gasoline passenger cars. A number of assumptions have been introduced in this comparison. First, a share of 98% HC and 2% NOx is assumed for the pollutant ratio in the exhaust of mopeds, in order to split the combined HC+NOx emission limit value for this vehicle category. Second, fuel consumption values of power two wheelers have been obtained from COPERT 4. Passenger car fuel consumption values have been assumed, based on type-approval CO2 emissions of a 1.2 l engine capacity vehicle (this is assumed to range from 140 g/km at Euro 1 level to 125 g/km at Euro 4 level). Third, the influence of the different driving cycles for each vehicle category is not taken into account; the comparison is a straightforward arithmetic comparison of the emission limits over the type approval cycle, when they are expressed per unit of fuel consumed.

The comparison shows that significant reductions have been taking place for motorcycles, with improving technologies from Euro 1 to Euro 3. However, limits of (in particular) HC emissions remain several times higher than gasoline passenger cars, of corresponding emission technology. This is even more so for mopeds, with HC emission at Euro 2 being 14 times higher than Euro 2 passenger cars of the same emission standard.

The reason of the difference in the emission limit values need to be sought in the performance requirements of the different vehicles. A typical 125 cc 4S motorcycle produces about 95 bhp/lt, compared to 65 bhp/lt of a typical passenger car. This is a 46% difference in specific power output, which calls for relaxed emission limits, if this power output needs to be retained. This is better visualized in Figure 2-14, which shows the market share of passenger cars and power two wheelers, as a function of their power-to-weight ratio. The big majority of passenger cars lies below 100 kW/ton, while only 35 % of motorcycle sales are below this limit. In fact, the motorcycle market structure is trimodal with one peak in the 20-40 kW/ton range, one in the 120-140 kW/ton range and one in the 220-240 kW/ton range. This shows that the motorcycle market is mostly tuned towards the high-performance range. The relaxed emission limits compared to passenger cars give the ground for this higher specific power output performance.

Table 2-4: Comparison of emission limits for power two wheelers and passenger cars, expressed per unit of fuel mass consumed

Vehicle / Stage	Category	FC (g/km)	CO (g/kg fuel)	HC (g/kg fuel)	NOx (g/kg fuel)
Moped					
Euro 1	≤ 50 cc	15	400	196	4
Euro 2	≤ 50 cc	12	83	98	2
Motorcycle					
Euro 1	2-Stroke	27	296	148	4
	4-Stroke	29	448	103	10
Euro 2	< 150 cc	29	190	41	10
	≥ 150 cc	29	190	34	10
Euro 3	< 150 cc	29	69	28	5
	≥ 150 cc	35	57	9	4
Gasoline PC (ca 1.2 l)					
Euro 1		44	72	15	11
Euro 2		42	52	7	5
Euro 3		41	54	5	4
Euro 4		39	25	3	2

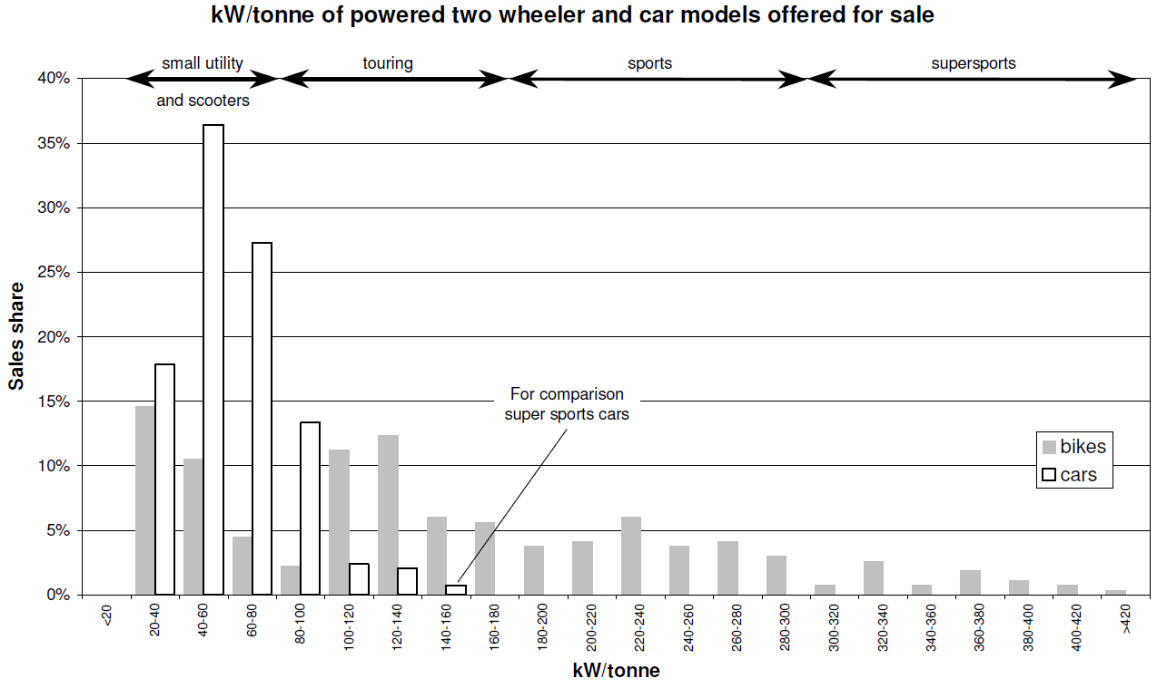


Figure 2-14: Comparison of power two wheelers and passenger car vehicles offered in the market, classified according to their power over weight ratio [7].

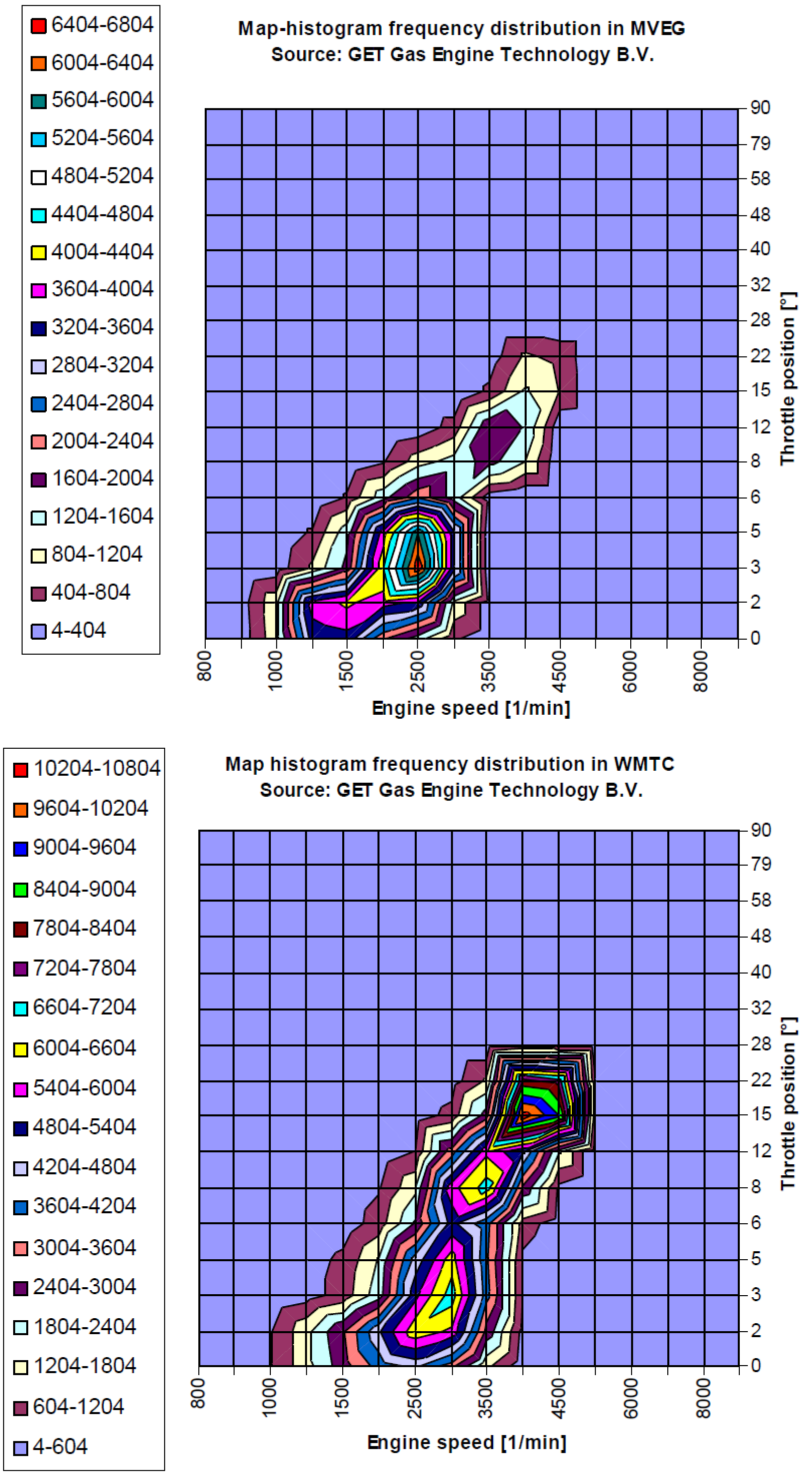


Figure 2-15: Comparison of motorcycle engine map operation frequency over the passenger car driving cycle (top), compared to the WMTC driving cycle (bottom) [2].

Further to power output, there are a few more boundary conditions that call for relaxed emission standards of motorcycles, compared to passenger cars. First, the available space for emission control devices is much less in motorcycles, compared to passenger cars. Any aftertreatment systems need to be installed in the exhaust line which is very close to the rider's body. The available space is not enough to fit sizeable catalysts while lower heat can be preserved at the point of the emission control. Also, weight (and balance) concerns are much more relevant for motorcycles than passenger cars. Finally, the different driving cycle also has an effect on the minimum attainable emission limits. Figure 2-15 shows a comparison of engine frequency operation of a motorcycle engine over the passenger car and the WMTC driving cycles. The frequency of operation is towards higher speed and load (represented by the throttle position) in the later case. It is therefore evident that the motorcycle type-approval cycle is a much more demanding cycle, compared to the passenger car one.

This discussion attempts to justify why, historically and technically, different emission standards have been put forward for motorcycles compared to passenger cars. Of course, pollutant concentration in the atmosphere does not distinguish between motorcycles and cars. Hence, sincere efforts are required to reduce emissions by PTWs as well. In this perspective, a balanced policy is required that will both respect the technologically-induced limitations of PTW emission control, but at the same time will aim at reducing emissions to preserve human health.

2.3.3 Current emission control technology

Improved technology has been required to meet these stringent emission standards, both from motorcycles and mopeds. A detailed reference to the relevant technology and associated costs of up to Euro 3 motorcycles and Euro 2 mopeds was included in the 2004 LAT/AUTh study. The range of application of the available technologies per emission standard is presented in Table 2-5 and a description and costs are summarized in Table 2-6 for mopeds and **Table 2-7** for motorcycles. The costs quoted for the different options have been obtained from the earlier study, but have converted to year 2008 currency values assuming an average 2% annual inflation rate in Europe in the period 2004 to 2008. Engine measures mainly focussed on the improvement of the fuel delivery system by introducing fuel injection and, more lately, direct injection for 2-stroke engines. Combustion chamber design, optimization of valve and spark timing and improvement of the air exchange process were additional measures that have been undertaken to reduce engine-out emissions. The need for improved engine out emissions has also led to the gradual shift from 2-stroke to 4-stroke engines, as the latter appear as much lower emitters of, in particular, HC emissions.

However, starting at Euro 1 but mainly at Euro 2 level, aftertreatment devices were used to further reduced emissions from their engine out levels. Euro 2 for mopeds was basically reached by introducing an oxidation catalyst to all models, sometimes assisted by secondary air injection to promote the oxidation of HC in the exhaust. The same also occurred to larger 2S engines for motorcycles and some small (<150cc) 4S ones. However, as most of the motorcycle engine families were already 4S at Euro 2 level, emission control consisted of lambda-control three way catalyst. Later, at a Euro 3 level, further control of the emissions was achieved with engine recalibration, use of more efficient catalysts and the replacement of carburettors by fuel injection systems to almost all motorcycle models.

Table 2-5: Technology considered necessary to reach the different emission standards for each PTW category

		FI	TWC	OxCat
4-stroke Class 1	Conventional	0%	0%	0%
	Euro 1	0%	0%	0%
	Euro 2	20%		80%
	Euro 3	100%		0%
4-stroke Class 2	Conventional	0%	0%	0%
	Euro 1	0%	0%	0%
	Euro 2	50%		50%
	Euro 3	100%		0%
4-stroke Class 3	Conventional	0%	0%	0%
	Euro 1	0%	0%	0%
	Euro 2	70%		30%
	Euro 3	100%		0%
		DI	**OxCat**	**CB 4-stroke**
2-stroke	Conventional	0%	0%	-
	Euro 1	0%	0%	-
	Euro 2	30%	100%	-
	Euro 3	100%	100%	-
Mopeds	Conventional	0%	0%	0%
	Euro 1	0%	100%	0%
	Euro 2	15%	50%	50%

Table 2-6: Technology per "Euro" standard for mopeds (Abbreviations: 2S: 2-stroke, 4S: 4-stroke, DI: direct injection, FI: fuel injection, OC: oxidation catalyst, SAI: secondary air injection, TWC: three-way catalyst)

"Euro" Class	Year	Technology	Driving Cycle	Directive	Cost of technology (to manufacturer @€ 2008)
Conv.	<1997	Mostly 2S engines, rich-tuned, carburetted, manual lube oil mixing	ECE47	ECE47	
Euro 1	1997	Mainly 2S only some 4S engines. 2S engines improved by using leaner mixtures, improved ignition systems and fuel delivery carburetors, and introduction of OCs. Few 4S engines meeting emission standards without particular emission control systems.	ECE47	97/24/EC	2S: 17-32 for OC 4S: 100-120 per vehicle over baseline 2S
Euro 2	2002	High number of 4S mopeds, carburettor or FI with SAI and catalyst. 2S are equipped either with carburettor, SAI and OC or with DI and OC.	ECE47	97/24/EC	2S: 26-30 for SAI 54-108 for DI 4S: 135-165 over baseline Euro 2

Table 2-7: Technology per "Euro" standard for motorcycles (Abbreviations as in caption of Table 2-6)

"Euro" Class	Year	Technology	Driving Cycle	Directive	Cost of technology (to manufacturer @€ 2008)
Conv.	<1999	4S engines, rich-tuned, carburetted. FI in some expensive models. Many 2S engines <250 (mainly <125 cc), rich tuned,			
Euro 1	1999	Euro 1 emission limits rather relaxed, assumed to be reached with conventional measures, hence no additional cost required over conventional. Some motorcycles already equipped with TWC, not to meed standards but rather for commercial reasons.	ECE40	97/24/EC	0
Euro 2	2003	2S equipped with either SAI+OC or DI+OC. Large 4S engines equipped with FI+TWC, smaller ones may alternatively carry SAI+OC.	ECE40	2002/51/EC 2003/77/EC	2S: 65-130 DI 21-39 OC 31-36 SAI 4S: 110-162 TWC 54-110 FI
Euro 3	2007	All 2S engines (if any) fitted with DI+OC and all 4S engines equipped with FI+TWC	<150cc: cECE40 >=150cc: cECE40+EUDC or WMTC	2002/51/EC 2006/72/EC	Investment cost for better calibration: 300 kEuro/engine family concept

2.4 Emission factors

In the 2004 study emission factors up to Euro 2 PTWs were produced using data already available within the COPERT III model [8]. These data were calibrated by new measurements performed within the UNECE EURO-WMTC correlation study as well as other measurement exercises from JRC, ACEM and TNO over the CITA-IM project. Also, emission factors up to Euro 2 for tricycles and quadricycles were estimated as in detail discussed and presented in the 2004 study [1] (Figures 2.19 and Figure 2.20 of that report).

In the case of Euro 3 motorcycles since there were no motorcycles type-approved at that time as Euro 3, an approximation methodology was applied. Motorcycles were classified according to their emission performance and emission related hardware and "simulated Euro 3" motorcycles were defined. Based on these data a set of Euro 3 emission factors was produced. This was based though on the potential of some Euro 2 motorcycles complying with the next emission standard without taking into account the effect of engine calibration and technology maturity at the actual implementation year.

2.4.1 Euro 3 emission factors

One of the main issues that needed to be addressed in the revised study was the determination of emission factors representative of the actual performance of Euro 3 motorcycles already in market. In addition to that, the potential of the current technology status should also be explored. For this reason a sample consisting of 10 Euro 3 PTWs measured by EMPA and 5 Euro 3 PTWs measured by AECC was used. The characteristics of the sample measurements are summarized in Table 2-8.

All motorcycles were tested over the EU legislative cycle as well as the WMTC cycle corresponding to the specific class. The emission factors have been derived as average of these measurements.

Table 2-8: Vehicle sample used for Euro 3 and post Euro 3 emission factor evaluation

Make	**Model**	**Engine Displacement [cm^3]**	**Emission class**	
			EURO	**WMTC**
Piaggio	VESPA LX 125	124	Euro 3	1
Honda	SH 125	125	Euro 3	2.1
Honda	Unicorn 150	149	Euro 3	2.1
Piaggio	X8	244	Euro 3	2.2
Kymco	Xciting 500i	500	Euro 3	3.2
Honda	CBR600RR	599	Euro 3	3.2
Kawasaki	ER-6N	649	Euro 3	3.2
Suzuki	GSX R 750	750	Euro 3	3.2
BMW	F 800S	800	Euro 3	3.2
Honda	VFR 800i	800	Euro 3	3.2
Yamaha	FZ1	998	Euro 3	3.2
Suzuki	GSX R 1000	999	Euro 3	3.2
BMW	R 1200 GS	1,170	Euro 3	3.2
Yamaha	FJR 1300	1,300	Euro 3	3.2
Harley Davidson	FXDC	1,584	Euro 3	3.2

Since the model itself performs calculations at three levels, i.e. urban, rural and highway driving, it was decided to derive driving mode related emission factors for these modes using the emission factors of each one of the 3 (or 2 in some classes) phases of the WMTC driving cycle. The EF correlation scheme is as follows:

Urban EF → WMTC phase 1

Rural EF → WMTC phase 2

Highway EF → WMTC phase 3

2.4.2 Emission factors of Best Available Technology

In order to study the effect of the application of the best available technology (BAT) in motorcycles in terms of emission benefit and technical feasibility, a separate set of emission factors for CO, NH, NO_x, and CO_2 was produced from the available measurement sample of the 15 Euro 3 PTWs that was described above. It was not possible to make any assessment for the PM emission factor due to lack of data.

The best emission performance was chosen for each driving mode (i.e. WMTC cycle) and vehicle class as the 20th percentile of emissions of the respective sample subset in order to avoid extreme cases where reduction in one pollutant is linked to an increase of a different one (emission trade-off). The notion of BAT in this case represents the best 20% performance of the Euro 3 motorcycle class per pollutant. The emission factors derived with this process, are arithmetically shown in Table 2-9. They are also shown in a graphical form in Figure 2-20 to Figure 2-22.

Table 2-9: Emission factors of the Best Available Technology scenario

Motorcycle class	CO (g/km)			HC (g/km)		
	Urban	Rural	Highway	Urban	Rural	Highway
MC <150 cc	2.682	2.564		0.343	0.136	
MC 150-750 cc	2.247	0.567	1.038	0.414	0.118	0.115
MC >750 cc	1.607	0.304	0.375	0.243	0.054	0.047

Motorcycle class	NO_x (g/km)			CO_2 (g/km)		
	Urban	Rural	Highway	Urban	Rural	Highway
MC <150 cc	0.102	0.107		47.2	45.8	
MC 150-750 cc	0.057	0.053	0.181	107.8	86.8	107.3
MC >750 cc	0.061	0.022	0.076	171.2	109.6	118.8

2.4.3 Emission factor evaluation and discussion

The emission factors produced for the revised study are presented in Figure 2-16 to Figure 2-19. In the same figures the simulated Euro 3 emission factors of the 2004 study are also presented, for comparison. In most cases, the assumptions of the 2004 study, which were not based on any experimental information but only assumptions on the new technology, match rather well with the new Euro 3 emission factors, which are based on measurements of the vehicles shown in Table 2-8. Moreover, any deviations are in both directions, i.e. both higher and lower emission factors were earlier assumed compared to the experimental data. This is a good indication that the emission calculations in the 2004 report rather well represent the actual emission levels of Euro 3 motorcycles.

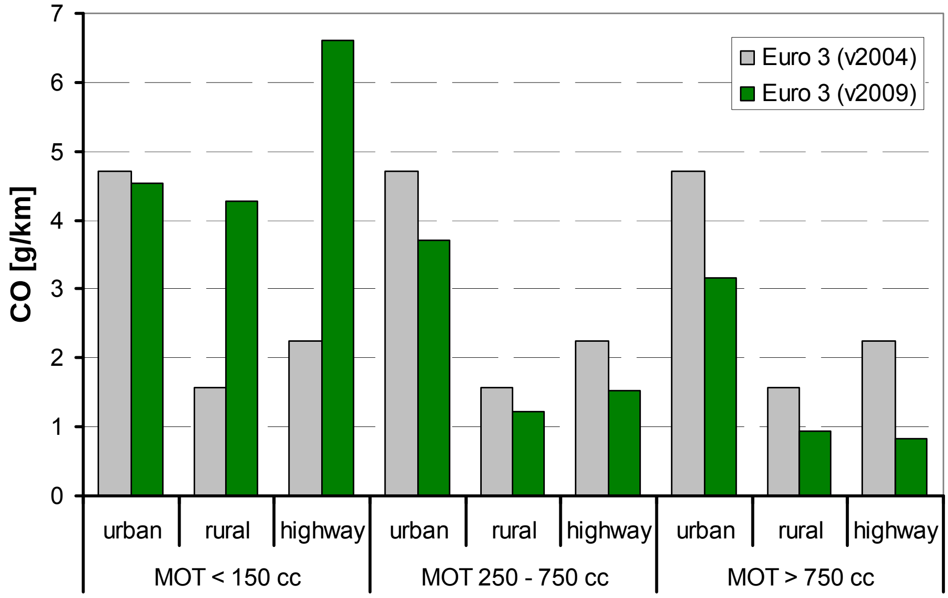


Figure 2-16: Comparison of revised (v2009) and version 2004 Euro 3 CO emission factors

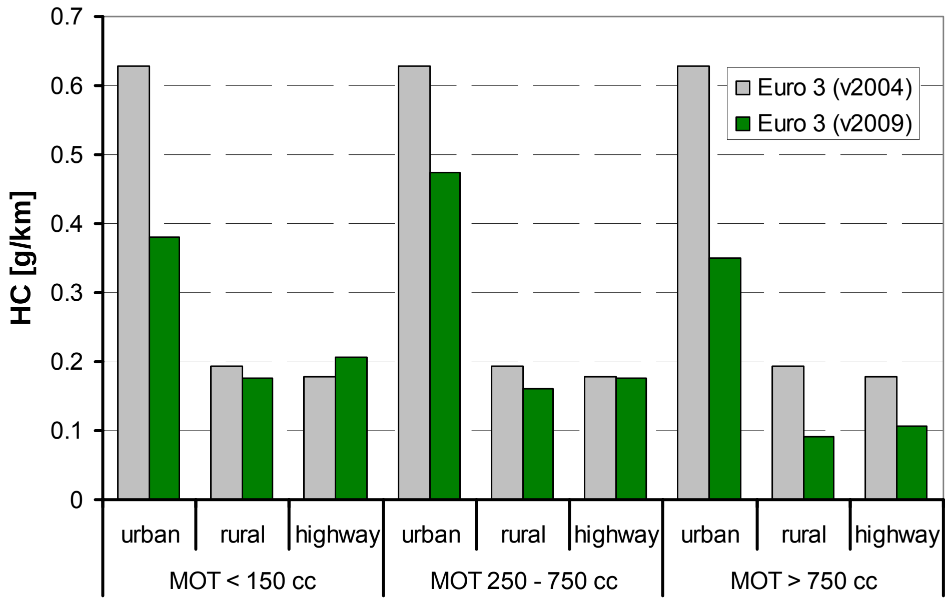


Figure 2-17: Comparison of revised (v2009) and version 2004 Euro 3 HC emission factors

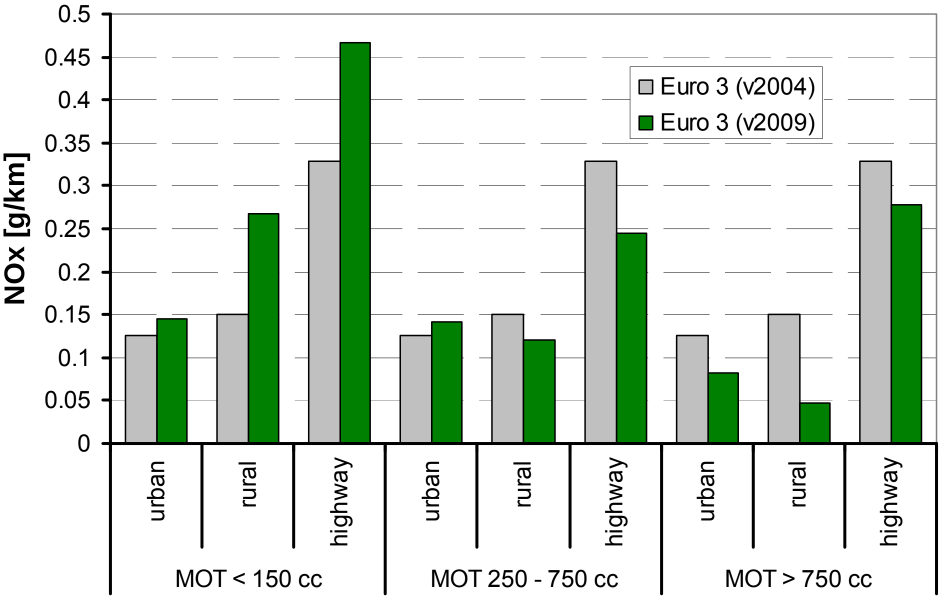


Figure 2-18: Comparison of revised (v2009) and version 2004 Euro 3 NOx emission factors

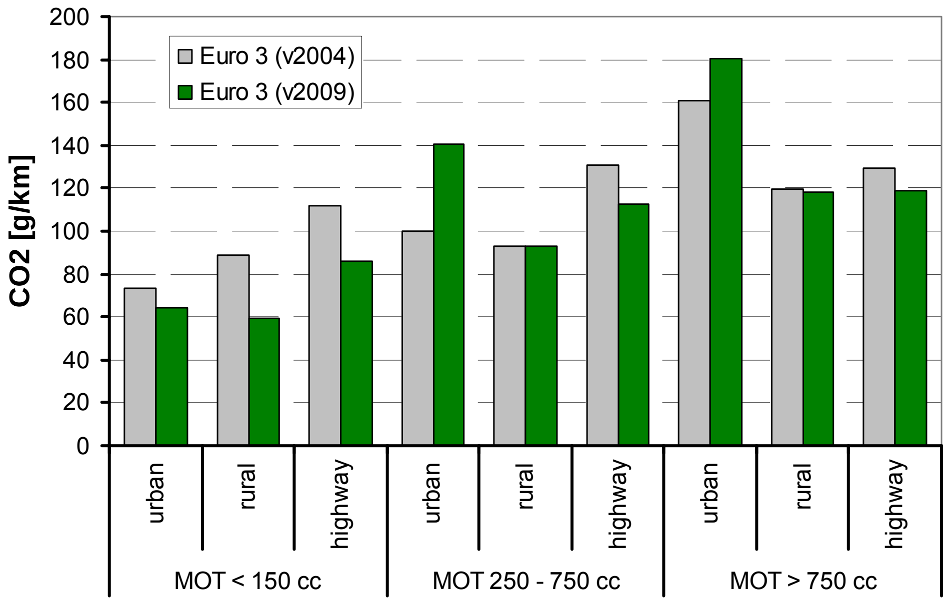


Figure 2-19: Comparison of revised (v2009) and version 2004 Euro 3 CO_2 emission factors

The trade-offs between CO-HC, NO_x-HC, CO_2-HC are explored in Figure 2-20 to Figure 2-22. These are shown to better clarify the derivation of the BAT emission factors. The data presented by points represent the pair of emissions of specific measurements while the dashed lines represent the emission factor chosen as representative of the best available technology for the respective axis (20% percentile per pollutant). The charts are presented for each of the 3 WMTC cycles – driving modes separately. It should be clarified, that the 20th

percentile is not vehicle specific, i.e. one vehicle may reach extremely low HC but high NO_x. Therefore, our approach is pollutant and not vehicle specific. However, we feel that this is a straightforward (mathematical) approach to express BAT and we considered this as the most appropriate to derive representative Scenario 3 emission factors.

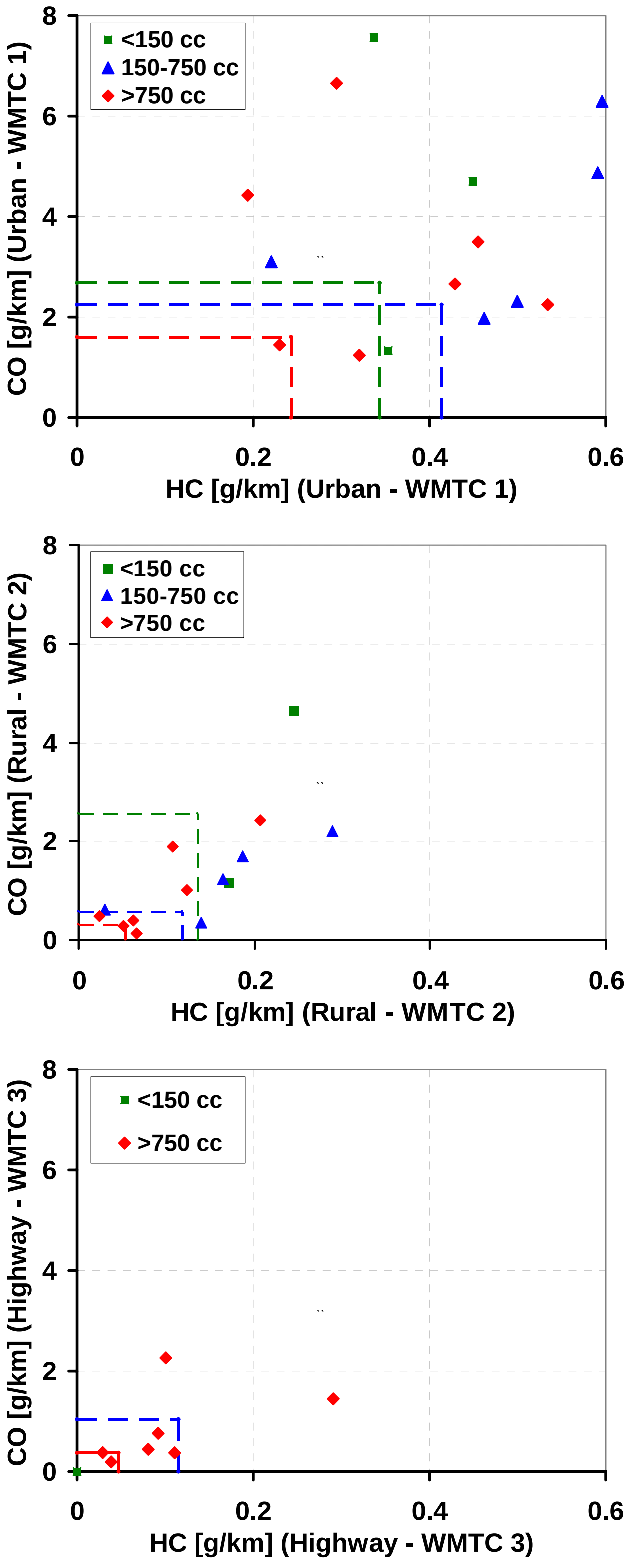


Figure 2-20: Derivation of emission factors for Best Available Technology (CO vs HC)

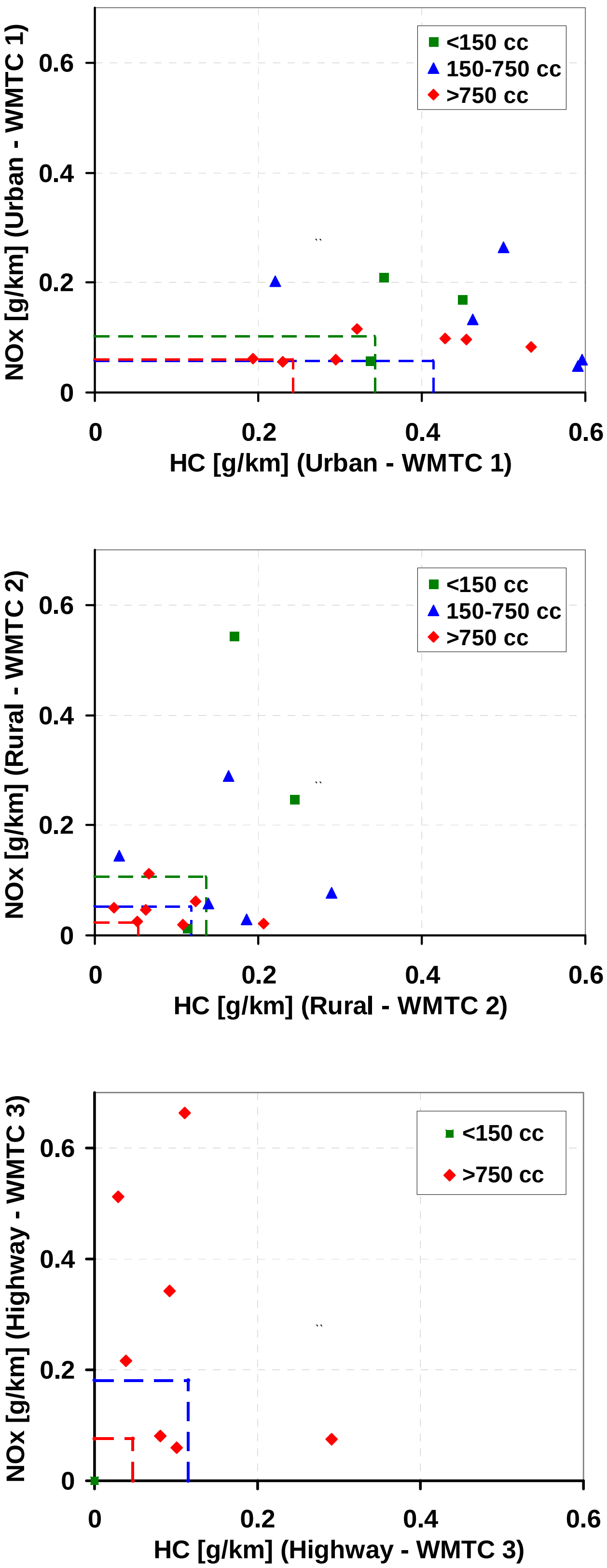


Figure 2-21: Derivation of emission factors for Best Available Technology (NO_x vs HC)

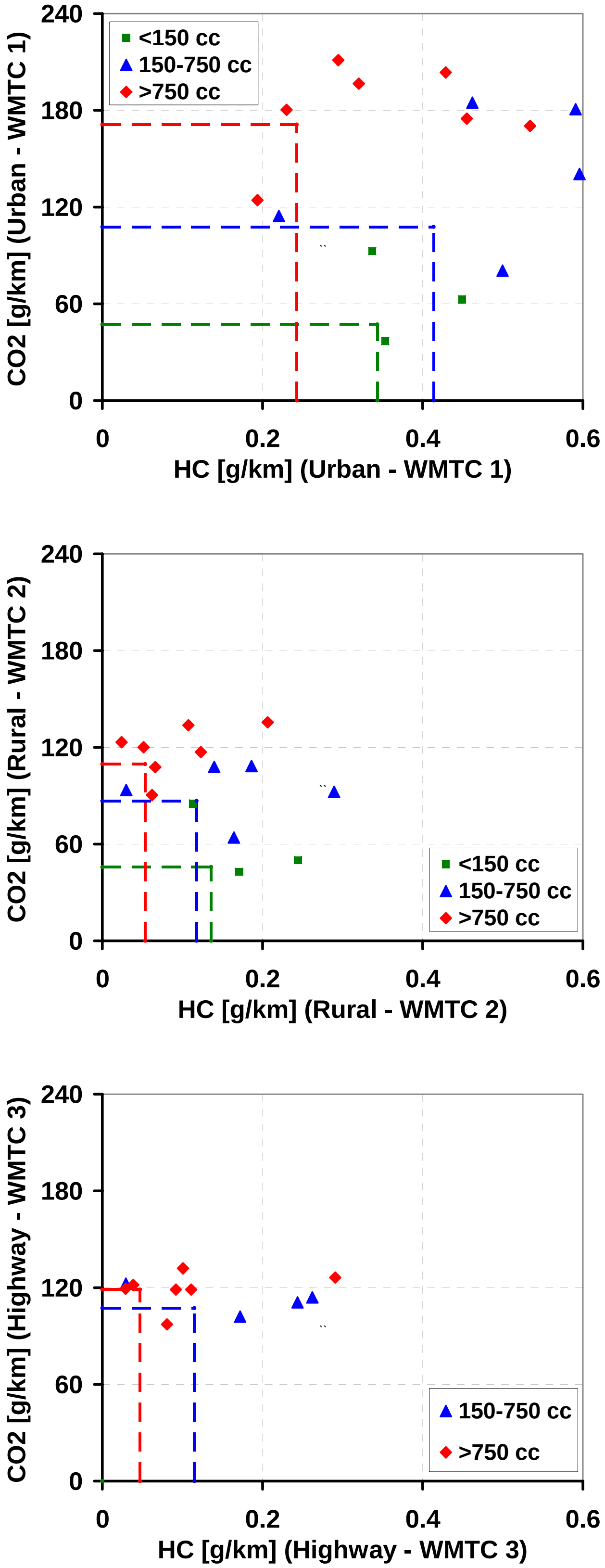


Figure 2-22: Derivation of emission factors for Best Available Technology (CO_2 vs HC)

2.4.4 Fuel evaporation factors

Evaporative emissions are volatile HC emissions due to:

- Breathing losses (directly from the fuel tank or through an activated carbon canister or through the open bowl of a carburettor)
- Fuel permeation and/or leakage through the fuel lines and circuit

The mechanisms causing evaporative emissions are:

- Diurnal emissions, due to the daily variation of ambient temperature (parked vehicle)
- Hot soak emissions, in addition over the diurnal due to the warmed-up fuel after an engine switch-off (parked vehicle)
- Running losses, due to the warming up of the fuel as the vehicle is running (vehicle engine running)

Within the previous study, COPERT III methodology was used for the determination of evaporative emissions. As already discussed back then, the development of that methodology was based on measurements mainly of uncontrolled passenger cars (i.e. without canister) that were updated using data provided by UBA. Although the fuel tank of PTWs is heated due to its close proximity to the engine, it was expected that actual PTW emissions would be lower than passenger cars due to the lower size of the fuel tank.

Since the previous study, a completely revised methodology for the determination of evaporative emissions has been developed by LAT. This methodology has been adopted by the latest version 4 of COPERT and it is presented in detail in the Emission Inventory Guidebook, Chapter 0706, Gasoline Evaporation from Vehicles (August 2007) [9, 10].

Figure 2-23 presents a comparison between the results of the new methodology (bars) against the output of the methodology of COPERT III (lines) that was used in the previous PTW study. The red line represents emissions from mopeds with no evaporation emissions control system. The new methodology clearly calculates half the emissions for mopeds. This is because of the smaller fuel tank of mopeds, which was not taken into account in the 2004 study. The blue line represents the emission level calculated by COPERT III for uncontrolled (without canister) motorcycles. The new methodology is closer to the previous one but stays slightly below COPERT III. Figure 2-24 shows a typical annual evaporation emission of HC, as a function of vehicle type and emission control technology.

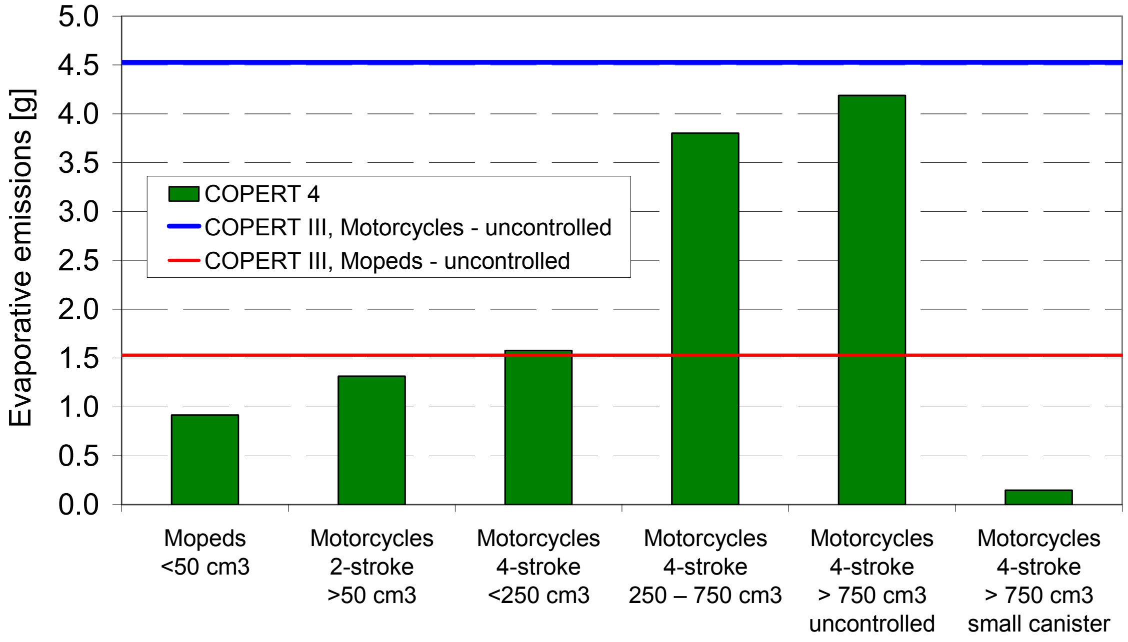


Figure 2-23: Example of typical daily evaporative emissions estimated with COPERT III and COPERT 4 methodology

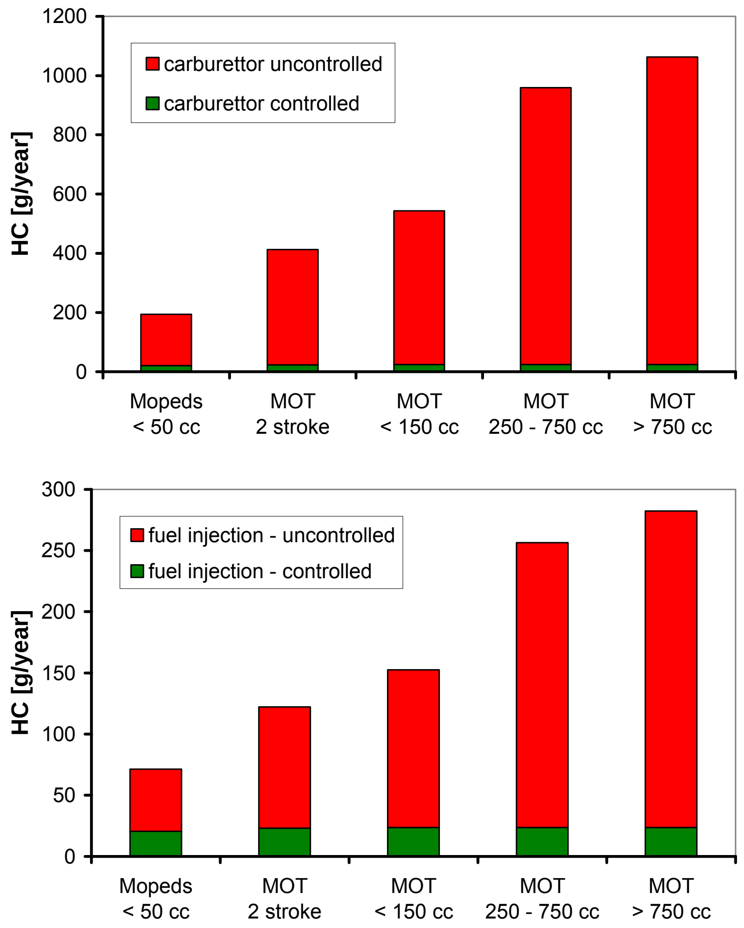


Figure 2-24: Typical annual emissions of HC due to evaporation per vehicle, as a function of vehicle cateory and emission control technology

The new methodology is part of a more detailed evaporative emission determination model [11] in order to further verify the model output, the detailed version of the model was used to simulate a test performed in a SHED according to the California certification test procedure, based on data submitted by ACEM. The test conditions and motorcycle input data are summarized below.

- Input parameters
  - Fuel vapour pressure: 60 kPa
  - Tank size: 17 l
  - Canister size: ~0.4 l (100 g activated carbon)
  - Fuel tank fill level: 50 %
  - Temperature variation: 16–36°C
  - Initial canister weight: 475 g

- Intermediate calculations
  - Fuel vapour generation: 8.1 g
  - Canister breakthrough emissions: 0.028 g
  - Permeation and/or leakage emissions: 0.056 g

- Total <u>calculated</u> evaporative emissions (original model): <u>0.084 g</u>
- Total <u>calculated</u> evaporative emissions (modified model): <u>0.113 g</u>
- Total <u>measured</u> evaporative emissions: <u>0.113 g</u>

The "calculated" value corresponds to the direct output of the model. Since there were some unknown conditions regarding the SHED experiment a set of indirect assumptions based on the available data was made. The typical values that were assumed were: initial canister loading with 60 g of vapour, hot-soak temperature 8.5ºC above ambient and metallic fuel tank. This resulted in the "modified model" value. Although the model was not calibrated against the expected result, the assumptions lead to exactly the same results as the actual SHED experiment. This demonstrates that the model much better estimates the evaporation emission from motorcycles, than the approach in the earlier study.

3 Baseline and scenarios

3.1 "Baseline"

The baseline scenario considered reflects the evolution of emissions from two, three- and four-wheelers if no additional measures to the ones decided so far will be taken. This corresponds to moped emission standards up to Euro 2 and motorcycle emission standards up to Euro 3, i.e. the situation reached up to regulation 2006/72/EC. The effectiveness of additional legislative measures will be accessed by estimating the additional reduction in emissions they could potentially bring, over the Baseline scenario.

The technical details of the baseline scenario are:

- Baseline emission factors for all vehicle categories as presented previously, reaching up to Euro 2 for mopeds and up to Euro 3 for motorcycles. As already mentioned, the latter were updated over the earlier report using new experimental data from measurements performed by EMPA and AECC on moderately aged as well as new Euro 3 PTWs.

- No particular durability control regulations. The deterioration of exhaust HC and CO emissions of all PTWs is considered to linearly increase to 20 % higher than the base emission factor over the useful life of the vehicles.

- No evaporation control specific legislation.

- Use of mineral oil in all 2-stroke motorcycles and mopeds.

- No OBD requirement. Emission deterioration due to the absence of OBD is discussed in section "OBD introduction".

- No In-Use Compliance (IUC) requirement. A probability of non-compliance is considered due to the absence of IUC, as described in section "In-Use Compliance procedure for PTWs".

The evolution of emissions with the baseline scenario was examined from 2007 up to year 2020. This time frame was chosen in the October 2008 version of the report, in order to study the emission evolution for a period of 10 years after the expected implementation of additional measures in 2010. In this revised version of the report, the introduction of measures has been examined to occur gradually in the period 2010 to 2016, depending on the scenario. Therefore, the 2020 horizon is rather short for deploying the full potential of some of the new emission limits proposed. However, due to time constraints, it has not been possible to revise the calculations to a more distant horizon, e.g. 2030.

3.1.1 PTW Share of total road-transport emissions

The contribution of PTWs in total road transport emissions in the version 2004 report was assessed up to 2012 and without considering the introduction of more advanced vehicle technologies than Euro 4 for passenger cars and Euro IV for heavy duty vehicles. Therefore, we repeated the same calculation, by considering the latest tested version of the Tremove model (V2.52). For this calculation we used scenario G5/A1, i.e. the one considering the introduction of Euro 5 and 6 passenger cars and Euro V and VI heavy duty vehicles. The particular scenario considers 50% allocation of the additional cost for Euro VI heavy duty vehicles to be attributed to the reduction of emissions of regulated pollutants (the other 50% considering to reflect performance and fuel economy improvements) and the cost of urea fully allocated to the reduction in pollutant emissions.

Figure 3-1 and Figure 3-2 shows the evolution of PTWs emissions, according to the baseline scenario, and the emission evolution from all other road transport categories. This scenario assumes no additional introduction of measures, further to the emission standards already agreed (Euro 2 mopeds, Euro 3 motorcycles). PTW emissions also include emissions from tricycles and quadricycles (therefore, in this sense the acronym PTWs- power TWO wheelers is not exact but it is used here in its wider context). In addition, the evolution of moped and motorcycle emissions share to the total road transport sector is shown with lines (right y-axis).

Two-wheelers are significant contributors only to HC and CO emissions. Despite the Euro 3 levels implemented for motorcycles (Euro 2 for mopeds), the contribution of PTWs in THC rises, reaching 62.4% in 2020 from 38% in 2007, with mopeds being the most significant contributors. This is mainly due to the significant reduction of the THC emissions from the other road transport categories.

PTW contribution to CO is significant (~20% of total in 2007) and further increases to ~36% of total road transport in 2020. However, there are practically no CO air-quality exceedances in Europe except of a few stations in the Balkans (seven stations), one station in Southern Italy (Sicily) and one in Portugal [12]. In total exceedances have occurred in only 9 out of 1065 monitoring stations in Europe. As exceedances are linked to areas with the lowest GDP around Europe, it is evident that CO exceedances are associated with old or no emission control technologies (for vehicles or stationary stations). For example, Bulgaria (where several exceedances exist) has an average passenger car age of 15 years[5] – amongst the oldest in Europe. For the older EU countries, annual-averaged 8h concentrations of CO were below 1 mg/m^3 with a limit at 10 mg/m^3. According to the report of Barrett et al. [12], normal technology replacement is expected to further alleviate any minor problems. Therefore, there is no urgent push from an air-quality perspective to further reduce CO emissions. For this reason, a need or strategy to further reduce CO in Europe does not exist. Therefore, the

[5] http://www.rec.org/REC/Publications/LeadOut/chapter32.html

increase PTW share in road transport CO emissions is less important than the increasing trend of HC emissions.

The contribution of PTWs to total PM emissions will be steadily increasing after 2013 due to the introduction of diesel particle filters on passenger cars and heavy duty vehicles. This contradicts the trend up to 2010 where the PM contribution from PTWs decreases. However, this is not due to the increase in the emission level of PTWs but due to the steep reduction in PM from all other sources. Despite the gradual increase after 2013, the contribution of PTWs does not exceed 5% of all road transport PM emissions by 2020. It will later be shown that the introduction of Euro 3 mopeds as well as additional measures for motorcycles further decrease PM emissions from PTWs.

PTWs are negligible contributors to total NO_x emissions, where heavy duty vehicles dominate. Therefore, although NO_x contribution from mopeds and motorcycles is increasing due to the gradual shift from rich to stoichiometric combustion, they are not considered to exceed ~2% of total road transport NO_x emissions by 2020.

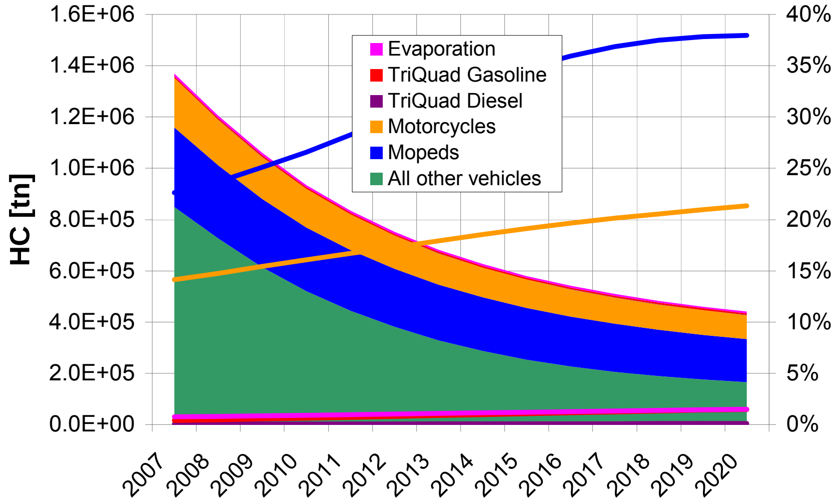
Finally, PTWs are a negligible contributor to total CO_2 from road transport (1 % in 2007 to 0.8 % in 2012). The slight decrease is both due to the fuel economy improvement of late motorcycle and mopeds models compared to earlier ones (better fuel utilization) as well as that the passenger car fleet is estimated to increase slightly faster than the motorcycle fleet.

In this July 2009 version of the report, an additional comparison is attempted where urban emissions of PTWs and other road transport vehicles are compared. This is done for two reasons: First because most of the people live in urban areas and it is important to know which are the significant sources of pollutants in the areas where people are actually exposed to. Second, because PTWs mainly operate in cities, hence comparing their emissions with cars and, in particular trucks, which run for long distances in highways is not relevant.

Figure 3-3 presents the comparison of PTW emissions with other road transport vehicles at an urban level. The contribution of PTWs increases with time for all pollutants. However, this relative increase is most important for NOx and PM. Although the contribution of PTWs in total road transport NOx emissions was projected to be 3.6% in 2020, this reaches 10% when only urban emissions are concerned. Similarly, while PM from PTWs was projected to reach 7.9% of total road transport in 2020, this becomes equal to about 20% when seen at an urban level. The reason for these significant increase in relative share of emissions when looking at an urban level, is that PM and NOx are pollutants mostly emitted by diesel heavy duty trucks. As heavy duty trucks mostly operate at a highway network, their contribution is much less at an urban level. Hence, emissions of other sources / vehicle categories become more important at an urban level. This is not so much the case for HC and CO because passenger cars are also significant contributors of these pollutants at an urban level.

The focus of the comparison at an urban level only, reinforces some of the observations reached at a regional level. In particular, if no additional measures are taken, mopeds and motorcycles will become significant contributors not only of CO and HC but also of NOx and

PM at an urban level. Therefore, measures to control these pollutants as well need to be taken.



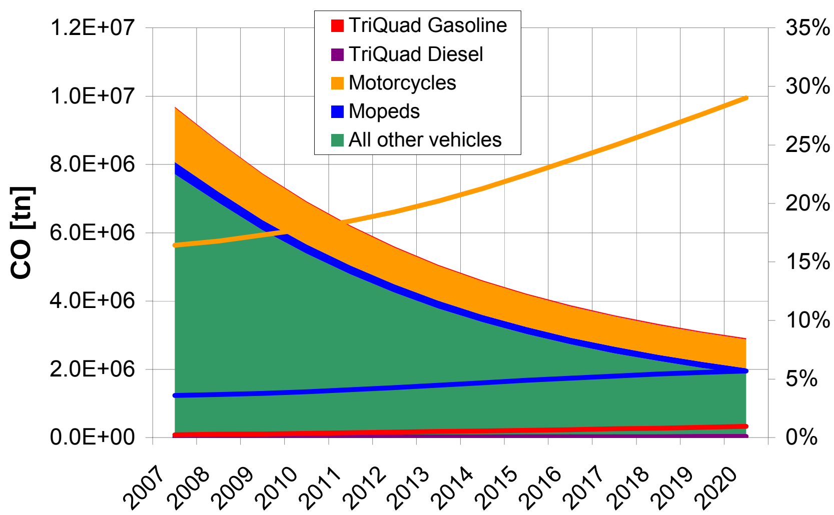


Figure 3-1: Evolution of PTW emissions according to the Baseline scenario. Comparison with emissions of all other road transport sources. Top: total HC (exhaust & evaporation), Bottom: CO

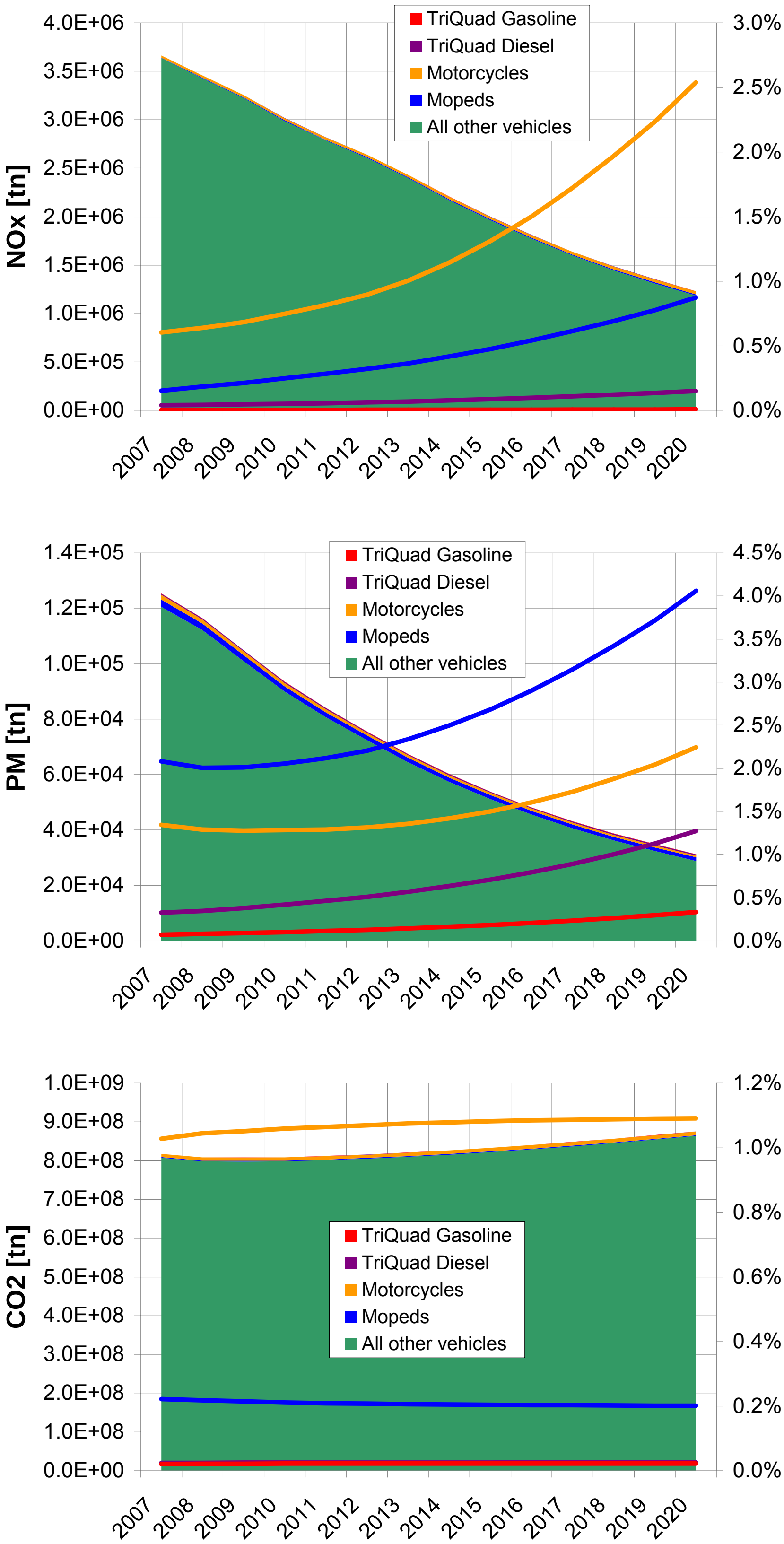


Figure 3-2: Evolution of PTW emissions according to the Baseline scenario. Comparison with emissions of all other road transport sources. Top: NO_x, middle: PM, bottom: CO_2.

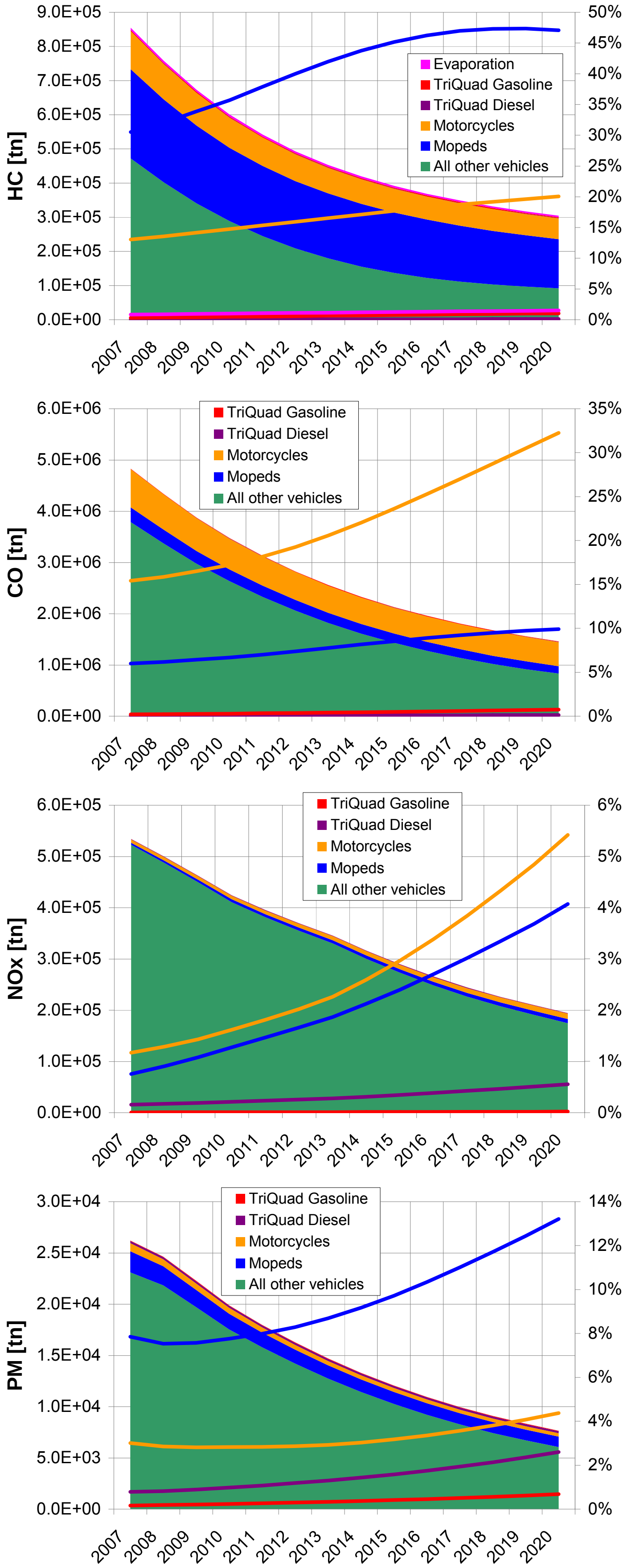


Figure 3-3: Evolution of urban PTW (incl. tricycles and quadricycles) emissions according to the Baseline scenario. Comparison with emissions of all other road transport sources

As a result, compared to the 2004 report, the extension of the projection to 2020 reveals the following conclusions, if one assumes no further PTW measures considered to what has already been decided today, i.e. up to Euro 2 mopeds and Euro 3 motorcycles (it is repeated that PTWs in this sense includes tricycles and quadricycles):

- The contribution of PTWs to HC emissions will be becoming even more important than what was assessed in 2004. PTWs are projected to emit more in 2020 than all other vehicle categories collectively (62.4% of total road transport emissions). This clearly shows the need to better control HC emissions from these two vehicle categories, as their contribution is even more important at an urban level.

- PTWs also become much more important contributors to CO emissions by 2020 (35.8% of total road transport). However, there are limited CO-related air-quality issues in Europe today and the emissions of CO are further assumed to decrease in the future due to normal technological development. Hence, the high contribution of motorcycles and mopeds to total CO emissions is not considered a significant environmental problem – at least not as significant as the HC one.

- The contribution of PTWs to NO_x and PM emissions seems to increase after 2013, due to the introduction of DeNOx and DPF aftertreatment systems in both passenger cars and heavy duty vehicles at Euro 5/V and particularly in Euro 6/VI level. Although, the absolute contribution of PTWs remains small (at ~2% and ~5% respectively) by 2020, there seems to be a need to further control emissions. This is particularly true when one focuses on urban emissions only, where the share of PTWs to total NOx and PM becomes ~10% and ~20%, respectively. Several of the measures considered by the European Commission and discussed in this report will have an effect on both pollutants and should therefore be promoted.

- Finally, CO_2 emissions from PTWs are overall a very small share of total emissions. Given the fact of much lower CO_2 emissions of PTWs per passenger, compared to passenger cars, the increase in trips conducted by PTWs will actually have a positive effect in the overall reduction of CO_2 emissions from road transport.

3.1.2 Contribution from tri- and quadricycles

Tri-cycles and quadric-cycles are a special category corresponding to a very small portion of the total vehicle fleet (see section 2.2 for details). All previous regulations included relaxed emission standards for this vehicle category, taking into account several small and medium size of the companies producing these vehicles. Emissions from tricycles and quadricycles have been included in the baseline scenario. We examine here in more detail the emission evolution from such vehicles to identify whether any more strict measures in the future will bring significant environmental benefits. In addition to the main assumptions of the baseline scenario for mopeds and motorcycles, the following assumptions were made for this vehicle category:

- ATVs (all terrain vehicles)
    - Equipped with spark ignition engines;
    - Fleet was estimated based on data provided by the All Terrain Vehicle Industry European Association (ATVEA) for the years 2003 to 2008;
    - The average lifecycle of 5 years suggested by ATVEA was used to derive the vehicle age distribution (simplified approach);
    - The increase of fleet after 2008 was assumed to be proportional to the increase of PTW.
- Mini-cars
    - Equipped with compression ignition engines (diesel);
    - The fleet was estimated based on data by the European Quadricycle League (EQUAL) for the current quadricycles fleet;
    - Age distribution was defined on reasonable assumptions based on data for large motorcycles and small passenger cars;
    - The increase of fleet after 2008 was assumed to be proportional to the increase of PTW.
- The useful life is 12000 km. This results to an annual deterioration of 10% for all pre Euro 3 vehicles and 5% for the Euro 3 ones.
- No additional deterioration of emissions due to failures, etc.
- Ambient conditions and fuel specifications for evaporation calculations selected according to Italian/French data, were most of these vehicles are sold.

Figure 3-4 and Figure 3-5 display the contribution of the tri-cycles and quadric-cycles to the total motorcycle emissions. Their contribution is calculated much higher than in the earlier report, which did not find them to exceed 2% of the total PTW emissions in no pollutant considered. The reasons for this higher share of tri- and quadric-cycles in total emissions are summarized in that:

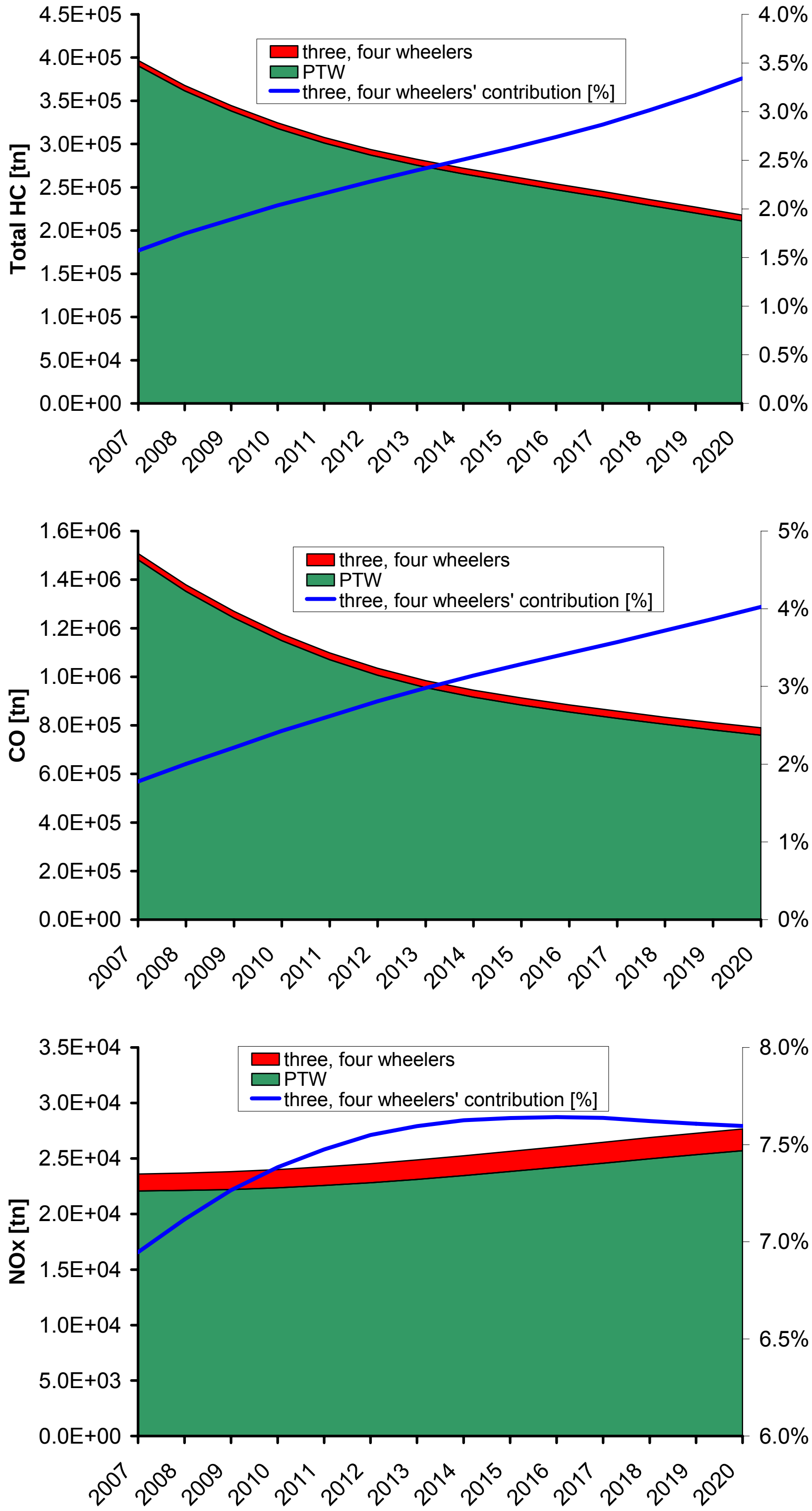


Figure 3-4: Evolution of emissions of 3 & 4 wheelers and comparison with total motorcycle emissions. top: total HC (exhaust & evaporation, middle: CO, bottom: NO_x.

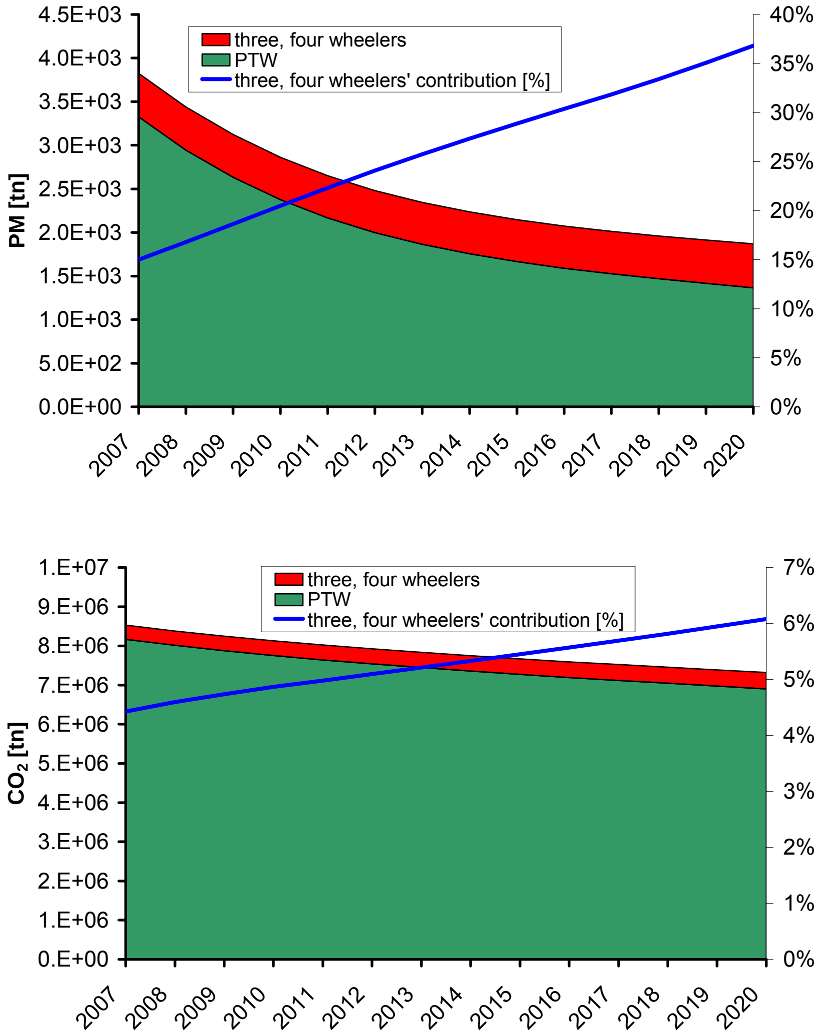


Figure 3-5: Evolution of emissions of 3 & 4 wheelers and comparison with total motorcycle emissions. top: PM, bottom: CO_2.

- The stock of these vehicles is much higher, than what earlier considered. With the inclusion of both mini-cars and ATVs, the total vehicle stock in 2007 exceeds 600 thousand vehicles and is projected to increase beyond 800 thousand vehicles in 2020, compared to 67.7 thousand considered in the 2004 report. The reason for this big difference is that the market of these vehicles has actually boomed from 2005 and later, which was impossible to predict in 2004.

- In the earlier study, 70% of the total stock was considered to consist of petrol vehicles and only 30% of diesel ones. The current information reveals that the share of mini-cars and ATVs is rather equally split. This leads to significantly higher emissions of NO_x and PM.

As a result of the new estimate, the contribution of such vehicles cannot be considered negligible, within the PTW sector. In particular, quadricycles will be responsible for more than

35% of total PM from the sector in 2020. This corresponds to almost 2% of the total PM emitted from all road transport sectors. Given the facts that the evolution of the mini-cars stock is quite conservative and that their operation mainly occurs in urban or tourist areas where air quality is of a high importance, this relatively high share of PM emissions is an issue that needs to be addressed.

The evolution of NO_x emissions from such vehicles is also an issue that needs to be looked at with some attention. The contribution of such vehicles is currently some 7% of the total PTW emissions. Due to the introduction of more Euro 3 motorcycles in the future years, which may actually have higher NOx emissions than conventional motorcycles, the share of tricycles and quadricycles to total emissions is not expected to significantly change in the future. As a matter of fact, quadricycles are projected to contribute to only about 0.15% of total road transport emissions. Attention however should be given to local environments (hotspots) with high concentrations of such vehicles.

The contribution of quadricycles in HC emissions is dominated by ATVs and their gasoline engines. While ATVs were about 1.5% of total PTW emissions in 2007, this is projected to more than double in the future, as emissions from PTWs drop with the improvement in technology. As a result, ATVs alone will be some 2% of total HC emissions emitted by road vehicles. Again, this is an issue that will have to be addressed by the regulations.

3.2 Emission Limit Scenarios

In this section, the cost, emission benefits and the cost-effectiveness of the different policy measures, related to the formulation of new emission standard values, strictly for power two wheelers (i.e. no tricycles and quadricycles) are assessed. Emission limits for tricycles and quadricycles are examined in section 3.3.6. A set of alternative scenarios were developed in addition to the baseline, in order to evaluate different policy options as regards possible future emission limits. As presented in the previous section, the baseline considered emission evolution assuming no legislative step beyond 2002/51/EC and 2006/72/EC. In this section, the cost of the baseline is assumed zero and all additional costs are estimated as incremental costs over this baseline.

3.2.1 Scenario 1

This scenario corresponds to the draft "Initial Commission Proposal", as reflected in the "Status Report Emissions" (Moto 105), which considered only introduction of a Euro 3 moped emission standard in 2010. The emission limit values at Euro 3 stage are equal to the Euro 2 ones, but the type approval cycle is the cold-start ECE-R47 with a 30% weighing of the cold-start part. No emission limit step further to Euro 3 (a step already included in the baseline) is considered for motorcycles. The emission factors used for mopeds in this case are in detail presented in the 2004 report (1).

Table 3-1: Emission standards introduced in Scenario 1

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 3 [2010]	MP	8 (4+4) ECE R47 cycles sampling (0.3 / 0.7 weighting cold / hot)	1 000 (3 500 for 3/4 wheel MP)	1 200		/

The emission control technology required to reach Euro 3 for mopeds has been also discussed in the 2004 version of the report. The majority of the market (70%) is projected to be consisting of 4S mopeds. These would be equipped with either fuel injection (50%) or electronic carburettors (50%) for more accurate delivery of the fuel in the cylinder. The exhaust would be equipped with secondary air injection and an oxidation catalyst. A pre-catalyst might also be necessary but this is not assumed to be occurring for a large share of the models to be offered. The main catalyst would also have to be more efficient than the Euro 2 one, i.e. a larger monolith with higher cell density and precious metal content would be required. No closed-loop three way catalyst system is projected to appear for mopeds. Some 30% of the market might continue to consist of 2S engines. These would need to be equipped with direct fuel injection although concepts with electronic carburettors and careful calibration have also been shown to attain the necessary cold-start engine control. Also, an electronic pump would be necessary to deliver precise quantities of lube oil in the combustion chamber. A precatalyst, secondary air injection, and a main catalyst would then be necessary to control the inherently higher HC engine-out emissions of the 2S engine.

In general, although the proposed Euro 3 emission standards impose a significant emission control step due to the introduction of a cold-start regulation, it seems that they can be attainable without significant performance compromises, especially in the 4S case. For 2S models, the introduction of a cold-start testing strains the technology close to the limits of its potential. In principle, what this means is that the proposed Euro 3 standards impose significant calibration and equipment costs for 2S at a level that makes 4S a more attractive (and simple) option. The reason for existence of 2S is the comparatively lower cost compared to 4S and, earlier, the performance and responsiveness benefits. If cost benefits are not existent anymore, 2S will gradual disappear or only retained in some niche applications (e.g. sport-performance mopeds) which can justify the extra cost.

Based on this rationale, two different cost categories were considered for Euro 3 mopeds. One was the additional/improved material cost over Euro 2 and the second was engine tuning/recalibration costs. For 2S, the first cost category (at 2008 currency values) was assumed to reach € 43-65 per vehicle over Euro 2, and costs for recalibration were considered at M€ 1.5-2.0 per engine family. For 4S models, material costs were assumed at € 97-125 per vehicle and M€ 1.0-1.5 for recalibration per engine family. Justification for these ranges is included in the 2004 report.

3.2.2 Scenario 2:

Scenario 2[6] assumes the introduction of two future emission standards for motorcycles, post Euro 3. A Euro 4 step introduced in 2012 offers a 25% reduction of all pollutants relative to Euro 3. A Euro 5 emission standard is then introduced in 2015. The emission limits for the Euro 5 standard have been derived in mathematical analogy to Euro 5 for cars, according to the equation:

$$EF_{PTW,\,EURO\,5} = EF_{PTW,\,EURO\,3} \times \frac{[Euro\,5\;PC\;Emission\;Limit]}{[Euro\,3\;PC\;Emission\;Limit]}$$

The Euro 5/Euro 3 PC factors are: CO = 0.435, HC = 0.5, NOx = 0.4. The HC reductions have been also applied on PM, as it is expected that better fuel utilization will also lead to lower particulate mass emitted.

For mopeds, two emission limit steps are considered. A Euro 3 step, with the same emission limits as in Scenario 1, is considered to be introduced in 2012. In addition, a Euro 4 moped step is assumed to be introduced in 2015, leading to a 33% reduction in THC+NOx over Euro 3 (and a 45% reduction in CO for three-cycle mopeds). It should be noted that PM emission factors have been also reduced in proportion to the HC reduction in this scenario, although this is not directly imposed by the emission standards. This is done as it is expected that better fuel utilization enforced to reach the HC standards will also result to lower PM emissions. The emission limit values for the emission standards in this scenario are presented in Table 3-2.

The Euro 3 moped introduction requires technology that has already been presented with Scenario 1. In Scenario 2, it is projected that the reduction of 33% in THC+NOx of Euro 4 over Euro 3 will force the market to shift mainly to 4S engines. Therefore 90% of mopeds (or, expressed differently, 28 of the annual 30 type approvals) are assumed to be four-stroke ones, equipped with fuel injection (by 80%) or electronic carburettor (by 20%), secondary air injection, and an oxidation catalyst. It cannot be certain whether 2S engines will make it into Euro 4. However, in order not to exclude the potential for technological breakthroughs, we have assumed that 10% (or 2 type approvals per year) will continue to be 2-stroke vehicles. The few 2S models surviving will need an improved oxidation catalyst, or even a precatalyst to control HC, and improved engine design and tuning to reduce NOx.

6 This scenario has been modified over the October 2008 version of the report and has been first presented in the June 29 MCWG meeting. A number of alternatives of this scenario, also including non technical measures (accelerated replacement scheme) may be found at http://ec.europa.eu/enterprise/automotive/mcwg_meetings/29_06_2009/lat_category_vehicle_5th_emission_scenario_v1.pdf. It should be stated that the scenario included in this report contains only the emission limit values proposed in the June 29 MCWG meeting. The durability and evaporation control policies, included as a package in the June 29 scenario, are separately presented in sections 3.3.1 and 3.3.5, respectively. Therefore, the emission benefits of this scenario may somehow differ from the results presented in the MCWG meeting.

Table 3-2: New emission standards introduced in Scenario 2

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 4 [2012]	MC vmax< 130 km/h	WMTC (ECE/TRANS/180/Add.2/ Amend.1 of 29 January 2008)	1 970	560	130	/
	MC vmax≥ 130 km/h		1 970	250	170	/
EURO 5 [2015]	MC vmax< 130 km/h	WMTC (ECE/TRANS/180/Add.2/ Amend.1 of 29 January 2008)	1 140	380	70	/
	MC vmax≥ 130 km/h		1 140	165	90	/
EURO 3 [2012]	MP	8 (4+4) ECE R47 cycles sampling (0.3 / 0.7 weighting cold / hot)	1 000 (3 500 for 3/4 wheel MP)	1 200		/
EURO 4 [2015]	MP	8 (4+4) ECE R47 cycles sampling (0.3 / 0.7 weighting cold / hot)	1 000 (1 900 for 3/4 wheel MP)	800		/

In order to reach Euro 4 in Scenario 2, the additional cost of 2-stroke mopeds over Euro 3 for introducing an improved catalyst was assumed to be € 15-30 per vehicle and the engine tuning cost at an additional M€ 0.8-1.2 per engine family. From a cost-effectiveness calculation perspective, even eliminating 2S engines from the market would have limited impacts to the results, as these vehicles correspond to a limited extent to the total stock. For 4S vehicles, the total cost was assumed € 30-40 per vehicle to introduce an improved fuel injection and a pre-catalyst, with the calibration cost estimated at M€ 0.5-1.0 per engine family. These values were just estimates based on the corresponding costs of transition from Euro 2 to Euro 3

For motorcycles, both engine and aftertreatment measures will be required to move technology beyond Euro 3. Several engine measures will have to be further promoted such as optimized fuel injection timing, air exchange improvement, combustion chamber designs to reduce fuel/lube oil interactions and crevice volume above the piston spacer, injectors with reduced sac volume, etc. Without diminishing the value of the reductions that can be achieved by engine measures, most of the reductions will be achieved by enhanced aftertreatment control, similar to the gasoline passenger car shift from Euro 4 to Euro 5. In principle, this would again mean the use of a pre-catalyst for fast light-off, together with a larger and/or more efficient main catalyst. More precise lambda control will also be required. The use of secondary air injection may also be required for some of the models to be offered, and this will depend on the specifications of the vehicle and the manufacturer considered. In any case, no 2S engines are foreseen to be viable at post Euro 3 level, except perhaps in some few niche applications with very limited audience.

ACEM performed an internal survey in several of their members to collect cost information of possible additional emission control measures over Euro 3 to reach the proposed Euro 5 limits in this scenario. Data were collected by four manufacturers and an additional one provided qualitative information regarding the possible introduction of additional measures. The ACEM members that came back with a response covered the range of available models, from scooters to high-end motorcycles. Naturally, costs vary depending on the market segment that different manufacturers aim at. Engine development costs reported ranged from M€ 0.15-2.5 for the first engine type of a new family series. Three out of the four manufacturers came with more consistent figures, in the order of M€ 0.5-1.0 for each new engine family concept, with the higher limit corresponding to the manufacturer of high-end motorcycles.

With regard to the catalyst costs, the cost of a pre-catalyst was estimated in the order of € 50-80 and the additional costs over Euro 3 for the main catalyst were assumed in the range of € 40-70.

Based on these data, we considered that the transition from Euro 3 to Euro 4 will only require a more efficient TWC, adding a cost range of € 40-70 to the Euro 3 technology. The transition from Euro 4 to Euro 5 will require both engine optimization and tuning at a cost of € 0.5-1.0 per new engine family plus an additional cost of € 50-80 for the precatalyst.

3.2.3 Scenario 3

In this scenario, a single emission step for motorcycles (Euro 4) is considered for introduction in 2010. This step is considered to introduce emission reductions already achievable by the 20^{th} percentile of the current motorcycle fleet. The emission factors utilized in this scenario, the data sources and the assumptions were presented in section 0 of this report. Based on the emission factors derived in this way, one may assess the corresponding emission standards required to reach these emission values. In order to do so, the BAT/Euro 3 emission factor ratios need to be derived. If one assumes equal shares of urban, rural, and highway driving, then the BAT over Euro 3 ratios become as shown in Table 2-9. The assumption of equal shares between driving modes has limited impact over any other alternative, as the ratios of BAT/Euro 3 only little differ between driving modes.

The three motorcycle classes used to derive the BAT emission factors are split according to capacity and differ over the two speed classes defined by Directive 2006/72/EC. Some assumptions are therefore required to derive equivalent emission standards. From the WMTC development work it is known that the MC<150 cc and the vmax<130 km/h classes largely overlap. Therefore, using the MC<150 cc reductions to derive the emission standard values for the vmax<130 km/h class is a good approximation. For the remaining two classes, the market volumes are used to derive an equivalent emission standard. Hence, the equivalent emission standard for the class vmax>130 km/h can be defined as 2/3 based on the reductions for the MC 150-750 cc class and 1/3 based on the reductions of the MC > 750 cc class. Based on these approximations, equivalent standards that can be set to reflect the current best available technology are given in Table 3-4.

Table 3-3: Ratios of BAT/Euro 3 emission factors per pollutant

Motorcycle class	CO	HC	NOx	CO_2
MC <150 cc	0.60	0.84	0.55	0.75
MC 150-750 cc	0.58	0.75	0.53	0.88
MC >750 cc	0.42	0.57	0.50	0.96

Table 3-4: New emission standards introduced in Scenario 3

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 4 [2010]	MC vmax< 130 km/h	WMTC (ECE/TRANS/180/Add.2/ Amend.1 of 29 January 2008)	1 570	630	94	/
	MC vmax≥ 130 km/h		1 380	228	110	/

As these standards correspond to best available technology, no additional engine tuning is considered to be required over Euro 3. However, it is expected that the best available emission control technology will be required. This includes an improved TWC at a cost of €40-70 per vehicle and a precatalyst at a cost of €50-80 per vehicle.

3.2.4 Scenario 4

The fourth scenario assumes the introduction of Euro 3 mopeds and Euro 4 motorcycles in 2013, and Euro 4 mopeds and Euro 5 motorcycles in 2016. The emission limit values for Euro 3 mopeds and Euro 4 motorcycles are equal to the Euro 5 emission limits proposed for large motorcycles (>150 cc, >130 km/h) in Scenario 2 with no further distinction to vehicle classes. The emission limits for Euro 4 mopeds and Euro 5 motorcycles are set arithmetically equal to the Euro 5 passenger cars. Based on these assumptions, the emission limit values are shown in Table 3-9.

Table 3-5: New emission standards introduced in Scenario 4

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 4 [2013]	All MC	WMTC (ECE/TRANS/180/Add.2/ Amend.1 of 29 January 2008)	1 140	165	90	/
EURO 5 [2016]	All MC	WMTC (ECE/TRANS/180/Add.2/ Amend.1 of 29 January 2008)	1 000	100	60	/
EURO 3 [2013]	MP	8 (4+4) ECE R47 cycles sampling (0,3 / 0,7 weighting cold / hot)	1 140	165	90	/
EURO 4 [2016]	MP	8 (4+4) ECE R47 cycles sampling (0,3 / 0,7 weighting cold / hot)	1 000	100	60	/

This scenario has been added in this revised version of the report at the request of the European Commission. No assessment of the feasibility to meet the strict emission limit values and the required technology could be done in this case. For the same reason, it was not possible to estimate the cost to reach these emission standards. Therefore, costs have been calculated as multiplicands of the emission technologies in scenario 2, just to provide an order of magnitude for the cost effectiveness of this measure.

Therefore, the transition from Euro 2 to Euro 3 mopeds in 2013 (83% reduction in HC, 86% reduction in NOx, and 43% reduction in CO) is assumed to cost double as much as the transition from Euro 2 to Euro 3 in scenario 2, while the transition from Euro 3 to Euro 4 (a further reduction of 39% HC, 12% CO, and 32% NOx) is assumed to cost equally to the transition of Euro 2 to Euro 3 (4S vehicles), however with a ±50% wider range of cost for engine tuning, due to the uncertainty of the calculation (i.e. engine calibration from Euro 2 4S to Euro 3 4S assumed to cost M€ 1.0-1.5 per engine family, while the cost from Euro 3 to Euro 4 assumed to cost M€ 0.5-2.25 per engine family). For motorcycles, the cost to introduce Euro 4 from Euro 3 is equal to the cost of introducing Euro 5 in Scenario 2, increased by 50% to account for the more strict emission limits for small motorcycles. This brings the cost to €135 – 225 / vehicle plus M€ 0.75-1.5 per engine family for tuning. Finally, the introduction of Euro 5 over Euro 3 is assumed to cost twice as much as the introduction of Euro 5 in Scenario 2 (€55-75 per vehicle and M€ 0.25-0.5 per engine family over Euro 4). It is repeated that these costs are just multiplicands of earlier technology step introduction.

In the 2008 version of the report, more relaxed future emission standards were proposed than in this version of the report. The relaxed emission standards were associated with minor additional cost and hence price increase for PTWs. In this revised version, more stringent emission standards are proposed, in particular in scenario 4, which are potentially associated with significant cost increases. It needs to be made clear that despite the high costs introduced per vehicle in some of the scenarios, the inevitable increase in the price of the end-product has been assumed not to affect the total demand projected in section 2.2. That is, the total demand is considered not to be flexible to cost increase in our simulations. This is a simplification which may introduce a positive or a negative bias to the emission calculation. This bias increases with increasing cost of a new measure. For example, substantially increasing the cost will inevitably shift some potential buyers to either gasoline or diesel cars. Substituting motorcycles with small gasoline cars will reduce all conventional pollutants from transport but will increase CO_2 emissions. Substituting motorcycles with diesel cars will decrease HC and CO emissions but will increase NOx, PM, and CO_2. In addition, substitution of motorcycles with cars will increase congestion and may aggravate pollution in cities with a substantial PTW population. These are highly non-linear effects that are not taken into account in the arithmetic calculations of this report, but need to be given substantial focus when developing the relevant policy.

3.2.5 Calculation results

All these scenarios were formulated using exactly the same stock evolution and activity data estimates made in the baseline scenario. Hence, comparison of the emission reductions achieved with the introduction of each emission standard shows the environmental benefit of each corresponding regulation. The evolution of all regulated pollutants and PM for PTWs in the EU due to the introduction of the different emission standards is shown in Figure 3-6. Figure 3-7 shows the emission benefits over the baseline scenario. Finally, Figure 3-8 shows the absolute emission level and the relative reduction over the baseline for PM.

The following observations can be done for these emission reductions:

1. Scenario 4 achieves the highest emission reductions in 2020 for CO, HC and NOx, due to the most stringent emission standards proposed, except for CO_2 where no emission standard is proposed. This benefit comes despite its late introduction (first step in 2013).
2. Scenario 2 achieves the second best emission reductions for HC and CO, as this introduces two new steps for motorcycles and two new steps for mopeds, albeit with more relaxed emission limits than Scenario 4.
3. A significant first step in reducing HC is already introduced with Euro 3 mopeds in Scenario 1. For example, the HC benefit of Scenario 1 in 2020 (one emission standard introduction) representσ 40% of the Scenario 2 benefits (four emission standards introduction). This shows the significance of introducing Euro 3 for mopeds. On the other hand, Scenario 1 achieves no reduction of NO_x (in reality, slightly higher NO_x emissions may be produced as 2-stroke mopeds shift to 4-stroke ones and combustion moves at or closer to stoichiometric).
4. NOx emissions are achieved with all other scenarios than Scenario 1. Scenario 3 that represents the currently best available technology (one emission step), achieves almost equal reductions with Scenario 2 (four emission steps) and only ~23% less benefit than the stringent Scenario 4. This means that even current technology has a large potential in reducing NOx emissions from PTWs
5. The CO_2 emission benefits introduced by the Scenarios 1, 2, and 4 originate only from the introduction of Euro 3 mopeds, as no measurable CO_2 benefit is expected from Euro 4 and 5 motorcycles. Therefore, Scenario 1 leads to somehow higher overall reductions in 2020, compared to the other scenarios because of the earlier introduction of Euro 3 mopeds in this case (2010 instead of 2012). The highest CO_2 reductions are achieved in Scenario 3 where the best 20% per motorcycle class has considered to estimate CO_2 emission factors. Obviously, Scenario 3 includes the lighter and lowest performing motorcycles per class.
6. PM emission reductions are achieved by all scenarios, except Scenario 3, in which no measured data were available to estimate the potential of the best available technology. Most of the reduction is already achieved with the introduction of the Euro

3 mopeds in Scenario 1, as this causes a large shift to 4-stroke engines and a better overall control of HC emissions, which are a good proxy of PM emissions from mopeds. Additional benefits are introduced with scenarios 2 and 4 due to the introduction of Euro 4 for mopeds and Euro 4/5 for motorcycles, as a result of the improved fuel utilization which is considered to reduce PM emissions. To put it into perspective, ~70% of PM reduction achieved in Scenario 4 (the most stringent – four emission standards) is already achieved by Scenario 1 (one emission standard).

A summary of the emission reductions achieved by each scenario (including the baseline but without fuel evaporation) is given in Table 3-6. The table presents the total emissions per pollutant in 2009 and 2020. In the baseline, reductions in 2020 over 2009 are achieved as a result of normal vehicle replacement, which are substituted by Euro 2 mopeds and Euro 3 motorcycles. The table also presents the percentage reduction over the baseline achieved by each scenario and the percentage of PTWs contribution over total road transport in 2020. Finally, the total emissions in the period 2007 to 2020 for which simulations have been drawn are presented. In addition to the conclusions reached in the previous paragraphs, the table also allows to calculate the total benefit expected from the introduction of the different emission control measures. Based on these:

- The absolute contribution of PTWs to total road transport emissions of CO, HC, and PM drops in the future, even at the baseline scenario. To put it in perspective, the absolute level of baseline emissions in 2020 is projected ~60% of the 2009 levels for these three pollutants. However, the contribution in NO_x and CO_2 increases in the baseline by 44% and 11%, respectively.
- The relative contribution of PTWs, as a fraction of total road transport emissions, is projected to increase in the baseline and in all scenarios considered, as a result of the substantial reductions projected to road transport emissions from all other vehicle classes. The result is a consequence of the fact that the emission standards proposed for PTWs come at a much later stage that emission standards for passenger cars and other classes. For example, Euro 5 for cars is introduced in 2010 which allows a period of 10 years to 2020 to deploy the potential of the technology. Motorcycles' Euro 5 is introduced in 2015 (Scenario 2) or 2016 (Scenario 4) which allows only 4 to 5 years to deploy the potential. A more distant horizon (e.g. 2030) would have provided a much more representative figure of the emission standards' potential.
- Despite the relative contribution of PTWs to road transport increases, the scenarios proposed all provide measurable reductions in the emissions of all pollutants (except of Scenario 1 in NOx). More specifically, in 2020 the scenarios achieve the following reductions over the baseline:
    - Scenario 1 achieves 1.5%, 6.5%, and 27% reduction in CO, HC, PM, and CO_2 respectively. NOx marginally increases (by +0.24%).
    - Scenario 2 leads to 16.3%, 15.3%, 37%, 1.77%, and 26.9% reductions in CO, HC, PM, CO_2, and NOx, respectively.

- Scenario 3 achieves reductions of 15%, 2.3%, 9.7%, and 22% for CO, HC, CO_2 and NO_x, respectively. No PM reduction could be assessed based on the available experimental data.
- Finally, Scenario 4 achieves 18.5%, 28.2%, 40.1%, 0.88%, and 36.7% reductions in CO, HC, PM, CO2, and NOx, respectively.

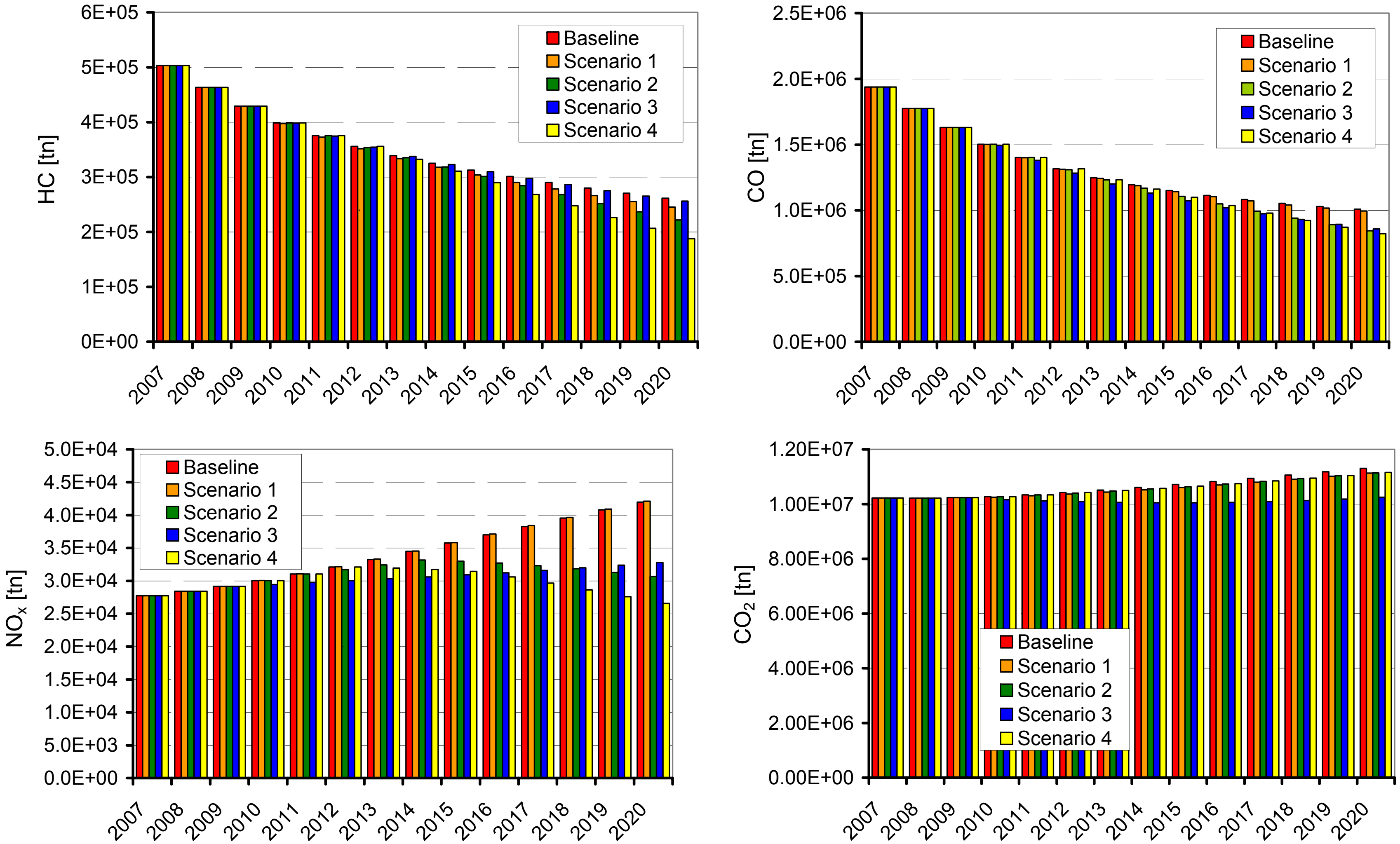


Figure 3-6: Estimated evolution of regulated pollutants from total PTWs in EU15 due to the introduction of different emission standards

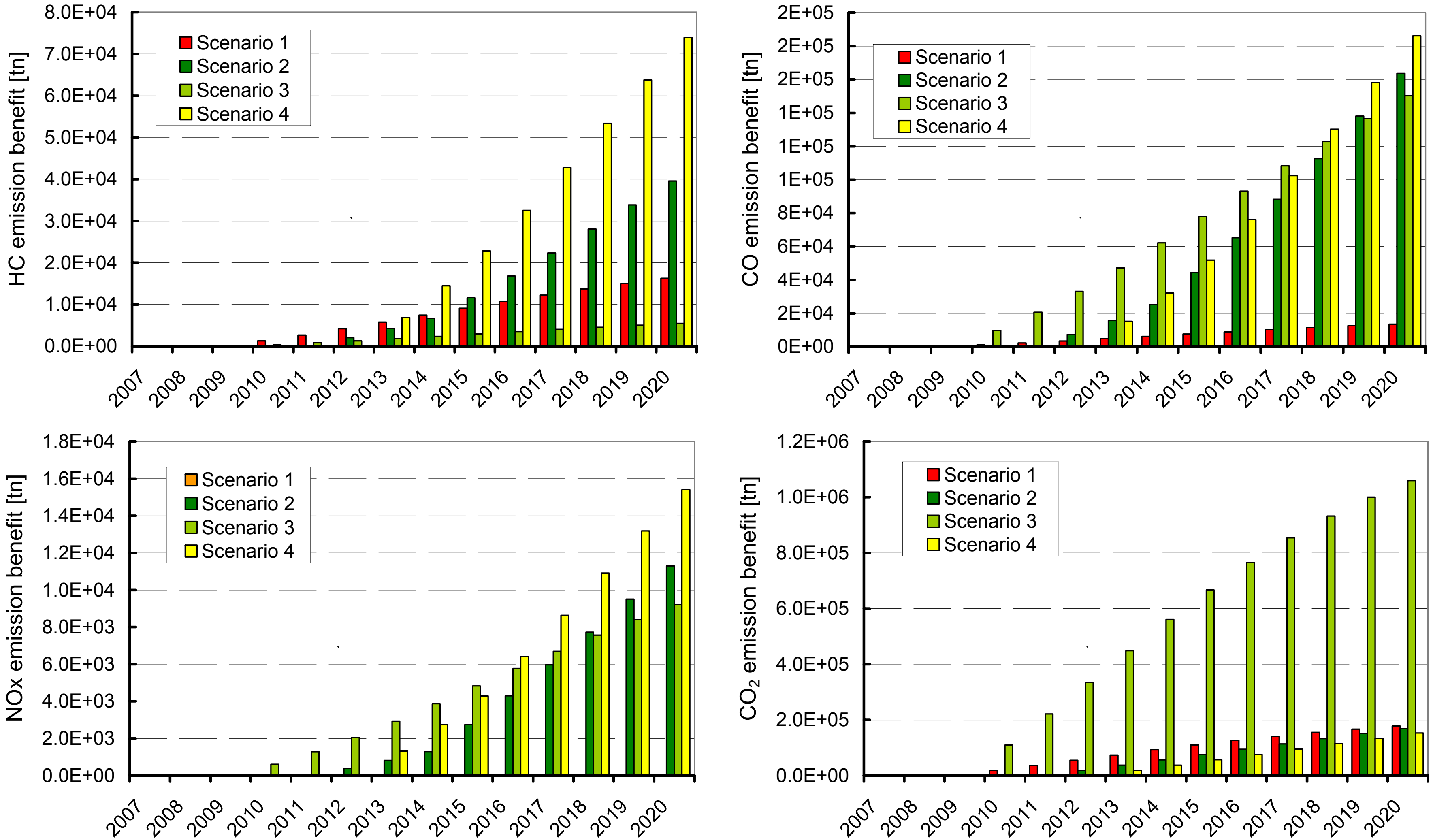
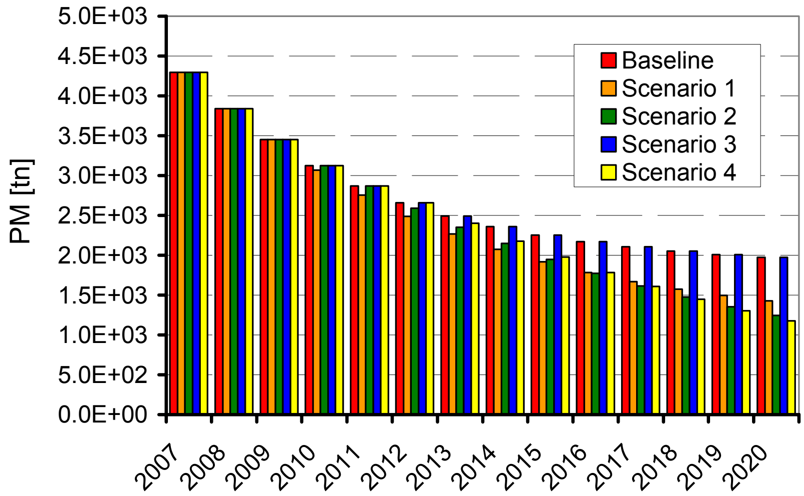


Figure 3-7: Estimated emission benefit evolution of regulated pollutants from total PTWs in EU15 due to the introduction of different emission standards



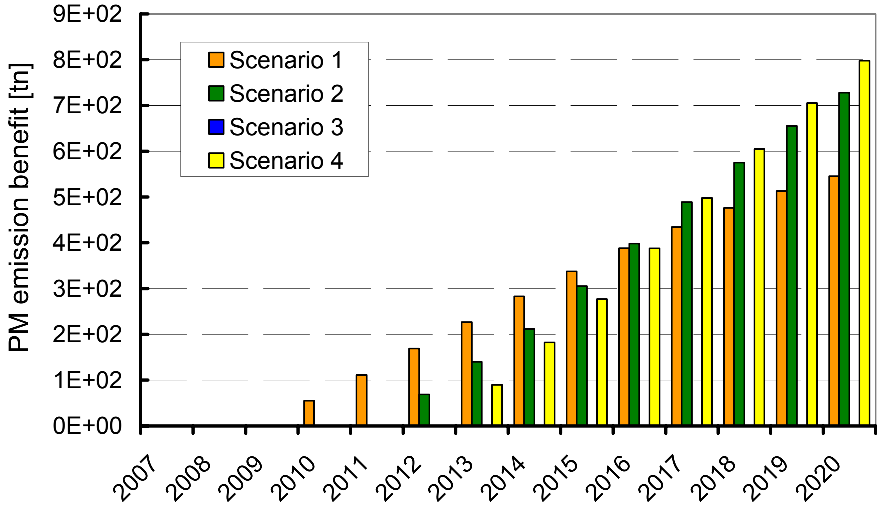


Figure 3-8: Estimated PM emissions (top) and PM emission benefit evolution (bottom) from total PTWs in EU15 due to the introduction of different emission standards.

Table 3-6: Summary of the effectiveness of the emission limits scenarios proposed

Scenario	Pollutant	Total [tn] (2007-2020)	2009 [tn]	2020 [tn]	Percentage reduction over baseline in 2020	Percentage of total road transport in 2020
Baseline	**CO**	1.84E+07	1.63E+06	1.01E+06		35.1%
Scenario 1		1.84E+07	1.63E+06	9.95E+05	1.3%	34.8%
Scenario 2		1.78E+07	1.63E+06	8.45E+05	16.2%	31.2%
Scenario 3		1.76E+07	1.63E+06	8.59E+05	14.9%	31.5%
Scenario 4		1.77E+07	1.63E+06	8.23E+05	18.5%	30.6%
Other road transport		5.66E+07	6.07E+06	1.87E+06		
Baseline	**CO_2**	1.49E+08	1.02E+07	1.13E+07		1.3%
Scenario 1		1.48E+08	1.02E+07	1.11E+07	1.6%	1.3%
Scenario 2		1.48E+08	1.02E+07	1.11E+07	1.5%	1.3%
Scenario 3		1.42E+08	1.02E+07	1.02E+07	9.4%	1.2%
Scenario 4		1.48E+08	1.02E+07	1.12E+07	1.4%	1.3%
Other road transport		1.15E+10	7.98E+08	8.64E+08		
Baseline	**HC**	4.91E+06	4.29E+05	2.62E+05		61.2%
Scenario 1		4.81E+06	4.29E+05	2.45E+05	6.2%	59.7%
Scenario 2		4.74E+06	4.29E+05	2.22E+05	15.1%	57.3%
Scenario 3		4.87E+06	4.29E+05	2.56E+05	2.1%	60.7%
Scenario 4		4.60E+06	4.29E+05	1.88E+05	28.3%	53.1%
Other road transport		5.37E+06	6.14E+05	1.66E+05		
Baseline	**NO_x**	4.80E+05	2.92E+04	4.20E+04		3.4%
Scenario 1		4.81E+05	2.92E+04	4.21E+04	-0.3%	3.4%
Scenario 2		4.36E+05	2.92E+04	3.07E+04	26.9%	2.5%
Scenario 3		4.26E+05	2.92E+04	3.28E+04	21.9%	2.7%
Scenario 4		4.17E+05	2.92E+04	2.66E+04	36.7%	2.2%
Other road transport		3.25E+07	3.22E+06	1.19E+06		
Baseline	**PM**	3.76E+04	3.45E+03	1.97E+03		6.4%
Scenario 1		3.41E+04	3.45E+03	1.43E+03	27.7%	4.7%
Scenario 2		3.41E+04	3.45E+03	1.24E+03	36.9%	4.1%
Scenario 3		3.76E+04	3.45E+03	1.97E+03	0.0%	6.4%
Scenario 4		3.41E+04	3.45E+03	1.18E+03	40.4%	3.9%
Other road transport		9.33E+05	1.01E+05	2.88E+04		

3.2.6 Total cost of the emission limit scenarios

In addition to these results of the four scenarios, and in order to provide a frame of reference for the cost and the cost-effectiveness of the additional measures proposed over the baseline, a complementary calculation has been executed, referred to as Euro 3. In this calculation, the costs and the emission benefits incurred by introducing the Euro 3 motorcycle technology in the period 2007-2017 (i.e a 10 year time frame) over Euro 2 have been introduced. This scenario has only been executed to compare the order of magnitude of costs of new emission standard scenarios. Although such a scenario was also executed in the 2004 report, it was only performed for a period of six years, so the results would not comparable to the current study. The total costs (Net Present Value – NPV) for the different scenarios are calculated according to the cost elements presented in sections 3.2.1 to 3.2.4. The total costs for the studied scenarios are illustrated in Table 3-7. In order to avoid misunderstandings, the following clarifications need to be made:

1. The total cost expresses the additional costs that customers have to pay to purchase new motorcycles and mopeds in the period 2007-2020. All costs are incremental costs expressed over the baseline scenario.
2. A "Euro 3 motorcycles scenario" is also shown in Table 3-7. This is just for comparison with the new scenarios and presents the cost-effectiveness of introducing the Euro 3 emission standard for motorcycles (which is already included in the baseline).
3. The absolute magnitude of the costs differs than in the 2004 study, because the time period which is now studied is much longer than in the earlier report.

Table 3-7: Total cost (NPV) for PTW emission standards

Run	Total cost (NPV) for the introduction of different emission standards (M€)		
	Low Estimate	High Estimate	Best Estimate
Baseline	0	0	0
Euro 3 motorcycles (2007-2017) (shown here for reference)	8 020	13 182	10 601
Scenario 1	4 996	6 681	5 838
Scenario 2	9 283	13 874	11 578
Scenario 3	6 023	9 229	7 626
Scenario 4[7]	17 358	28 051	22 705

Table 3-7 shows that the total cost (best estimate) of introducing any of the scenarios is from 5.8 to 22.7 billion Euros. The total cost is estimated from the year of introduction of the different emission standards until 2020. The date is 2010 for scenarios 1 and 3, 2012 and 2015 in scenario 2, and 2013 and 2016 in Scenario 4. For comparison, the 10-year (2007-2017) total cost for the introduction of Euro 3 motorcycles is estimated at 10.6 billion Euros.

[7] Cost calculations are based on very rough estimates, with cost items expressed as multiplicands of the cost of technology required to meet the emission standards in Scenario 2. Details are given in section 3.2.4.

3.2.7 Cost–Effectiveness Analysis

The cost-effectiveness (cost per mass of pollutant saved) for the studied scenarios is presented in Table 3-8 and Table 3-9 and in Figure 3-9 to Figure 3-12.

Table 3-8: Cost–effectiveness of different PTW emission standards (€/kg ≡ M€/kton). HC and NO_x.

Scenario	Cost–effectiveness of different motorcycle emission standards (€/kg ≡ M€/kton)		
	Low Estimate	High Estimate	Best Estimate
HC			
Euro 3 motorcycles (2007-2017)	14.0	22.9	18.4
Scenario 1	36.2	48.4	42.3
Scenario 2	50.4	75.3	62.8
Scenario 3	86.6	132.8	109.7
Scenario 4[8]	50.1	80.9	65.5
NO_x			
Euro 3 motorcycles (2007-2017)	18.1	29.8	24.0
Scenario 1	-	-	-
Scenario 2	8.0	12.0	10.0
Scenario 3	3.8	5.8	4.8
Scenario 4[8]	10.5	17.0	13.7

Table 3-9: Cost–effectiveness of different PTW emission standards (€/kg ≡ M€/kton). PM and CO_2.

Scenario	Cost–effectiveness of different motorcycle emission standards (€/kg ≡ M€/kton)		
	Low Estimate	High Estimate	Best Estimate
PM			
Euro 3 motorcycles (2007-2017)	128.6	211.3	169.9
Scenario 1	93.9	125.6	109.8
Scenario 2	171.6	256.4	214.0
Scenario 3	-	-	-
Scenario 4[8]	323.4	522.6	423.0
CO_2			
Euro 3 motorcycles (2007-2017)	3.3	5.4	4.3
Scenario 1	2.3	3.0	2.7
Scenario 2	11.0	16.4	13.7
Scenario 3	0.8	1.2	1.0*
Scenario 4[8]	25.3	40.9	33.1

* see observation #5 in the list following

[8] Cost calculations are based on very rough estimates, with cost items expressed as multiplicands of the cost of technology required to meet the emission standards in Scenario 2. Details are given in section 3.2.4.

The following remarks need to be made with regard to the cost-effectiveness of the different measures:

1. The HC cost-effectiveness of the four future scenarios considered depends on the scenario. Scenario 1 appears as the most cost-effective of the scenarios examined and Scenario 3 appears as the least cost-effective scenario. The latter is counter-intuitive, as Scenario 3 introduces the best available technology, which should be considered ready for introduction without substantial costs. The reason for the poor cost-effectiveness is that although the same emission control technology to Scenario 2 is used (pre-catalyst and more efficient main catalyst), the emission standards imposed are more relaxed than in Scenario 2. The additional emission benefit in Scenario 2 originates from improved engine tuning and calibration to maximize the performance of the same emission control devices used in Scenario 3. Therefore, the rather limited additional cost required to move from Scenario 3 to Scenario 2 leads to significant emission benefits.

2. Compared to the Euro 3 for motorcycles, all four future scenarios appear less cost-effective for HC. The reason is the higher cost for engine recalibration but also material costs over Euro 3. In addition, the Euro 3 cost-effectiveness (similar to Scenarios 1 and 3) refers to a ten-year duration, while Scenario 2 and Scenario 4 refer to a much shorter period. This reduces cost-effectiveness since the impact of a new technology is not fully deployed.

3. The cost-effectiveness of Scenarios 2 to 4 is very satisfactory for NO_x and appears much better than the cost-effectiveness of introducing Euro 3 for motorcycles. The reason is that these regulation proposals will in fact be the first to address NO_x emissions from motorcycles. The previous regulations were either too loose with respect to NO_x, or the (rich) combustion performance of the motorcycles did not lead to high NO_x emissions in any case. As Euro 3 motorcycles have already been equipped with stoichiometric combustion and TWCs, a more stringent emission standard will lead to true NO_x emission benefits and this improves the cost-effectiveness of the measure.

4. Scenario 1 appears as a rather cost-effective measure with respect to PM and definitely more effective than the Euro 3 for motorcycles. This is an additional reason to promote the control of mopeds at a Euro 3 level.

5. With regard to CO_2, benefits are not directly associated with the introduction of a new emission standard but as complementary effects of the technology introduced to meet the emission standards. In particular for Scenario 3, the very satisfactory cost-effectiveness is not an effect of the technology introduced to reduce pollution but a result of the fact that the 20% lighter and more fuel efficient motorcycles per class have been selected from the sample used to derive emission factors for Euro 3 and later technologies. A more precise cost-calculation in this case would most probably come to the conclusion that CO_2 benefits would have been accompanied by cost benefits as well (lighter and less powerful motorcycles are usually also cheaper). However, our calculation assumes that all motorcycles in a specific class are of the same cost, therefore

introducing lighter models does not bring cost down. The additional cost therefore originates from the introduction of catalysts in Scenario 3 that do nothing for CO_2 but increase the cost of the vehicle.

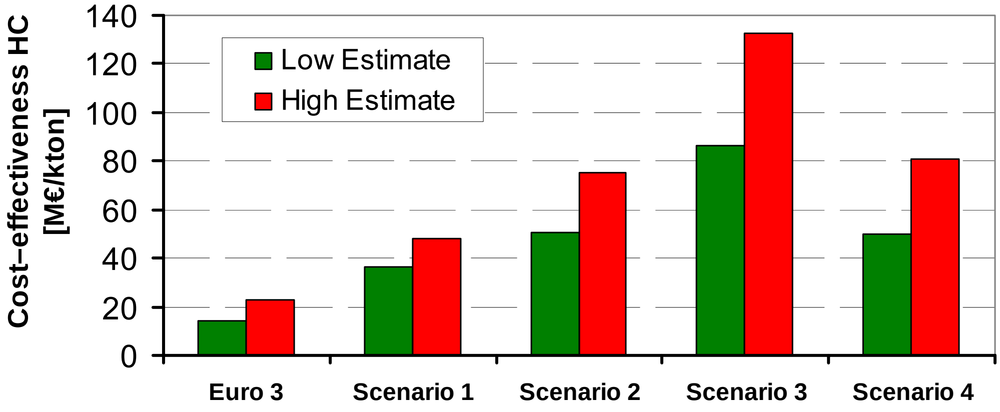


Figure 3-9: HC cost effectiveness for different PTW emission standards

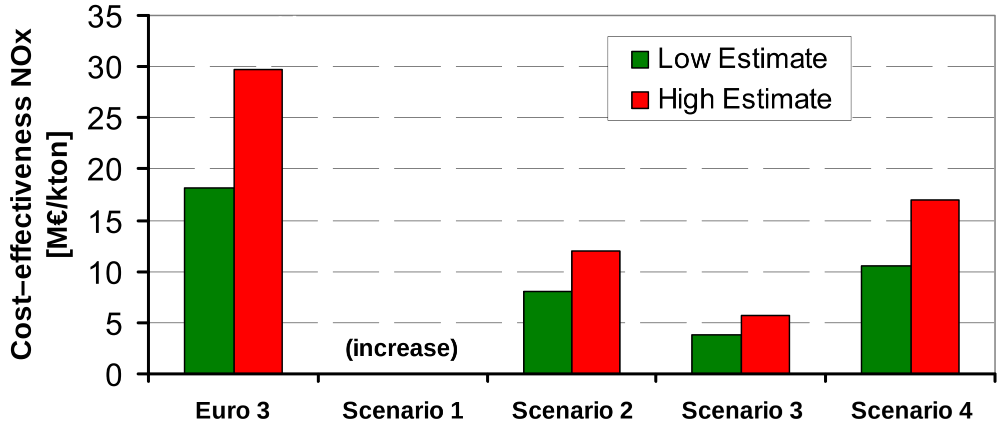


Figure 3-10: NO_x cost effectiveness for different PTW emission standards. ("Increase" for NOx refers to the fact that there is actually an increase to NOx from mopeds by introducing Euro 3).

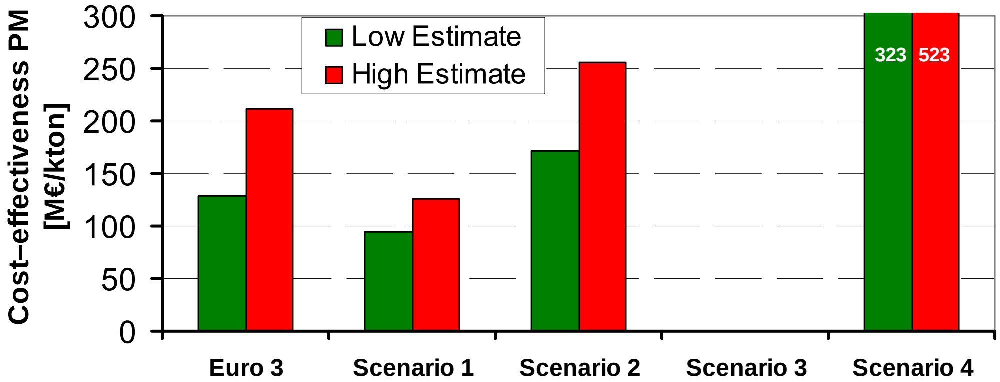


Figure 3-11: PM cost effectiveness for different PTW emission standards

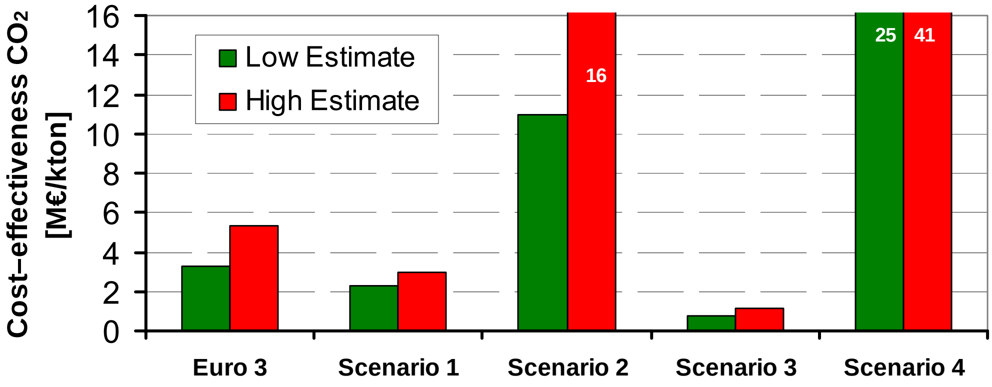


Figure 3-12: CO_2 cost effectiveness for different PTW emission standards

3.2.8 Social Impacts

The link between emission standards and social impacts of vehicles is a complex function of the ownership of these vehicles (cost, status, image), usage (engine and environmental performance, noise, transport needs, recreation), the market structure and volume, the urban development and traffic conditions, the industry producing such vehicles (OEMs, suppliers, specialized SMEs, dealers and retail shops, type-approval authorities) and the industry supporting their use (maintenance and tuning centres, aftermarket component suppliers, specialized press, …). Because of the complex nature of these functions, impacts are easier to describe in a qualitative rather than a quantitative manner.

With regard to the involvement of SMEs, it is known that the PTW market is dominated by a few large OEMs. However, there is a much higher number of companies supplying PTW components. According to ACEM's Newsletter #20 (http://www.acem.eu/NWSL/newsl20/ smes.htm) "*Eurostat recorded 870 powered two-wheeler companies as manufacturers in 2006, and their average yearly turnover of Euro 8 million suggests a significant proportion of SMEs. The downstream sector depending on the PTW industry is represented by a network of over 37,000 dealers and independent repair shops*." The motorcycle industry therefore involves several SMEs in one way or the other. The strength of such companies is linked directly to the market volume of two-wheelers.

The introduction of more stringent emission standards is of course beneficial from a societal perspective, as this will reduce pollution and will improve the environmental conditions, in particular in urban areas. This is even more so for particular groups of people exposed to high concentrations of pollutants, such as road workers, cyclists, etc. since two wheelers, and in particular older models and 2-stroke engines, are known to be visible smoke emitters, caused by the combustion of lubricant oil. In addition, technology improvement, for example the shift to 4-stroke mopeds and the improved control of engine fuelling , reduces fuel consumption, a fact that is also reflected to lower operation costs for the owners. Finally, as environmental awareness of citizens increases, the group of people that seek vehicles with high environmental performance also increases. It is expected that this trend will continue into the future. Therefore, substantially improving emissions from motorcycles will be necessary in order to improve their image in terms of environmental performance and to sustain acceptance by the society.

However, emission standards need to be balanced with the technological developments. Very strict emission standards will increase the development costs for new models that will be transferred to the potential owner, via price increases. The motorcycle market appears much more volatile than passenger cars. As an indication, the motorcycle market dropped by 35% in the current financial turmoil, compared to 17% for passenger cars. This appears to be the result of at least two reasons. First, a much larger share of motorcycles than passenger cars is used for recreational instead of transport needs. Therefore, this share is much more sensitive to price changes than the rather inelastic passenger car market which basically serves fundamental transportation needs. In addition, this share is particularly vulnerable to potential performance reductions.

In general, and recalling conclusions from the 2004 report, any policy option that will be introduced to formulate new legislation, contributes uniquely to a "common purpose", which is the reduction of pollutant emissions from PTWs, including three- and four-wheelers. All policies related to pollutant emission control are associated with "*General Social Impacts*", which can be described as follows: Any regulation/implementation of emission standards stricter than today's may lead to an upward pressure of either direct costs (i.e. purchase price) or associated costs (i.e. maintenance, periodically scheduled checks, etc.). This cost increase may cause a decline in new PTWs sales and especially in these categories that are popular to youngsters or low income consumers in general. Therefore, a stringent emissions policy may result in environmental benefits from new motorcycles, but on the other hand it may shift the market towards cheaper second-hand vehicles and/or increase in the lifetime of all vehicles, with the inevitably associated negative effects. Furthermore, a too stringent emission policy may lead small vehicle fleets to their extinction, introducing an economic burden to small companies and SMEs. It is not easy to find a balance between those conflicting trends, since there are many counter arguments to the above qualitatively described trends, such as (a) tighter emission controls may lead to production of many components that will not require any maintenance nor replacement during normal vehicle life (b) the reactions of the consumers will depend also on the balance between how much money they spend on increasing power and shiny wheels vs. increases to make these vehicles less pollutant for their children and safer for themselves and the people around them (c) there is a big part of the consumers that only buy new vehicles and therefore not affected by the second hand market etc.

For the better organisation of the concepts analyzed and the arguments discussed in this section, a summary is presented as SWOT analysis in Figure 3-13.

3.3 Effectiveness of additional measures

In addition to the Baseline scenario, we have estimated the effectiveness of additional measures that the European Commission considers for inclusion in the PTW regulation of the future. The following paragraphs present the objective of each additional measure, the technical details associated with this and the expected environmental benefits and costs. The cost is then split per pollutant and the cost-effectiveness is derived for each pollutant considered. As most of these measures have been already extensively discussed in the 2004 report, the detail of the analysis is sometimes limited in this report. In this July 2009 version of the report, we have mostly focussed on points where either new information has become available or some additional points need to be made compared to the 2004 report. It is therefore highly recommended that the reader first consults the 2004 report and then this updated information. For the same reason we have retained some of the introductory and the concluding sections of the 2004 report, in cases this is necessary to explain our argumentation.

Strengths

- reduction of harmful atmospheric substances (HC, NOx, CO, PM) that directly affect a large fraction of the population
- reduction of harmful species that contribute to the formation of photochemical pollution (HC, NOx)
- minor reduction of greenhouse-gas (mainly CO2) emissions
- reduction of visiblel smoke
- products (motorcycles, mopeds, three and four wheelers) of superior quality
- possible generation of new jobs in suppliers of emission control systems

Weaknesses

- costly measures with the cost transferred to the customers
- generally, cost increases with increasing stringency of emission standards
- the emission standards should have appeared earlier to maximize benefit

Opportunities

- good environmental performance is a marketing asset for all products sold today. Improving emissions will also have a positive impact on PTWs' image
- low CO2 vehicles are promoted and are increasingly desirable. Clean and efficient motorcycles are a very good candidate
- emission standards from other vehicle categories become more stringent; this provides the ground to reduce emissions from PTWs as well

Threats

- small motorcycles and mini-cars are mostly sold due to their low price, while large motorcycles and ATVs are mainly used as recreational and not prime transport vehicles; hence PTWs market is inherently more sensitive to price increases; large price increases may lead to loss of jobs including SMEs (
- increasing cost may shift buyers to other vehicle classes (i.e. small cars); shift of the market to cars will increase congestion and greenhouse gas emissions. Shift to (small) diesel cars may also increase pollutant emissions
- increasing cost may also lead to less frequent PTWs replacement, hence degrading the rate of reducing emissions
- stringent emission standards may lead to loss of performance which is a marketing asset for motorcycles; hence increasing tampering practices

Figure 3-13: SWOT analysis of the introduction of new emission limit values for PTWs

3.3.1 Durability of emission control systems

3.3.1.1 Objective, Background and Scenarios Definition

The European Commission is considering the introduction of a durability requirement for the emissions of PTWs in order to better control emission levels over the lifetime of the vehicle. There is however a need to determine the appropriate total distance (useful life) for which a durability requirement should be issued.

The durability requirement is one of the issues extensively discussed during the ad-hoc MVEG meetings. The Commission initially looked into ACEM's proposal in Moto 105 [14]. ACEM's proposal was along the lines of the respective regulations in US (for motorcycles) and in Europe (for passenger cars). The proposal addresses the need to distinguish different "useful life" (or "normal life") periods according to the vehicle size, proposes deterioration factors for application in these periods in lieu of conducting the actual test, describes the mileage accumulation driving cycles and the details for emission testing and allows for extension of the durability type approval to vehicles which share similar technical specifications.

In order to select an appropriate operating distance for implementation of a durability requirement, the different sizes, engine principles and applications of the vehicles falling under the scope of Directive 97/24/EC should be considered, because they imply a variability in the frequency of use, daily trip distances and hence annual mileage. Also, the operation of each motorcycle is a function of its type and size; it is expected that the smaller the motorcycle the more frequent its operation under full-throttle condition, hence the more stress is put to the emission control devices. In order to take into account the different technical issues, the following scenarios were considered:

- Scenario "Baseline": This scenario assumes that there will be no further legislative step beyond 2006/72/EC i.e. no durability requirements for PTWs will be imposed. In this way, an arbitrary deterioration over the useful life is set to 20%.
- Scenario 1: Deterioration reduced to 10% for the useful life and application of linear extrapolation for higher mileage (Moto 105 proposal).
- Scenario 2: Useful life increased by 60%, i.e. equivalent to the increase incurred to passenger cars when shifting from Euro 3 (100 Mm) to Euro 5 (160Mm).

Table 3-10 summarizes the characteristics of the alternative scenarios that were studied for the durability of emission control systems:

Table 3-10: Durability scenario summary

Element	Category	Baseline	Initial Commission proposal	Euro 5
Deterioration per useful life	Conventional	20%		
	Euro 1	20%		
	Euro 2	20%		
	Euro 3	20%	10%	10%
Useful life [km]	Mopeds	10000		16000
	Mot 2 str	12000		19200
	Mot 4 str <150 cc	12000		19200
	Mot 4 str 150 - 750 cc	30000		48000
	Mot 4 str > 750 cc	30000		48000

Deterioration in the emission levels has been considered for CO and HC emissions from all pre-Euro 3 motorcycles. NO_x emissions are not considered to degrade by pre-Euro 3 models because there are no technical reasons that would justify this (mixtures for older motorcycles are mainly rich and reduction catalysts are not widespread). The deterioration for Euro 3 motorcycles was considered for NO_x emissions as well, due to the extensive use of TWC.

3.3.1.2 Environmental Benefit

The difference in the total regulated emissions over the baseline scenario for the two alternative scenarios considered is summarized in Figure 3-14 as evolution of emissions and in Figure 3-15 as emission benefit over the studied timeframe.

3.3.1.3 Cost Calculation

It was not possible to estimate the cost to develop emission control devices that would be necessary to achieve a longer useful life. In addition, given the very small benefit that a 60% increase in useful life would bring (Figure 3-15), we considered that it would not be necessary to further investigate this.

3.3.1.4 Discussion

The effectiveness of durability measures was compared against a baseline, in which a 20% degradation over the useful life was arbitrarily selected. Obviously, the effectiveness of durability would be much different if the baseline degradation was higher or lower. There has been no solid information on what is the actual degradation of motorcycles. However, two specific studies have been made available to the study team. The first concerns a Honda motorcycle which was tested to examine its durability distance by its manufacturer. The results of this test are shown in Figure 3-16. This shows that over 30000 km, the degradation of HC and CO emission is of the same order of magnitude (20-25%) to what was assumed in the baseline. The degradation of NO_x was marginal. This shows that what was considered in the baseline may fairly well represent reality with the exception of NO_x, where the degradation may be in fact lower. In any case, this rather reconfirms what is evident from the earlier study, that PTWs put a large strain on aftertreatment in what concerns CO and HC, while NO_x regulation is rather easier to attain.

There is also a second example available to the study team. This concerns the 2008 AECC programme which, in addition to measuring the emission level of several Euro 3 motorcycles, they also examined the degradation performance of a motorcycle by a Far-east manufacturer. The results of this exercise are shown in Figure 3-17 and are distinctly different than results from the previous study. CO emissions exceed the emission standard already after 2000 km of driving. NO_x exceed the emission standard after 5000 km of driving and continue to increase over the whole distance (20000 km). In fact, NO_x emissions at 20000 km are more than three times higher than at the beginning of the testing.

These measurements lead to the following conclusions:

1. The actual degradation of current stock motorcycles is largely unknown as the two experimental campaigns available led to distinctly different behaviour. There is therefore the need to improve our understanding of emission control durability of motorcycles.

2. The 20% degradation over the useful lie considered in the baseline, rather appears at the low range of expected values.

3. It is absolutely critical that a durability regulation is introduced for PTWs, otherwise significant departures from the emission standard may occur at rather short distances.

4. Once a durability regulation has been decided, the actual useful life is not a critical parameter. Increase of the durability by 60% led to additional reductions in emission levels in the order of 4 ktn of HC, 30 ktn of CO and 1.1 ktn of NO_x. This corresponds to 1.6%, 3.0%, and 2.6% per pollutant respectively, of total PTW emissions in 2020.

5. When the durability regulation is put in place, the second step would be to evaluate how this represents reality. In particular, statistics of motorcycle use as a function of age will have to be compared against the useful life included in the regulations. It should also be assessed how much the durability driving cycle is representative of real-world driving.

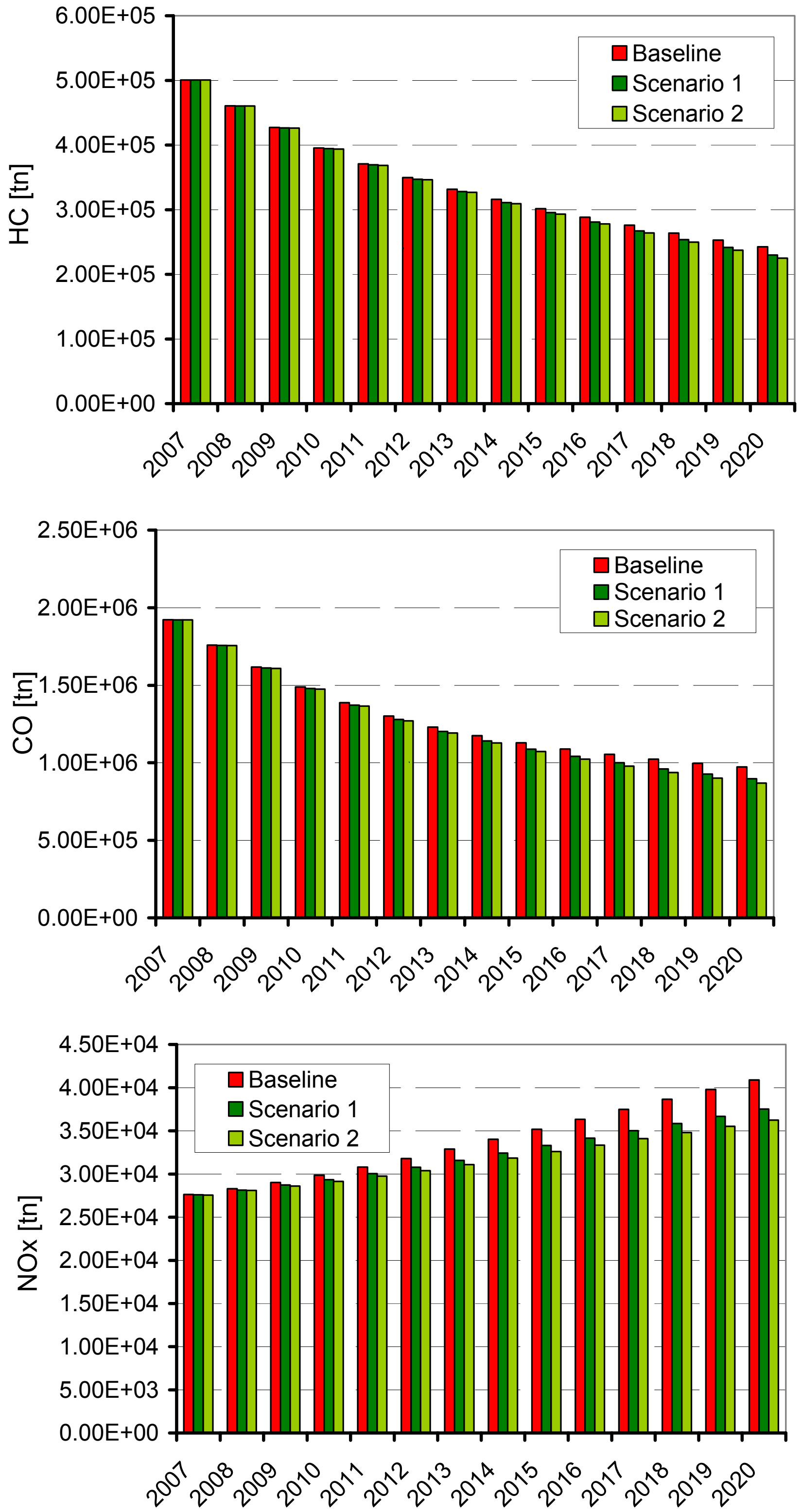


Figure 3-14: Estimated evolution of regulated pollutants from total PTWs in EU15 due to the introduction of different durability requirements

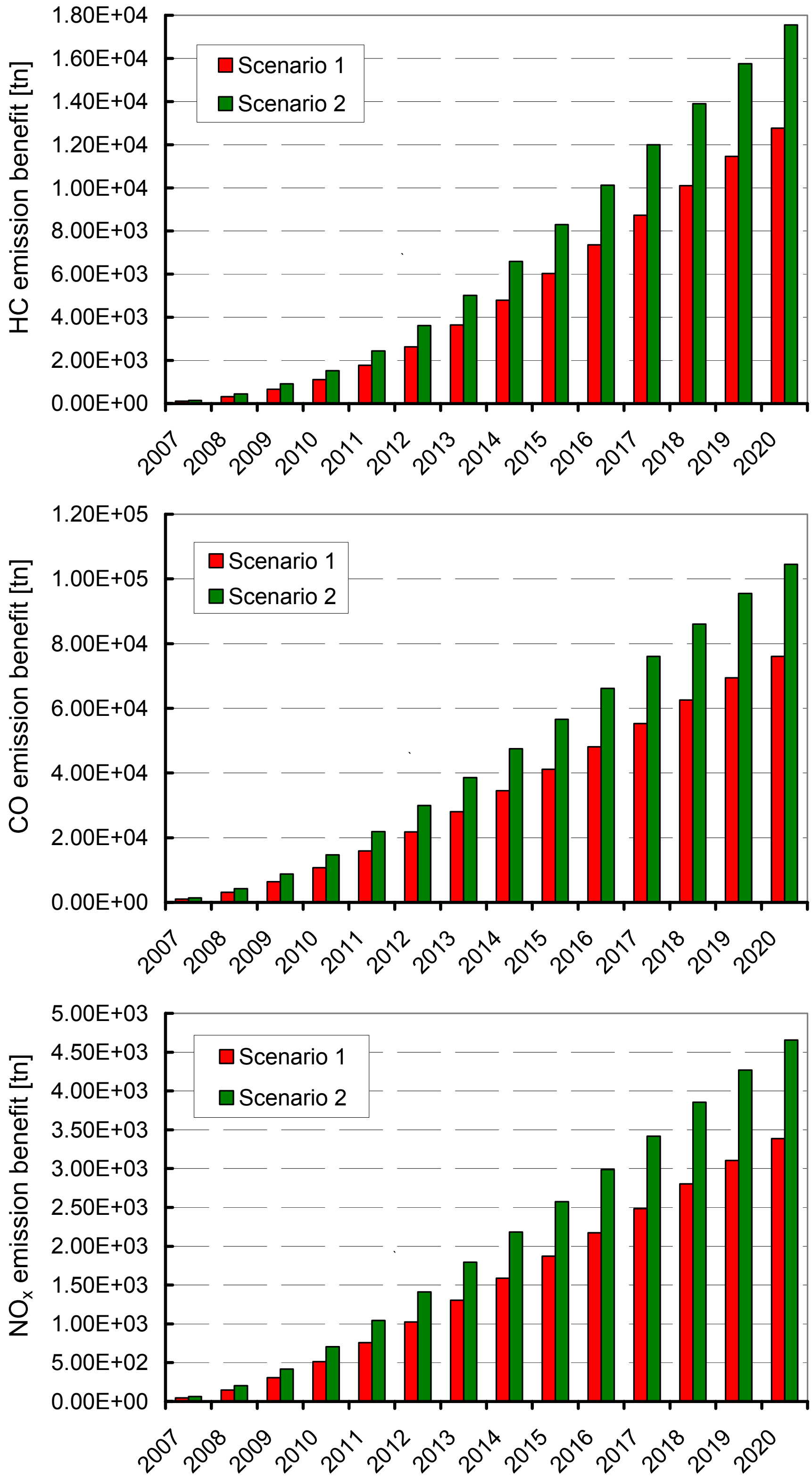


Figure 3-15: Estimated emission benefit of regulated pollutants from total PTWs in EU15 due to the introduction of different durability requirements

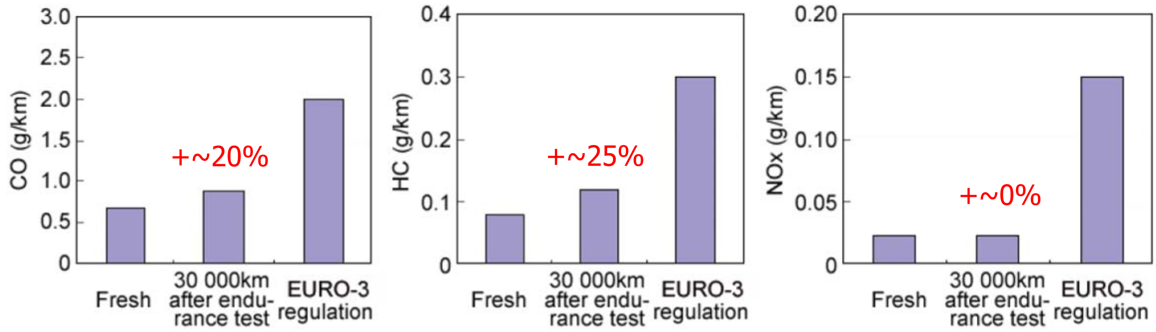


Figure 3-16: Results on durability from a 1100 cc Honda Motorcycle (Honda R&D Co, SAE Paper 2004-32-0032)

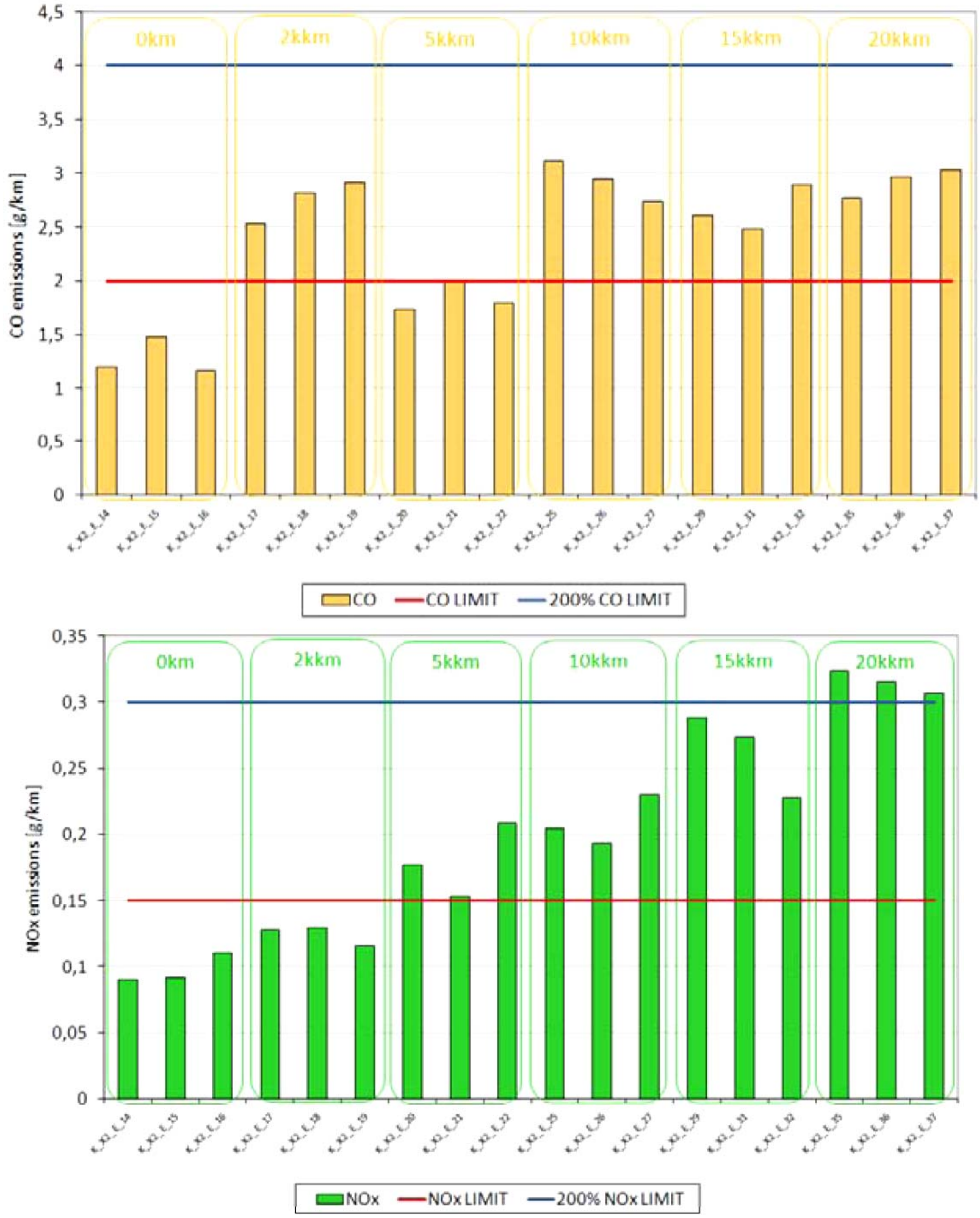


Figure 3-17: Results of the 2008 AECC Motorcycle Test Program of AECC on one 500cc scooter run for about 20000 km

3.3.1.5 Social and SME impacts

There are no particular issues related to the introduction of emission control durability regulations, further to the control of emissions, which is a benefit to the society. All emission control systems are produced by large manufacturers (OEMs or suppliers).

3.3.2 In-Use Compliance procedure for PTWs

3.3.2.1 Objective, Background and Scenario Definition

In-Use compliance (IUC) regulations are established to make sure that the emission levels of a vehicle type in the real-world complies with its type-approval limits. IUC is a manufacturer's responsibility. IUC requires that a small sample of fleet vehicles is randomly selected and is tested according to the certification test conditions to check whether the vehicles comply with their corresponding emission standards. Depending on the results of this procedure, the manufacturer may be forced to remedy the situation, if the vehicles selected do not comply with the emission standards. This should be considered as a direct environmental benefit of an IUC requirement. As an indirect benefit, the manufacturer takes all necessary steps to ensure that the long-term emission behaviour does not differentiate (at least much) from the type approval limits. It is obvious that it is not possible to simulate the indirect effect of IUC.

In-use compliance (IUC) procedures with a European-wide scope have been established for passenger cars with the implementation of Directive 2002/80/EC since October 2002. The evaluation of the actual environmental benefits introduced with this procedure and the practicalities raised in its application are still largely unknown. According to Directive 2002/80/EC, the whole IUC procedure might be reassessed depending on the reports to be supplied (initially targeted by December 31, 2003) by the different member states on the application of the IUC.

As has been very well addressed by Swedish EPA in earlier MVEG meetings, the main structural components of any IUC procedure (even for two wheelers, would be):

- Manufacturers responsibility for durable and functioning emission controls in use, for a certain driving distance (durability period).
- Test procedure: type-approval emission laboratory test or, for surveillance, some other in-use emission test data supplied by manufacturers or an authority.
- Procedure for selection, procurement, and maintenance of vehicles to the test sample (audit procedure).
- Procedure to examine test data and information, emission failure and technical faults.
- Recall/remedial actions, how to perform and report, labels, etc.

The necessity and scope of each of these components needs to be examined in connection to additional legislative measures considered in the regulations, such as conformity of production (COP), the emission control durability requirements and the potential for an emission roadworthiness (RW) procedure introduction. There is a certain level of overlapping between these regulations. For example, IUC also checks the durability of emission control systems (after real-world operation) which is also the objective of any durability-specific measure (which is applied with controlled ageing though). Also, IUC examines the compliance of vehicles produced and sold with the type approval limits. COP examines whether vehicles to be delivered to the market comply with type approval (TA) limits. Finally, with regard to well-maintained vehicles, a RW procedure is a simplified equivalent to IUC, in a sense that the vehicle examined needs to pass a simple emission test with an emission limit value which (ideally) would be a calibrated equivalent of the TA limit.

These considerations need to be evaluated simulating the direct environmental benefit of introducing an IUC for motorcycles. According to the study team's knowledge, there has been limited benefit from the establishment of IUC for passenger cars – at least in a direct manner – in the sense that recall campaigns for emission compliance reasons have been few (if any) in Europe so far. To our knowledge there is a limited number of public reports on the effectiveness of IUC measures for passenger cars. One very informative report comes from the German Umweltbundesamt [13], which summarizes some experience with IUC testing in Germany in the period from 1998 to 2000. The report summarizes experience with IUC testing of nine vehicle types, eight of German specifications and one of Dutch specifications. The latter one was a vehicle type equipped with the - at that time – new concept of direct injection gasoline engine. In fact this was found the only vehicle type not complying the type-approval limits. However, the author justifies this by stating that this was a car not type-approved for German conditions (high-speed driving). Therefore, in that study, none of the regular specifications cars was found non compliant.

Based on current experience, and in order to simulate a maximum potential environmental benefit and its cost-effectiveness, a scenario can be examined where a percentage of new registrations per year (i.e. 1-2%) is found to emit (e.g. 50%) above the limits and a recall procedure is initiated. Such a scenario can be simulated with the tools described in the following sections.

Furthermore, several issues need to be specifically addressed for the application of an equivalent in-use compliance procedure for motorcycles, due to the different engine concepts available at the market. In particular:

- The type of test(s) which will be adopted depending on vehicle size and engine concept (4-stroke, 2-stroke, CI).
- Particular parameters defining the in-service family (e.g. exhaust aftertreatment for two-stroke engines)
- Parameters affecting the testing conditions (e.g. lubrication oil aging)
- Definition of an outlying emitter to account for the durability of the different emission control systems.

Finally, a significant aspect for in-use compliance is the actual condition of the vehicles operating on the road. In particular, it is unfortunate that the users of particular vehicle classes (e.g. small two-stroke motorcycles) have a higher tendency to tampering and are little aware of regular maintenance requirements. Hence, both strict legislation but also in-use compliance checking procedures may be significantly undermined by such behaviour, because no representative sample can be found, either because the owner is unwilling to provide the vehicle for testing or because vehicles do not comply with manufacturer's standards of selection. Such an expected artefact is expected to increase the costs of the audit on one hand and, on the other, to limit the focus and the benefit of establishing IUC checking.

Obviously, such limitations are not that important when larger and more expensive motorcycles are considered, or when the production volume exceeds a certain limit. Hence, if introduction of an IUC test is deemed necessary, then its application only to relatively large production volumes is associated with two indirect IUC benefits: the first emerges from the fact that the manufacturer is mainly forced to take all necessary precautions to achieve IUC for several model series without this being explicitly requested by the regulation (because the manufacturer will not know beforehand which models will exceed the limit production volume). Secondly, actual IUC checking would consider models with a relatively large market share and whose possible no-compliance would bring more significant effects to the environment. All this will be made possible with less demanding auditing (due to their larger production volumes). On a qualitatively basis therefore, limiting the scope of IUC to specific model series seems as a more cost-effective option than introducing IUC for all types, including small production and special use two wheelers.

The details of an IUC procedure can be determined in proportionality to passenger car regulations, taking into account the population size considered, and selecting appropriate sample sizes and pass/fail procedures.

In order to demonstrate the potential direct benefits from the introduction of an IUC requirement, we have deliberately degraded the performance of some new registrations in the baseline scenario. In particular, we have assumed that 3 % of the new registered Euro 3 vehicles will exhibit 20 % higher regulated emissions from the average. The same assumption was also done for Euro 2 vehicles. Introduction of an IUC would mean that the relatively high Euro 3 emitters would be identified and their emissions would be reduced to the original levels, on the manufacturers' responsibility. These estimates should be considered to represent the order of magnitude of deviation that may be expected at a maximum. This estimate can be used then to evaluate the effect of an efficient IUC procedure.

In order to evaluate what would be the environmental benefit from the introduction of an IUC procedure, one scenario was examined over the Baseline:

- "Baseline" (identical to the European Commission proposal): No IUC requirement for any of the PTWs. A deliberate not-attainment is introduced in this case.

- Scenario 1: IUC procedure mandatory to for all Euro 3 motorcycles. The IUC is considered to identify all not attainments which are consecutively corrected.

In order to investigate what would be the maximum environmental benefit of an ideally efficient IUC procedure, we assume that the IUC procedure would reveal all high emitting new registered Euro 3 motorcycles. Moreover, the remedial measures taken would bring the emission levels back to the baseline levels.

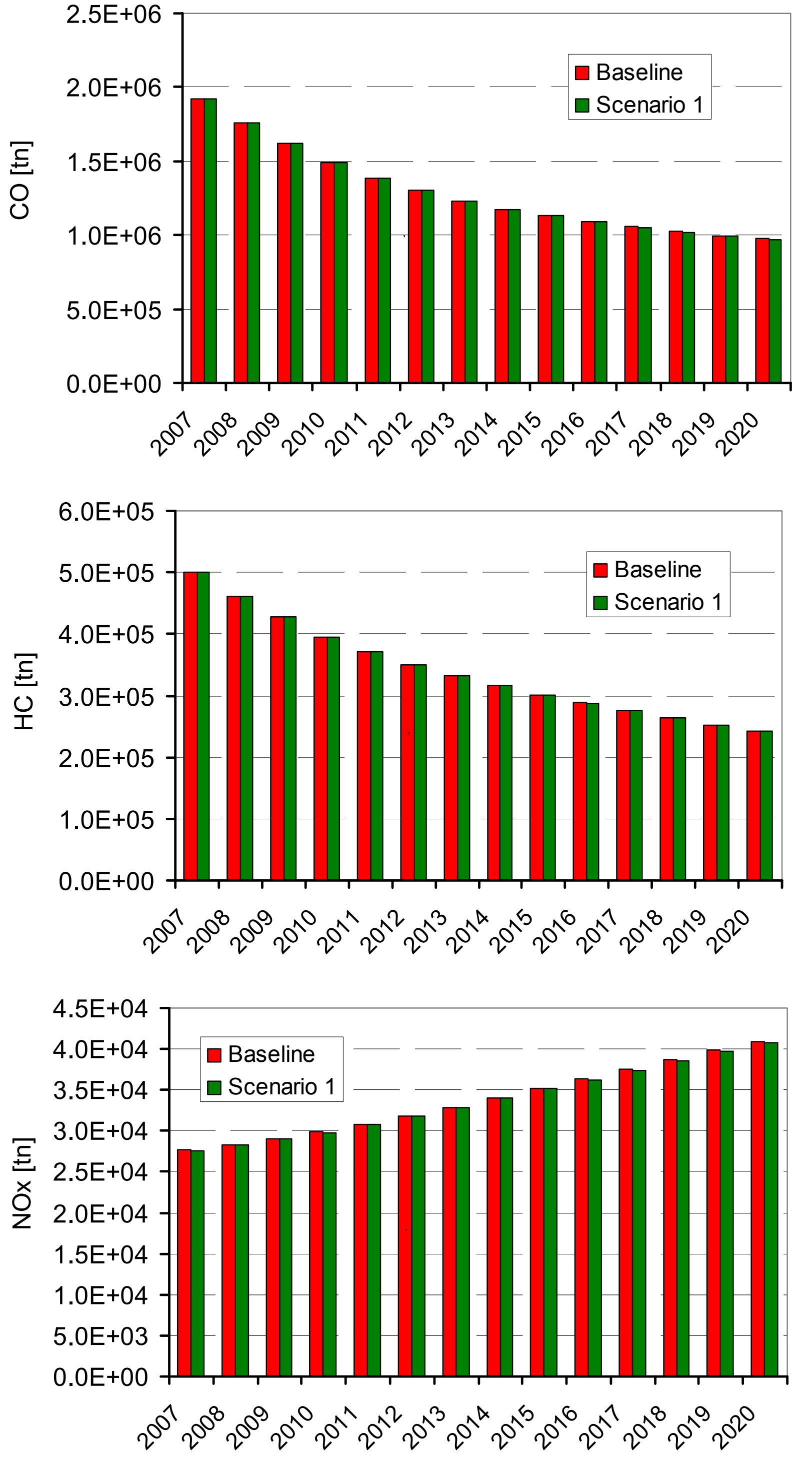


Figure 3-18: Estimated evolution of regulated pollutants from total PTWs in EU15 due to the introduction of In Use Compliance requirements.

3.3.2.2 Environmental Benefit

The difference in the total regulated emissions over the baseline scenario is summarized in Figure 3-18 as evolution of emissions and in Figure 3-19 as emission benefit over the studied timeframe.

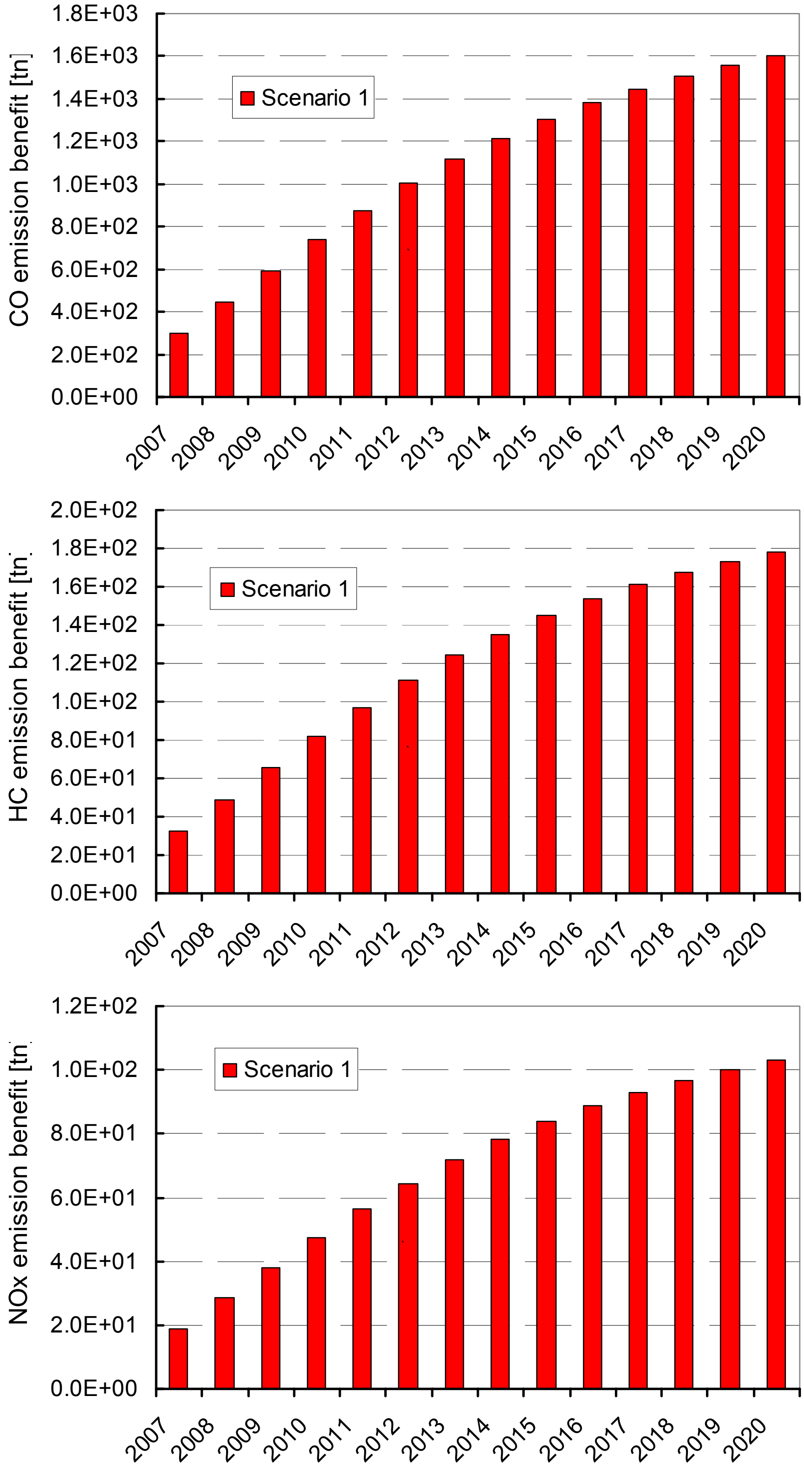


Figure 3-19: Estimated emission benefit of regulated pollutants from total PTWs in EU15 due to the introduction of In Use Compliance requirements

3.3.2.3 Cost Calculation

The procedure assumed for IUC testing of motorcycles is a dynamic test on a dynamic chassis dynamometer. We assume that the assumed IUC regulation defines three repetitions of the testing for three vehicles per engine family (9 tests in total). We assume that each of the repetitions costs €650 (Rijkeboer, 2004).

Further to testing, the IUC setup cost includes the cost of supplying the motorist with another vehicle, the transfer cost of the motorcycle to the testing facilities, bureau and reporting costs and the certification cost. The cost of transfer & reporting is assumed to be equal to the cost of 16 man-hours and the cost of approval & inspection equal to 4 man-hours, whereas the mean European cost per man-hour is estimated to be €150 – €300. The mean cost of replacing the motorist's vehicle is around €50 per day; the testing procedure lasts three days, hence this cost is estimated to be €150. The sum of the afore–mentioned costs is multiplied by the number of the corresponding Type Approvals for all Motorcycle Manufacturers in Europe per year for each Motorcycle type. More specifically, we have approximately 10 and 84 type approvals for all European manufacturers per year for 2-stroke and 4-stroke Motorcycles, respectively.

The implementation cost of an IUC test results to a mean additional cost per new vehicle for every manufacturer, which is illustrated in Table 3-11.

Table 3-11: Mean additional cost per motorcycle (€/vehicle).

2-Stroke		4–Stroke	
Low Estimate	High Estimate	Low Estimate	High Estimate
0.95	1.09	0.80	0.92

3.3.2.4 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each policy is illustrated in Table 3-12 and Table 3-13 and in Figure 3-20 to Figure 3-21.

Table 3-12: Total costs (NPV) of IUC scenarios

	Total cost (NPV) of the application of IUC (M€)		
	Low Estimate	High Estimate	Best Estimate
Scenario 1	6.33	8.34	7.33

Table 3-13: IUC cost-effectiveness per motorcycle type (€/kg ≡ M€/kton).

	Cost–effectiveness of the application of IUC (€/kg ≡ M€/kton)		
	Low Estimate	High Estimate	Best Estimate
HC			
Scenario 1	3.6	4.8	4.2
NO_x			
Scenario 1	0.3	0.4	0.3

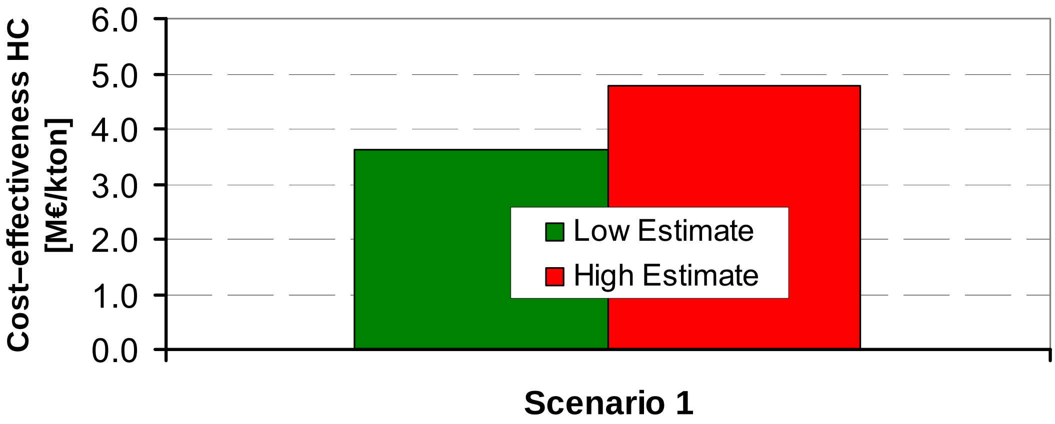


Figure 3-20: HC cost effectiveness for IUC of motorcycles.

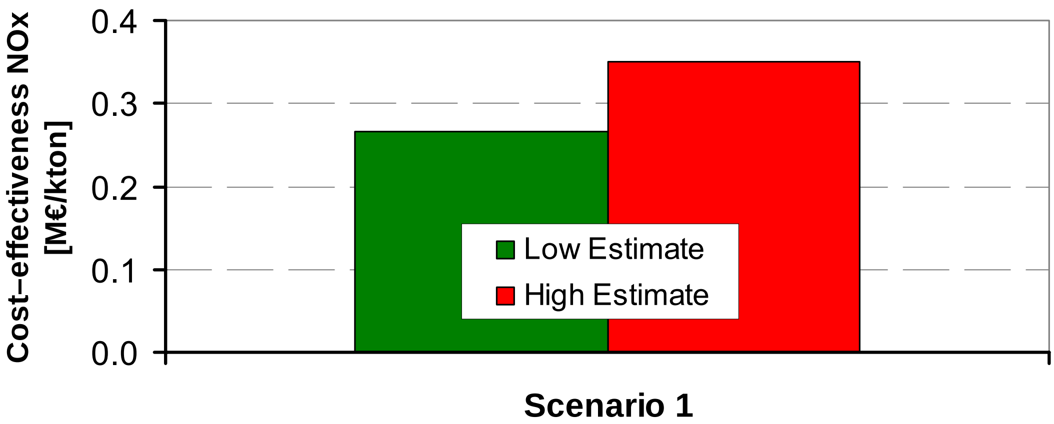


Figure 3-21: NO_x cost effectiveness for IUC of motorcycles.

3.3.2.5 Social and SME impacts

IUC is a measure involving the collaboration of the authorities, the industry and private motorcycle owners. Its success depends also to the willingness of owners to offer their motorcycles for testing to third bodies (the sentimental link between motorists and motorbikes needs to be considered in that respect). In addition, the probability to find motorcycles that comply with the prerequisites set by the manufacturer for IUC acceptance (maintenance level, modifications, etc.) may be considered. These may not be significant problems in the passenger car sector where both less tampering takes place and larger vehicle fleets are sold. On the other hand, it is extremely plausible that the manufacturers will bear in mind that their products will be inspected in their total lifecycle, if an IUC is introduced. This will obviously have an indirect effect of developing products of higher quality in their emissions performance.

An important social dimension of IUC testing comes from the report of Kolke [13]. The author states IUC authority competition as a limiting factor in the effectiveness of an IUC procedure. In principle, the author states that German experience has shown that inspection stations are reluctant to declare non-compliance of a vehicle because this may harm their relationships with the customer. While the extent of this practice is impossible to quantify, this may indeed be a serious real-world limitation of the IUC testing effectiveness.

This measure can be beneficial for SMEs, at least for these private certification authorities that can be classified in this category.

3.3.2.6 Conclusions

There are no different conclusions reached for the effectiveness of IUC over the previous report. Therefore, IUC is considered as one of the no-regret measures, in the sense that an IUC procedure works as a reminder that any vehicle can be potentially subjected to an emission test, even after leaving the manufacturer's facility. In that sense, the manufacturer rather adopts the precautionary principle that all products leaving the production line should be compatible to their type approval. This allows limited – if any – space for a direct IUC effect, i.e. the actual discovery of a vehicle family which does not comply with its type approval and the initiation of a remedial process, including the recall, the repair of the defected component, etc.

The cost-effectiveness is actually found better than in the earlier study, as the extended time horizon means that a vehicle that would not attain the emission standard is now considered to circulate for a larger time frame. Still, the emission reductions achievable are marginal (180 tn of HC to a total of ~80000 tn). The actual cost of implementing the measure is also not too high. However the difficulty to locate appropriate vehicles and willing users to provide them for a test may be a significant limiting parameter. This is even more so in countries with low quality fuel (e.g. Asia).

These issues led the MVEG to the decision not to introduce IUC as part of the Moto 105 proposal. We have not identified any reasons to reconsider this decision with the present analysis.

3.3.3 Type approval for CO_2 and fuel consumption

This issue has been also thoroughly discussed in the 2004 report (see section 1.1) and a large discussion is not repeated here. Only new experience with CO2 labelling, earned in the period 2004 to 2008 is discussed here.

3.3.3.1 Objective, Background and Policies Definition

The labelling and monitoring of CO_2 emissions and fuel consumption (FC) is an action adopted for vehicles falling in category M1 (passenger cars) in order to promote more energy efficient vehicles, in an attempt to contribute to global warming reduction. Similar approaches are envisaged to be adopted for other vehicle categories too (e.g. N1 – light commercial vehicles). The actual mechanism by which CO_2 labelling leads to a reduction of total fleet emissions is not straightforward but it is achieved by subsequent measures, including voluntary agreements (i.e. the ACEA agreement), taxation and monetary incentives (i.e. the CO_2-related taxation in UK) and others. A similar approach may be also followed in the case of two and three wheeled vehicles. The draft proposal for CO_2 and fuel consumption measurement in document Moto 105 [14] represents the conclusions from the earlier LAT/AUTh study and, therefore, there is not much new technical information to be added in this report.

However, the formation of the regulation should allow for a uniform characterisation of PTWs with respect to their energy consumption. The risk is that countries will come up with their own labelling system based on the internal structure market. This means that in a country with focus to scooters and mopeds, an energy classification may appear within the scooter category, which will be different than the classification in other countries. Figure 3-22 shows an example of energy classification for the same vehicle type in different countries. It appears that a various degree of efficiency is considered for the same vehicle model, depending on the internal (national) market structure. For example, a 2.0 VW Golf TFI is assumed to belong to class A in Switzerland and class D in Belgium (four classes difference!). This is poor guidance to the potential customer.

	CO2 (g/km)	Energy efficiency classes					
		Absolute comparison			Relative comparison		
Model		B	DK	UK	NL	SP	CH
VW Golf 1.9 TDI	135	C	B	C	C	B	A
VW Golf 1.9 TDI	135	C	B	C	B	B	A
VW Golf 1.9 TDI (MT6)	140	C	B	C	C	C	A
VW Golf 2.0 SDI	143	C	B	C	C	C	A
VW Golf 2.0 TDI	146	D	B	C	C	C	A
VW Golf 1.9 TDI (direct MT)	151	D	B	D	D	C	A
VW Golf 1.9 TDI 4Motion	157	D	C	D	D	D	A
VW Golf 2.0 TDI (direct MT)	159	D	C	D	D	D	A
VW Golf 2.0 TDI 4Motion	159	D	C	D	D	D	A
VW Golf 1.4 FSI	149	C	B	C	B	A	A
VW Golf 1.6 FSI	154	C	B	D	B	A	B
VW Golf 1.4 16V	163	D	C	D	C	B	C
VW Golf 1.6	173	D	D	E	C	B	C
VW Golf 1.6 FSI	173	D	D	E	C	B	C
VW Golf 2.0 FSI	173	D	D	E	C	B	C
VW Golf 1.6	194	E	E	F	E	C	D
VW Golf 2.0 FSI	194	E	E	F	D	C	D
VW Golf 2.0 FSI 4Motion	202	E	E	F	E	C	E
VW Golf (IV) R32 (direct MT)	245	F	G	F	G	G	G
VW Golf (IV) R32	276	G	G	F	G	G	G

Figure 3-22: Example of energy efficient classification of the same passenger car in different countries (Source: ADAC Study on the effectiveness of Directive 1999/94/EC)

One way of limiting such unequal characterisation is to label the energy efficiency within certain categories. One could propose a classification based on capacity and/or market segment (e.g. scooter, enduro, super-sport, etc.). It is of interest to investigate, if this measure will be more relevant for small, low cost motorcycles than for the sport bigger models, where, as in the case of high-performance passenger cars, fuel economy may have a lower priority as a selection criterion.

3.3.3.2 Social and SME Impacts

Fuel consumption may influence the purchasing decisions of potential Motorcycle customers, given that lower fuel consumption is always preferable in terms of consumer cost. Hence, there is a possibility that a labelling procedure would be helpful for a potential consumer in order to make up his mind. On the other hand, direct comparison of fuel consumption with a passenger car may provide some good arguments in shifting some potential car buyers to the two-wheelers market. As has been discussed before, the true social impacts of a labelling procedure will occur if one considers to link CO_2 to taxation or implement different fiscal measures for low CO_2 emitting vehicles. However, this is a complementary policy, which is not the target of the regulation under preparation. Assuming that type-approval authorities include SME operations, this measure is beneficial to SMEs as motorcycles will have to be approved for their fuel consumption, in addition to the regulated pollutant emissions.

3.3.4 OBD introduction

3.3.4.1 Objective, Background and Scenarios Definition

In order to reduce the effect of malfunctions to fleet emissions, the Commission considers the introduction of On-Board Diagnostic (OBD) units on motorcycles. Emission related OBD systems for passenger cars have been in-use for almost 10 years in Europe and 15 years in US. In principle, the OBD technology that could be applied to monitor the emission control systems of stoichiometric 4-stroke PTWs is expected to be similar to the one already used by gasoline passenger cars. The first generation of OBD units (OBD1) function by monitoring the circuit continuity and system integrity. The main systems monitored are the fuel and air metering devices, the charging system, the coolant temperature sensor, the lambda sensor etc. Whenever the system diagnoses a failure, it informs the driver by lighting a Malfunction Indicator Lamp (MIL). The driver should then visit a service area where the maintenance personnel communicates with the vehicle via a hardware link, identifies and fixes the error, thus resetting the system. However, although the relative technology is already available for passenger cars at least, there are still issues regarding the functionality of these systems in terms of reliable driver alert and avoidance of "false failure" indications.

The current generation of OBD (OBD2) additionally monitors the catalyst performance and misfiring, among other technical differences to OBD 1. The diagnosis of the catalytic converter is accomplished by the installation of an additional oxygen sensor downstream the catalyst. The signals of the up- and downstream sensors are processed via special algorithms to check the oxygen storage capacity and hence the activity status of the catalyst. This technology is also already mature for passenger cars and the effort is to link the OBD signal to the actual emission levels of the vehicle. This could potentially be used to efficiently characterise high emitters.

The issue for motorcycles in considering OBD introduction, is what kind of system would be feasible to develop and apply. For 4-stroke motorcycles, an OBD1-like system is already in use in some models. However, there is no experience yet how an OBD system which monitors catalyst efficiency and misfiring could perform. The critical issues in the case of high specific power two wheelers is that their engine operation is much more transient than passenger cars, and current diagnosis algorithms would be probably not applicable. The situation is even more questionable for non-stoichiometric 4-stroke and more particularly 2-stroke engines, in which the emission control is based mainly on oxidation catalysts. In this case, the traditional 3-way catalyst monitoring system is not applicable and therefore alternative technologies will be needed. Although the monitoring of oxidation catalysts can be technically made possible in short-to-medium term (e.g. via temperature measurements), the relative experience is very limited and the cost associated could be quite high.

In discussions with industry representatives, but also consulting the limited information available via the MVEG meetings, it seems that the OBD issue is one of the most difficult objectives of the particular regulation. The industry seems not prepared to consider introduction of OBD for all motorcycle categories due to limited experience on its operation and because R&D has today focused on the development of technologies to meet 2006 emission standards. The situation is different for manufacturers of larger (and more expensive) motorcycles where some kind of OBD is already installed for monitoring of the vehicle's major functions.

The contractor requested from the industry to provide an "OBD-package" which will include the technology options to implement an OBD system, the functions of such a system and the costs associated. Following this invitation, the industry indeed submitted their views on the issue. According to the industry, there are two options to implement an OBS system on new vehicle types: Either develop and fit an OBD1 type on existing engines or add OBD1-compliant engine management systems to their products. The first option means that the supplier of the ECU needs to modify the ECU and would necessitate rewiring and retooling of the ECU and the motorcycle. In the second option, a new calibration of the engine management will be required to include OBD function. The costs in each case were estimated to be M€ 2.0 – 2.1 per engine type.

The industry also questioned the true environmental benefit of an OBD system, mainly because the user may intervene and disable the system (to avoid maintenance costs) but also because experience so far has shown that the failure rates of OBD-monitored motorcycles were below 0.2% (based on a research campaign conducted within the industry). Based on this considerations, and in case that the Commission would proceed towards an OBD implementation for two-wheelers, the industry would consider an OBD1-type of system, with no catalyst efficiency or misfiring detection, because no such systems have been developed so far for two wheelers. A Malfunction Indicator Lamp (MIL) would communicate any error to the user but the link with the maintenance personnel could be established by either On-Board or by Off-Board diagnosis.

This introduction is a deliberate repetition of the discussion in the earlier LAT/AUTh report and shows that not much has changed over the last four years and confirms that OBD for motorcycles is one of the difficult components of this package of regulations. However, although the decision in the previous MVEG round was not to promote the OBD, we decided to update the calculations to present the environmental benefit, given the fact that the new extended time horizon (2020) allows for a higher probability of malfunctions to occur.

In order to estimate the environmental benefit from the installation of an OBD system in motorcycles, the exact assumptions agreed in the previous round of discussions, have been also incorporated in this report. The emission factors in the baseline scenario have been deliberately deteriorated to simulate emission control system malfunctions in Euro 2 and Euro 3 vehicles. Also, three types of impairments/malfunctions are considered for motorcycles, each resulting to a different relative increase of regulated emissions:

- Type 1: Malfunction requiring a minor repair.
- Type 2: Malfunction requiring a major repair.
- Type 3: A serious damage requiring replacement of the aftertreatment device.

We would assume that an OBD 1 system, performing in a way that the industry has proposed, is expected to identify the first two types of malfunctions. An OBD system that would monitor the catalyst performance is expected to also identify failures of the 3rd type.

The occurrence of a malfunction has been assumed to be a function of vehicle age. Table 3-14 summarizes the probability used in the calculations. Figures in this table mean that, for example, a malfunction occurs in 1 out of 10 6-year old motorcycles. This probability is further allocated to the three different types of malfunctions discussed above, according to the probabilities shown in Table 3-15. Finally, Table 3-16 shows the suggested increase in regulated emissions caused by the occurrence of each of these types of malfunctions.

Just to give an example of the calculation, the increase in the emission levels of 3-year old Euro 3 motorcycles due to malfunctions are 5% x (61 % x 2 + 29% x 5 + 10% x 10) = 18%. Obviously, the effect of this deterioration to fleet emissions need to also take into account the vehicle age distribution.

Table 3-14: Probability of occurrence of a malfunction that would result in increased emissions.

Age	0	1	3	6	9	>=12
Probability	0%	0.2%	5%	10%	20%	40%

Table 3-15: Probability that the failure of an engine component or the aftertreatment device will require minor repair, major repair or a complete replacement of the catalyst is required.

	Minor Failure	Major Failure	Failure requiring replacement of the aftertreatment device
Euro 2	66%	34%	0%
Euro 3	61%	29%	10%

Table 3-16: Ratio of emission factor when a failure occurs over baseline emission factor.

	Minor Failure	Major Failure	Failure requiring replacement of the aftertreatment device
Euro 2	2 x	5 x	-
Euro 3	2 x	5 x	10 x

The scenarios that were executed were somehow modified from the previous study, in order to better reflect the current understanding of the Commission's view of the OBD subject. In principle, two scenarios were executed over the baseline:

- "Baseline": No introduction of OBD systems
- Scenario 1: Application of OBD systems of similar technology to PCs (EOBD), including catalyst efficiency monitoring to all motorcycles.
- Scenario 2: This scenario assumes use of best available technology: minor malfunction monitoring (e.g. circuit integrity check) (OBD1) to all motorcycle, no catalyst efficiency monitoring.

It should be stated that in both Scenario 1 and 2, the assumption is that OBD immediately diagnoses any malfunction and this is treated with no time delay. This is equal to have an OBD emission threshold similar to the type-approval limit and that any malfunctions are cured instantly. Evidently, the simulations refer to the maximum potential benefit from and OBD application.

3.3.4.2 Environmental Benefit

The difference in the total regulated emissions over the baseline scenario for the two alternative scenarios considered is summarized in Figure 3-23 as evolution of emissions and in Figure 3-24 as emission benefit over the studied timeframe.

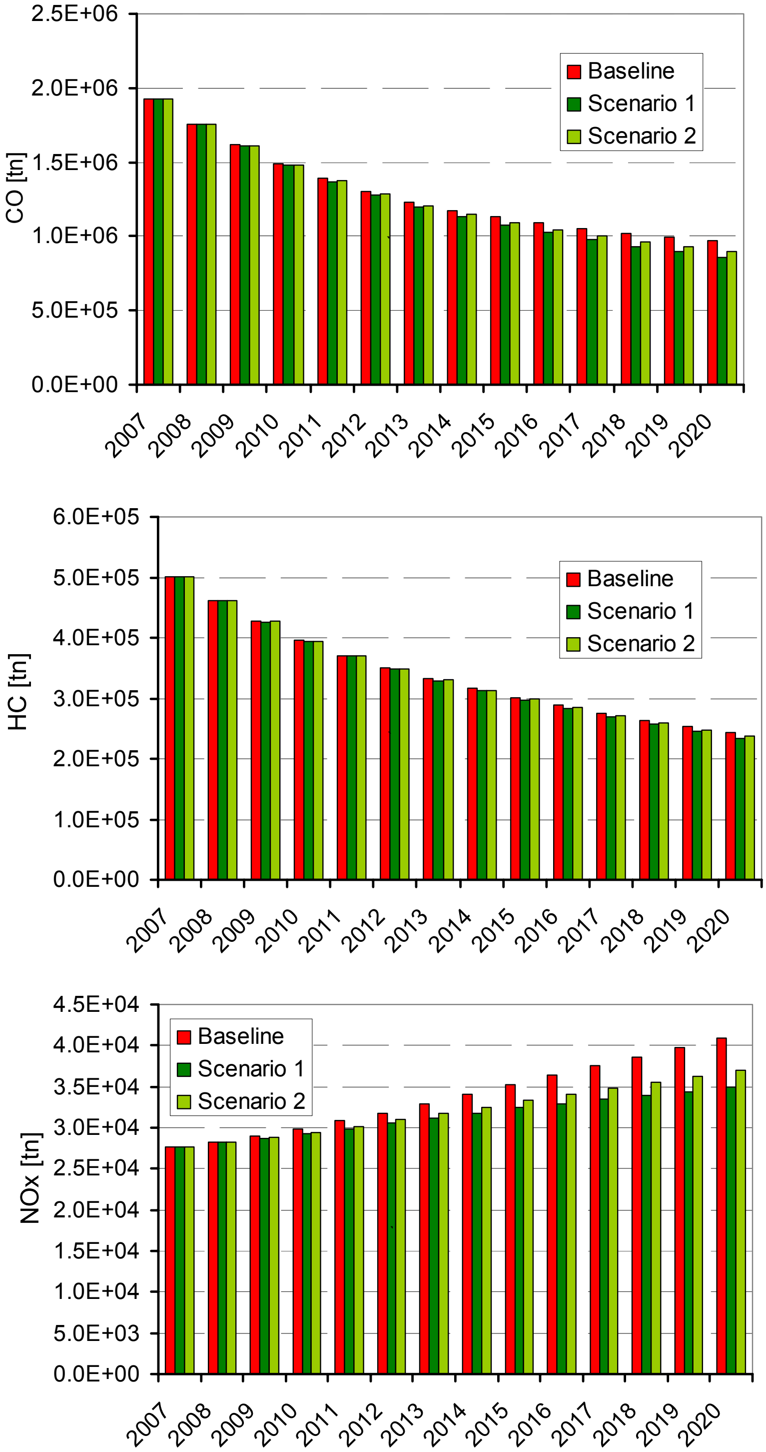


Figure 3-23: Estimated evolution of regulated pollutants from total **PTWs** in EU15 due to the introduction of different OBD requirements

Introduction of an OBD system that would also monitor catalyst performance similar to PC systems obviously expected to bring the greatest decrease in motorcycle emissions. Even in that case though, this mean reduction over the period of OBD application is not high. The higher decrease in NO_x emissions is due to the assumption that NO_x emissions of non TWC equipped vehicles are not degraded.

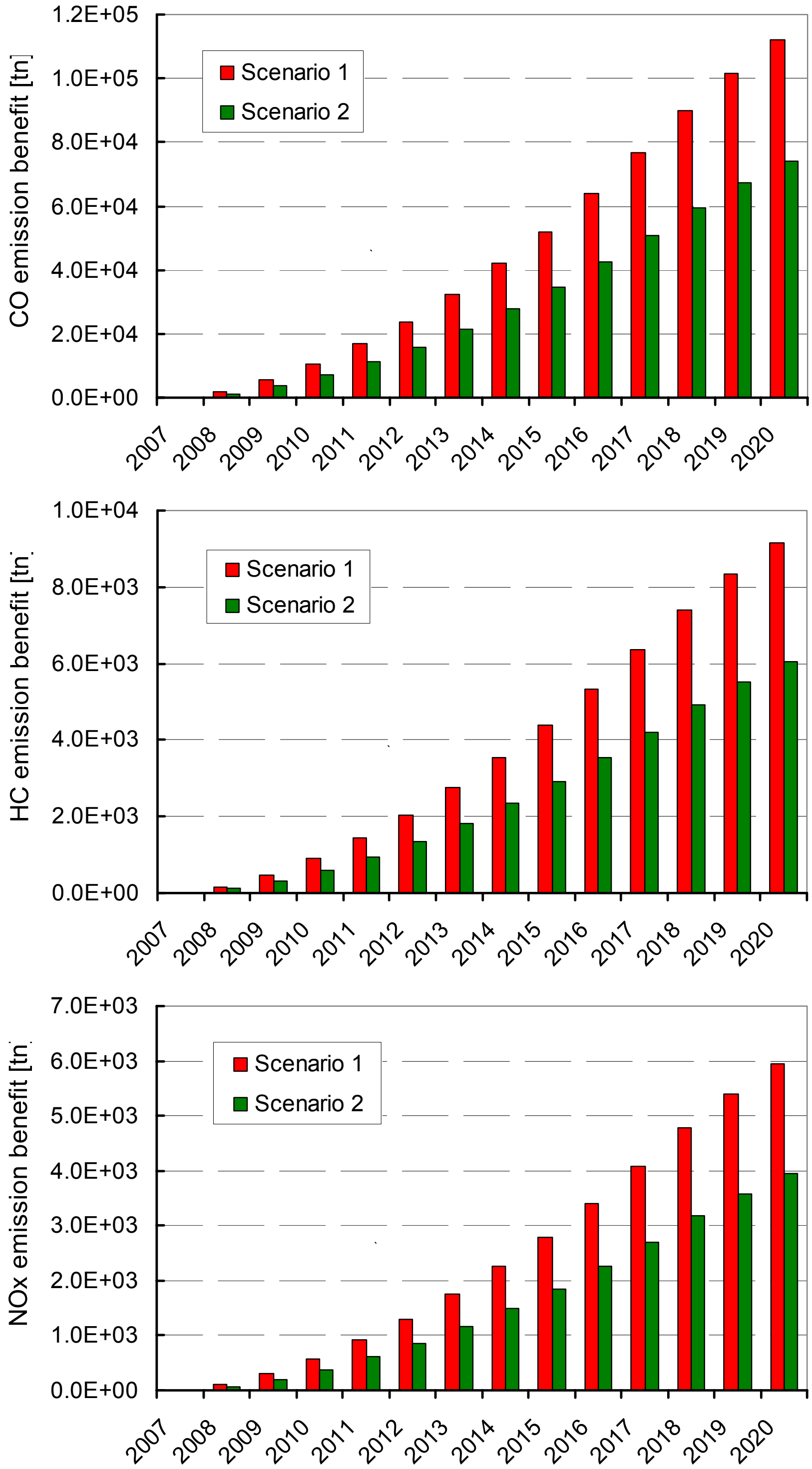


Figure 3-24: Estimated emission benefit of regulated pollutants from total PTWs in EU15 due to the introduction of different OBD requirements.

3.3.4.3 Cost Calculation

The same assumptions of the previous report with regard to the cost elements of the OBD introduction are also assumed in this study, as no objections and no new data have appeared since publishing the previous report. The Research & Development cost for the calibration and the installation of an OBD1 system per engine family is estimated to be M€1.7 – M€1.8. The estimation of the industry for introducing an OBD1 type of system was M€2.0 – M€2.1, including a calibration cost of 250 k€ in case that an OBD was introduced on existing management systems. However, given that the cost estimate conducted over the Baseline Scenario already includes a calibration cost per engine family (300 k€) to comply with the new emission standards and durability requirements, we excluded the cost of calibration for OBD compliance, not to double-count it. The investment cost, involved during the first year of implementation of this task, is defined by the Research & Development cost for the installation of an OBD system to each new type of engine family introduced in Europe. Thereafter, we consider only the calibration and the peripheral costs, due to the experience earned within the industry in the previous years. This amounts to M€0.3 – M€0.8 per new type introduced. Moreover, the introduction of an OBD system with catalyst performance monitoring is estimated to lead to an additional 10% cost in the research & development costs per engine family.

In order to calculate the aggregated annual inspection cost we first assume a 2-year warranty period for every malfunction that may appear to any vehicle. Furthermore, we estimate that the cost per inspection per consumer (per motorcycle) is €3 to €4 (CITA, 2002). Added to this, the cost of the time lost by the motorist for scanning the OBD system (5 minutes) and for commuting to the service station is estimated by valuing a total time loss of 25 – 30 minutes. Using the default value supplied by the World Bank - 30% of the mean household income per hour is used for the valuation of non-work time, which results to €0.05 per minute - this cost amounts to €1.25 – €1.75 per vehicle (CITA, 2002). The aggregated annual inspection cost derives by considering the sum of the above costs and the number of failed vehicles each year.

To conclude the cost estimate for implementation of OBD, we need to add the maintenance cost. The maintenance costs are estimated 30% less than the equivalent for passenger cars (LAT et al. 1998):

- The cost to fix minor repair is set at €70.
- The cost for a major repair is €140.
- The cost for a catalyst replacement is €420.

We apply these cost estimates to all vehicles in Scenarios 1 and 2 (in Scenario 1 we excluded the costs associated with catalyst performance monitoring).

All the above costs were derived from the previous study and corrected for 2% annual inflation.

3.3.4.4 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each scenario is illustrated in Table 3-17 and Table 3-18, and the same results are also shown in Figure 3-25 and Figure 3-26.

Due to the extended time horizon, the cost-effectiveness is calculated much improved, compared to the earlier LAT/AUTh study. In the earlier report, the cost-effectiveness of introducing a Euro-5 equivalent OBD for all 4-stroke motorcycles in order to control HC emissions was found between 81 and 155 €/kg. In the current study this is limited to the range of 22.5-35.8 €/kg. The reason for the rather large difference is the probability for malfunctions increases for this extended time horizon and therefore, for the same cost, the effectiveness of the OBD becomes much higher.

Table 3-17: Total cost (NPV) of OBD introduction

	Total cost (NPV) of different OBD policies (M€)		
	Low Estimate	High Estimate	Best Estimate
Scenario 1	1227	1949	1588
Scenario 2	1040	1697	1369

Table 3-18: Cost–effectiveness of OBD introduction (€/kg ≡ M€/kton).
(No emission reduction calculated for PM).

	Cost–effectiveness of different policies (€/kg ≡ M€/kton)		
	Low Estimate	High Estimate	Best Estimate
HC			
Scenario 1	22.5	35.8	29.1
Scenario 2	28.8	47.0	37.9
NO_x			
Scenario 1	1.5	2.4	1.9
Scenario 2	1.9	3.1	2.5

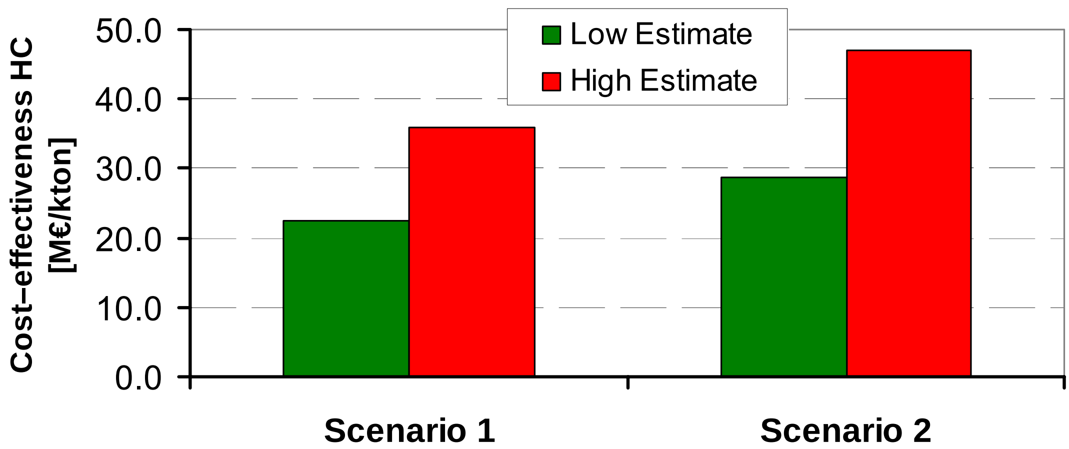


Figure 3-25: HC cost–effectiveness of OBD introduction

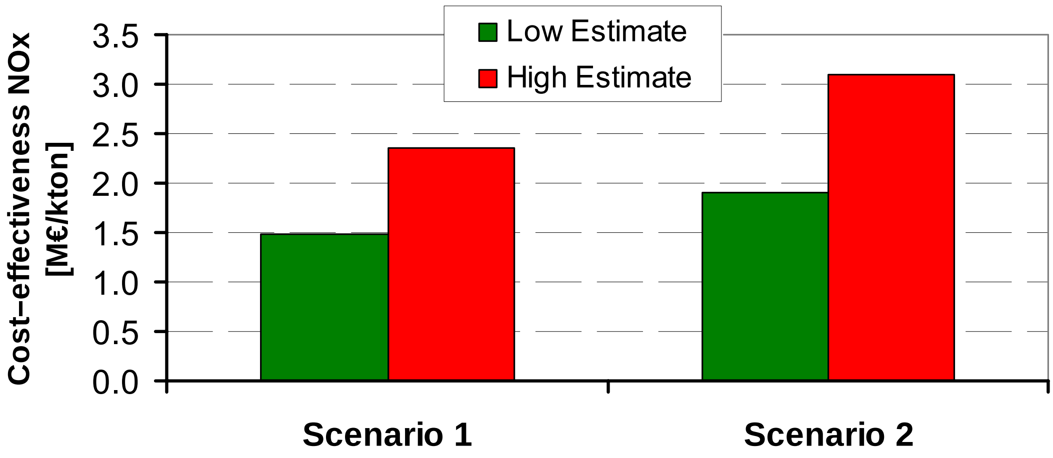


Figure 3-26: CO cost–effectiveness of OBD introduction

3.3.4.5 Social and SME Impacts

Judging from the passenger car sector, the introduction of OBD has not led to any particular disturbance to the drivers, except of cases where false failures are diagnosed. While there is little to do on a passenger car, but visiting the maintenance centre, in a motorcycle it would be fairly easy to interrupt this "annoying" signal because all connections are quite easily reachable. This would be even more so because several of the motorcycles are just considered cheap transportation vehicles and any disproportional increase in their maintenance costs should be avoided.

An additional parameter that needs to be examined is whether OBD will continue to be effective in case that the exhaust line is replaced with a custom made one, which is a typical behaviour for several motorists. It would be generally expected that an OBD error may be activated if the exhaust line is replaced with a non-approved component. However, the issue is how to make sure that OBD is not activated when replacing the exhaust line with a component that has a separate type-approval than the vehicle (i.e. following the expected regulation on this issue). In this case, the manufacturers of both the vehicles and the exhaust units need to make sure that their parts will be interchangeable, also for the OBD to function properly. It is uncertain whether vehicle manufacturers will be willing to share OBD-sensitive information with third parties. This is also common in passenger cars when owners try to tune new engine using free flow filters and induction lines and an OBD error occurs. Presumably, the interference between OBD operation and exhaust line replacement is an issue that needs to be addressed in the relevant regulation. Solutions that may be given include the design of a specialised hardware link between the engine outlet and the exhaust line where only custom-made components may be fit to avoid the use of cheap, non type-approved replacements. The condition of this hardware link can then be examined during roadworthiness tests to make sure than no invalid components have been used. A second solution is a software link between the OBD unit and the exhaust line (by means of a signal from the oxygen sensors etc.). Obviously, both solutions may be also by-passed but their main aim would be that they increase the cost of tampering, making the use of non approved components at least equally expensive to the use of approved ones.

On the positive side, an OBD system will certainly improve any inspection & maintenance procedure, diminishing the probability of the failing diagnose a true malfunction and could also potentially decrease the cost of maintenance in some cases where it speeds up diagnosis.

3.3.4.6 Conclusions

Using the 2020 as a time horizon compared to the 2012, used in the previous study improves the cost-effectiveness of the OBD introduction. The reason is that the probability of severe malfunctions increases with age and, therefore, the emission benefit of a system that could diagnose these malfunctions increases. However, there are significant uncertainties of this calculation as it largely depends on a scenario of emission malfunction probability and not solid experimental data on the behaviour of actual motorcycles. There also continues to be a difficulty in the technical implementation of catalyst efficiency monitoring in motorcycles because the technology from passenger cars is not directly transferable to motorcycles (operation range, transient performance, thermal gradients, etc.).

The recommendation from the current study is, again, that other measures have a higher priority than the introduction of OBD. This means that durability regulations and roadworthiness procedures need to be first established. These will provide better information on the actual degradation and malfunction probability of motorcycles. After such information becomes available, one would be in better position to reassess the introduction of OBD for motorcycles.

3.3.5 Evaporative emissions

3.3.5.1 Objective, Background and Policies Definition

HC emissions from fuel evaporation via tank vents and engine openings may become a significant contributor of total HC emissions as exhaust concentrations decrease. The question arises then, whether the control of evaporative emissions should be considered. In order to calculate the share of evaporation HC to total emissions, we need a realistic estimation of hydrocarbon loss due to evaporation. Figure 3-27 shows the contribution of evaporation to total HC emissions from motorcycles. Both exhaust and evaporation emissions seem to drop until 2016. The reason for the drop in evaporation emissions is the gradual replacement of carburetted with fuel injection vehicles, also in the baseline scenario. As a result, evaporation emissions also drop, together with exhaust emissions.

A further reduction in evaporative emissions can be achieved by mandating the use of a charcoal canister and low permeability tanks and transfer lines. Such a measure is suggested to have 95 % efficiency in decreasing diurnal losses. In order to investigate the maximum potential of such a measure, an alternative scenario was investigated which would require the use of charcoal canister and low permeability tanks and transfer lines in all Euro 3 motorcycles.

In order to assess the effectiveness of the evaporation control measures, the following scenarios were considered.

- "Baseline": No measures against evaporative emissions

- Scenario 1: Replacement of all new carburetted models with fuel injected ones. Due to the closed circuit, fuel injection engines result in much lower evaporation emissions than carburetted ones

- Scenario 2: Introduction of evaporation control (canister and low permeation lines) for all motorcycles (not mopeds).

Figure 3-27 shows the contribution of evaporative emissions to total HC emissions for the baseline scenario up to year 2020. The contribution appears much lower than in the previous study, because the new experimental information (see section 2.4.4) results to much lower evaporation emissions from motorcycles, compared to what was earlier considered. Figure 3-28 shows the evolution of the total evaporative emissions for the baseline and the two alternative scenarios examined.

3.3.5.2 Environmental Benefit

Figure 3-29 shows the corresponding annual reduction in THC emissions over the baseline scenario. Significant benefit is being introduced by the use of canister for all motorcycles.

3.3.5.3 Cost Calculation

The calculation of the cost for evaporation control has been different for the two scenarios. For Scenario 1, which concerns the introduction of only fuel injection mopeds, the cost is equal to the additional cost of introducing a fuel injection system, as this was discussed in section 2.3.2.

The cost for the introduction of evaporation control is what has been clarified in the Moto_109 document which can be summarised in the following bullet points:

- Cost range for emission control measures per vehicle (cost to the manufacturer):
  Low estimate: €10, High estimate: €50.
- Mark-up cost for overhead and profit: 29%
- Evaporation type-approval cost per motorcycle: €1500
- New types of motorcycles per year:
  2-stroke:10 models, 4-stroke: 84 models, equally distributed in different engine classes.
- Discount rate: 4%

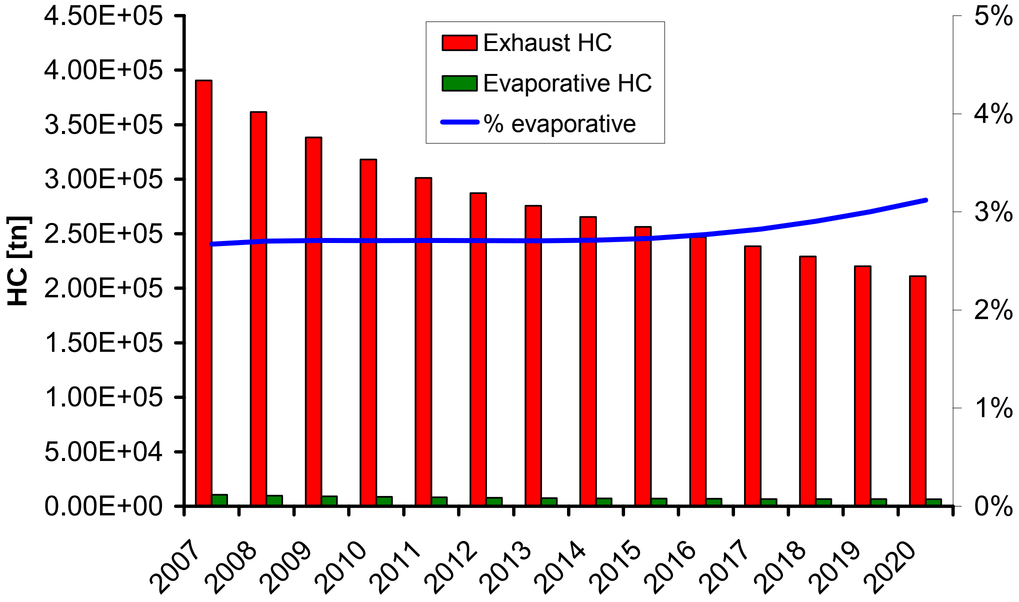


Figure 3-27: Evolution of exhaust and evaporative HC emissions from motorcycles and % contribution of evaporative losses to total HC emissions for the baseline scenario

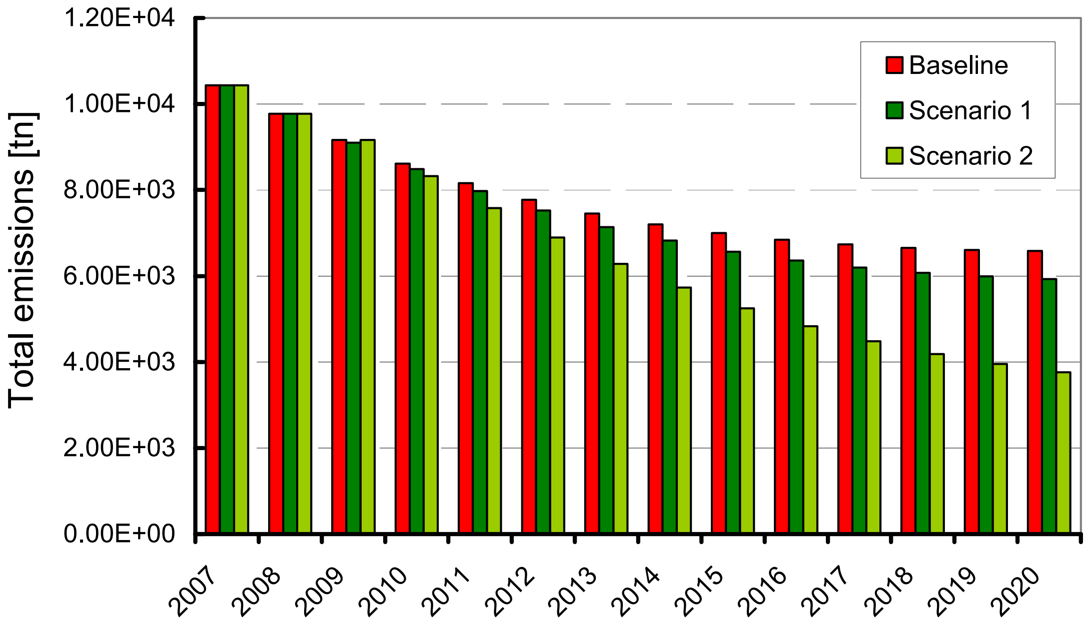


Figure 3-28: Evolution of the total evaporative emissions for the examined scenarios

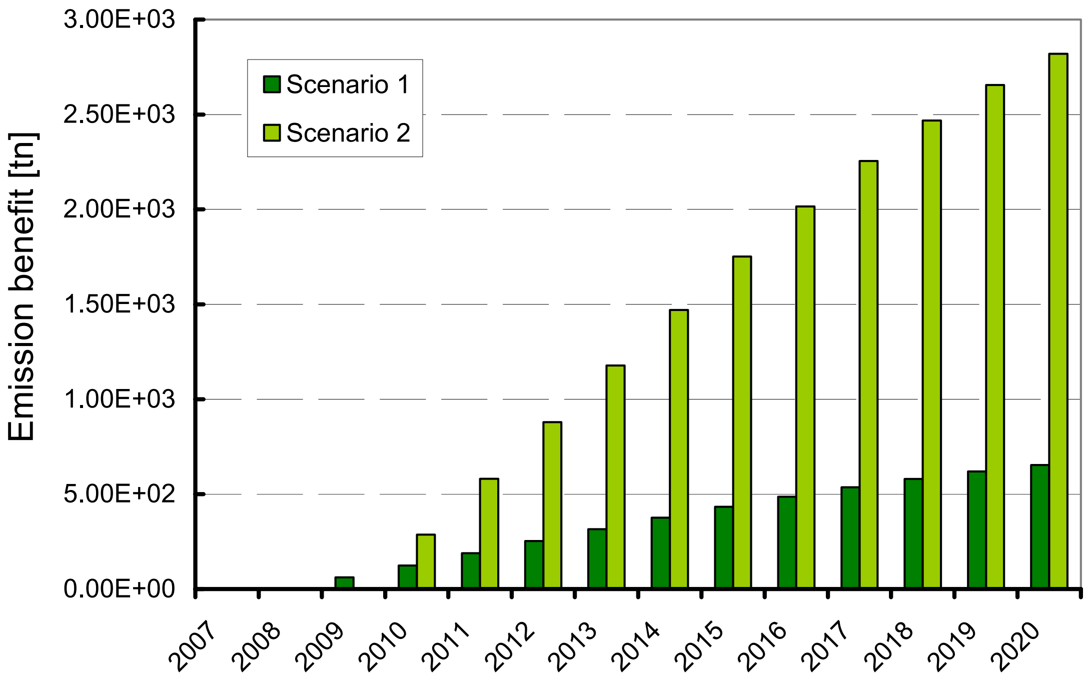


Figure 3-29: Total evaporative emissions benefit for the examined scenarios

3.3.5.4 Cost-Effectiveness

The outcome of the cost-effectiveness analysis is illustrated in Table 3-19 and in Table 3-20. The evaporation control for motorcycles by introducing fuel injection to all new models appears a very expensive measure when all the cost for the fuel injection system is allocated to the control of moped evaporation. Of course, fuel injection can also lead to exhaust HC emissions reduction, therefore not all cost of fuel injection should be transferred to evaporation control. However, from a technology neutral standpoint, Euro 3 for mopeds may be reached with either carburettor or electronic fuel injection. Therefore, forcing the use of electronic fuel injection also leads to allocating all costs to evaporation control As a result, introducing fuel injection just for the control of evaporation emissions appear as a non realistic approach from a cost-effectiveness perspective. Even assuming that 50% of all mopeds will be in any case equipped with fuel injection to fulfil the Euro 3 exhaust emission standards, the cost for fitting the rest will be much higher, and the cost-effectiveness much worse than the canister approach for motorcycles.

The evaporation control of motorcycles, on the other hand, appears as a much more cost effective solution. In fact, in comparison to the previous study, the cost-effectiveness appears worse, as a result of the lower evaporation emissions of motorcycles equipped with fuel injection, than what earlier considered. In the past, all motorcycles were assumed to emit about 1.2-1.3 kg HC/year/vehicle. The new experimental information shows that this is rather true for large motorcycles equipped with carburettor. The introduction of fuel injection already significantly reduces evaporation emissions by ~60%. In addition, the actual emission level drops for smaller vehicles. However, we continue to consider evaporation control as one of the technical and socially mature measures for the further control of emissions. Also, the corrected cost-effectiveness calculation still results to quite reasonable values for cost-effectiveness. Therefore, the proposal for introduction of evaporation control in Document Moto_87 is still considered a reasonable approach in controlling emissions.

Table 3-19: Evaporation control total cost (NPV)

	Total cost (NPV) of different evaporation control policies (M€)		
	Low Estimate	High Estimate	Best Estimate
Scenario 1	792	1585	1189
Scenario 2	171	855	513

Table 3-20: Evaporation control cost–effectiveness per implementation year (€/kg ≡ M€/kton).

	Cost–effectiveness of different evaporation control policies (€/kg ≡ M€/kton)		
	Low Estimate	High Estimate	Best Estimate
Evap. HC			
Scenario 1	171.2	342.4	256.8
Scenario 2	9.3	46.6	27.9

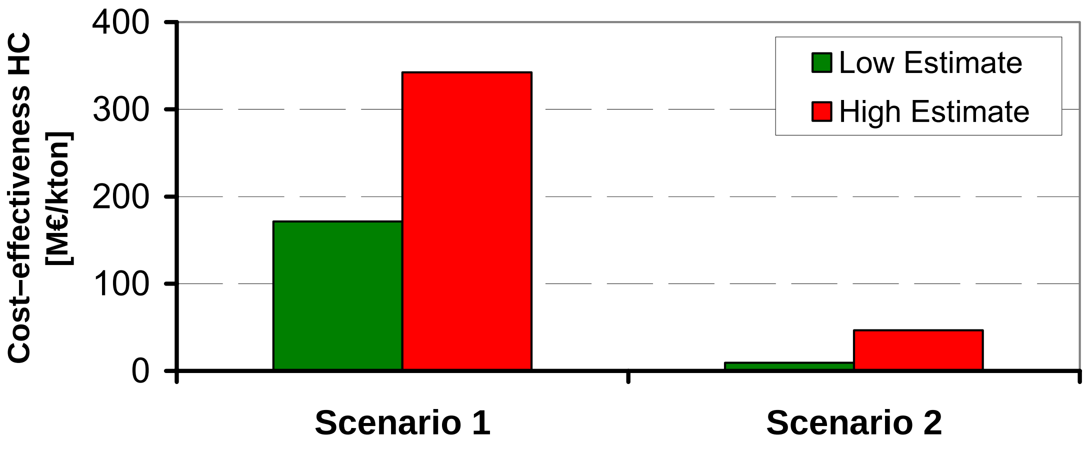


Figure 3-30: Evaporation control cost–effectiveness.

3.3.5.5 Social and SME Impacts

No particular difference is expected compared to the General Social Impacts. One might consider that the motorcycles become rather odourless and (only marginally) more fuel efficient (e.g. saving 1.3 kg fuel/year) but these should not be considered particular arguments to promote or demote motorcycle sales. The impact on SMEs is expected minimal, as all evaporation control components are produced by large manufacturers.

3.3.6 Tricycles and quadricycles

3.3.6.1 Scenarios

Four scenarios were developed for tricycles and quadricycles, in analogy to PTWs (section 3.2). As already mentioned, based on the communication with ATVEA and EQUAL, ATVs are considered to be equipped with petrol engines while mini-cars are considered to be powered mainly by diesel engines.

- Scenario 1:

Euro 3 emissions factors considered equal to the emission limits set out in "Moto_105" [14] for tri- and quadricycles (petrol and diesel). The emission limits are shown Table 3-21. In this revised version of the report, the date of introduction has been transferred to 2012, as it is not possible to introduce the standard in 2010, as originally included in Moto_105 document.

Table 3-21: Emission standards considered in Scenario 1 for 3 / 4 wheelers

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 3 [2012]	3/4-wheelers Positive Ignition	2 UDC warm-up + 4 UDC sampling (without 40s idling)	4 000	1 000	250	/
	3/4-wheelers Compression Ignition		1 000	150	650	100

- Scenario 2:

Scenario 2 emission limits have been designed in equivalency to Scenario 2 of motorcycles, to provide equivalent emission standards to Euro 5 of passenger cars. To do so, one emission limit step (Euro 3) is considered for introduction in 2012. For petrol vehicles, the emission limits are calculated by first introducing the Euro 3/Euro 2 emission standard ratio of motorcycles <150 cc (2002/51/EC) to the Euro 2 tri/quadricycles emission limit. On top of this, we introduce the same reduction ratio (Euro 5 PC emission limit / Euro 3 PC emission limit) as the one for motorcycle Scenario 2, to reach Euro 5 passenger car equivalent emission limits. Emission limits proposed in this scenario are shown in Table 3-22. For diesel mini-cars, the same emission standards to Euro 5 diesel cars were introduced, assuming that diesel engines used in these small cars do not have significant performance differences to larger passenger cars. This is particularly stringent for PM control, as this would in principle necessitate the use of a diesel particle filter to reduce emissions down to 4.5 mg/km.

Table 3-22: Emission standards considered in Scenario 2 for 3 / 4 wheelers

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 3 [2012]	3/4-wheelers Positive Ignition	2 UDC warm-up + 4 UDC sampling (without 40s idling)	1 100	500	80	/
	3/4-wheelers Compression Ignition		500	50	180	4.5

- Scenario 3

Scenario 3 introduces emission standards which should be equivalent to the 'best available technology' for tricycles and quadricycles. The best available technology is difficult to determine for this particular vehicle class, as there are very few measurements available, in contrast to what was available for motorcycles (section 0). Therefore, the emission limits will have to be defined by comparing the emission performance of these vehicles to power two wheelers. For petrol cars, it has been assumed that their emission standard can be equivalent to the emission standard of Euro 3 motorcycles of 150 cc (according to 2002/51/EC, i.e. over ECE40), which are tested in the same cycle to tricycles and quadricycles. Although this is defined as 'best available technology' this introduces significant reductions, in the range of 70% for CO, 46% for HC, and 63% for NOx. The emission standards in this case are shown in Table 3-23. Diesel emission standards on the other hand have been assumed equal to Euro 4 passenger cars and are also shown in Table 3 23. This does not require a particle filter to reach PM emission limits.

Table 3-23: Emission standards considered in Scenario 3 for 3 / 4 wheelers

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 3 [2012]	3/4-wheelers Positive Ignition	2 UDC warm-up + 4 UDC sampling (without 40s idling)	2 000	800	150	/
	3/4-wheelers Compression Ignition		500	300 (NOx: 250)		25

- Scenario 4:

Petrol and diesel emission limits set arithmetically equal to the emission standards of motorcycles and mopeds, as discussed in Scenario 4 for PTWs (section 3.2.4). This introduces two emission limits, one at Euro 3 (2013) and one at Euro 4 (2016) level. Driving cycle for type-approval is ECE-R40 cold start. A summary of the emission standards is shown in Table 3-24.

Table 3-24: Emission standards considered in Scenario 4 for 3 / 4 wheelers

EURO stage [impl. date]	Vehicle type	Test cycle	CO (mg/km)	HC (mg/km)	NO_x (mg/km)	PM (mg/km)
EURO 3 [2013]	3/4-wheelers Positive Ignition	ECE-R40 cold start	1 140	165	88	/
EURO 3 [2013]	3/4-wheelers Compression Ignition		500	300 (NOx: 250)		25
EURO 4 [2016]	3/4-wheelers Positive Ignition	ECE-R40 cold start	1 000	100	60	/
EURO 4 [2016]	3/4-wheelers Compression Ignition		500	230 (NOx: 180)		4.5

No CO_2 effect has been estimated with the introduction of different emission standards, although CO_2 benefits may be obtained with some technologies. The reason for not introducing such a correction has to do with the very low contribution of such vehicles to total road transport CO_2 emissions (0.05%). Introducing a correction would be well within the uncertainty of our projections and would in any case have negligible impact to the CO_2 policies in Europe.

3.3.6.2 Environmental benefit

As already mentioned in section 3.1.1, tri and quadricycles are a special category corresponding to a very small portion of the total vehicle fleet. All previous regulations included relaxed emission standards for this vehicle category, taking into account the small and medium size of the companies producing these vehicles. However, new information from tri- and, mainly, quadricycle manufacturer associations and market figures though show a general trend for increased sales (section 2.2). For this reason, the emission benefit from the application of stricter emission policies has been examined in this report.

In addition, this category clearly consists of two different vehicle categories. ATVs and mini-cars. ATVs are used primarily for off-road use and are equipped with single-cylinder gasoline engines. Mini-cars are quadricycles powered by diesel engines used in urban and suburban passenger transport applications. The diverse nature, use and technology of these vehicles makes it difficult to produce uniform conclusions from both vehicle classes.

Figure 3-31 presents the emission evolution for tri and quadricycles of the four examined scenarios from 2007 to 2020 while Figure 3-32 shows the corresponding emission benefit achieved by the application of each of the three alternative scenarios compared against the current situation.

No cost calculation has been performed for the emission control of these vehicles. The reason is that they are produced in small series and it is difficult to collect information on the cost of individual component. Also, there is some uncertainty related to which vehicle types the new regulation should cover (e.g. the coverage or not of ATVs). Finally, this is a rather fresh market with little history on which to base projections about its evolution. For example, will the diesel mini-car market continue to grow similar to the past? Could this be fast replaced by electrical micro-vehicles? This makes difficult to quantify the cost-effectiveness of the different measures.

In any case, the scenarios of executed with regard to the emission evolution of these vehicles leads to some solid conclusions with regard to their emission regulation needs:

1. The stock size of these vehicles increases and their emission control needs to be given more attention compared to what thought in the past. Details of the emission contribution of these vehicles in the baseline scenario (up to Euro 2 regulations) are given in section 3.1.2.

2. If no additional measures will be taken (i.e. no step beyond Euro 2 emission standard), the contribution of such vehicles in all pollutants (CO, HC, NO_x, PM) will significantly increase in the future. With no additional measures, it is projected that quadricycles will be responsible for 1.75% of total road transport PM emissions, despite they represent only ~0.09% of total activity. The contribution becomes even more important as several of these vehicles (in particular mini-cars) operate in areas where the population is highly exposed to their emissions (e.g. tourist areas, near parks, schools, etc.).

3. An effective regulation for tricycles and quadricycles should also cover ATVs, as there is no other directive addressing emissions of such vehicles. Therefore, an explicit statement to include "four-wheelers designed primarily for use in non-paved streets" should also be included in the regulation.

4. The emission limits included in document Moto_105 (Scenario 1) result to a rather effective control of CO and HC emissions of such vehicles, leading to emission levels at 56% and 63% respectively over the baseline level in 2020. Following this proposal their contribution to road transport HC is projected to only slightly increase from 0.6% in 2009 to 1.0% in 2020 of total road transport. The corresponding numbers for CO are 0.3% and 0.6%, respectively.

5. The emission limits in Moto_105 document do not sufficiently address NOx and PM emissions from these vehicles. Their share in NOx is projected to more than triple from 0.05% in 2009 to 0.16% in 2020 and their share in PM is projected to more than double from 0.5% to 1.2%. Despite this is not much in absolute terms, the operation of these vehicles in environmentally sensitive areas and the immediate exposure of youngsters and elderly (the main market target groups of ATVs and mini-cars) to high pollutant concentrations is a fact that magnifies the problem.

6. Scenarios 2 to 4 offer more substantial reductions of all pollutants, compared to the baseline and Scenario 1. Scenario 3 manages to keep the CO and HC relative contribution in 2020 at the 2009 levels, while NOx and PM only slightly increase over their 2009 relative levels (0.09% and 0.9% of total road transport respectively). Scenario 4 achieves the highest reductions, despite the later introduction of emission standards compared to the other scenarios, just because of the stringent emission limits proposed. In fact, the relative contribution of these vehicles in 2020 is projected to be only ~50% of their relative contribution of total road transport in 2009 for CO and HC according to Scenario 4, while the relative contribution to PM and NOx appears at the same levels between 2009 and 2020. Finally, Scenario 2 reduces CO and HC relative contribution to below the 2009 levels, while NOx and PM relative contribution roughly doubles over 2009.

7. Selecting emission standards based on the scenarios performed depends on the target that one needs to fulfil. All Scenarios achieve quite substantial reductions of total emissions from such vehicles in 2020 in absolute terms, assuming that their stock does not evolve differently than projected in this report. If the criterion is to keep the relative contribution of these vehicles to levels equal to 2009, then the following can be said: Scenario 1 leads to marginal increases in HC and CO and substantial increases to PM and NOx. Scenario 2 decreases the relative contribution to CO and HC and leads to only marginal increases in NOx and PM. Scenario 3 leads to slight reduction of CO, slight increase in HC and roughly doubles the contribution in NOx and PM. Scenario 4 reduces the relative contribution in CO by 2.4 times, the HC contribution by 4.8 times, and leads to 1.5 and 1.2 times increase in the relative contribution of NOx and PM respectively.

8. For diesel mini-cars, a number of existing technologies from the passenger car sector can be proposed for emission control, such as exhaust gas recirculation for NOx control and high pressure injection or even diesel particle filters for PM control. At least some of these measures will be required in order not to substantially increase the contribution of these vehicles to PM and NOx emissions. The difficulty in introducing low emission limits is not so much on the technology, although some adjustments are required given the small engine size, but on the cost and size of these devices in proportion to the small size of the vehicles.

9. For gasoline tri-cycles and quadri-cycles, emission control technology from motorcycles can be also transferred. The engines used in these vehicles, in particular ATVs, are mostly single-cylinder engines to save weight and cost, and keep a low centre of gravity. However, alternative concepts, i.e. two-cylinder and systems for better fuel utilization may be proposed to decrease emissions.

3.3.6.3 Social and SME Impacts

Several of the manufacturers of ATVs and in particular mini-cars fall within the SME scope and rather in the category "medium enterprises" (between 50 and 250 people). Therefore, any policy measure will have direct effect on the SME manufacturers. Moreover, the technology used for these vehicles (with the exclusion of electric ones) is basically technology which is established in the motorcycle (ATVs) and passenger cars (mini-cars). Therefore, the R&D departments of these companies are relatively smaller compared to larger manufacturers. However, the ATVs market also involves a few big manufacturers of motorcycles as well.

Therefore, the possibilities to introduce big technological improvements in this class is limited for as long as the stock continues to be in the order of 600000 cars and the annual market keeps to about 70000 vehicles. If the stock and the market increase, then the revenues will be higher and the possibility for R&D also in the area of emission control will increase (vice versa if the market decreases). In addition, low emission limits may lead some players out of the market while retaining the big companies who have larger experience in meeting strict emission limits.

On the other hand, ATVs are used in the nature and minicars are used by the elderly and by youngsters (due to simplicity of operation and the non-requirement for driving license) so good environmental performance is also a requirement. This is particularly true for NOx and PM due to their health effects and the many exceedances of the air-quality standards of these two pollutants in many areas in Europe. Also, since driving some of these vehicles does not require a driving license and they are small in size, these may be also driven in close proximity to pedestrian areas or to areas with many youngsters (schools, parks, etc…). Therefore exposure-related concerns may be higher than for normal passenger cars.

Therefore, the introduction of an emission standard should take into account the evolution of the market and the split between mini-cars and ATVs. The criteria for establishing efficient limit values should take into account both environmental concerns and the fact this is a business area that, at least today, directly involves many SMEs. In addition, the potential shift of the market to electric vehicles (at least for mini-cars) should be taken into account. Mini-cars constitute the first candidate category to introduce pure electric vehicles, since these vehicles are mostly used in urban conditions. In fact, a few of the manufacturers of such vehicles have already introduced pure electric vehicles in their products. It is considered that establishment of strict limits will accelerate the shift to electric mini-cars than diesel.

3.3.6.4 Conclusion

This vehicle category is diverse, including both mainly off-road (ATV) and urban low performance quadricycles (mini-cars). Except of the different use, these two differ as ATVs are prime emitters of CO and HC (and secondarily PM), while mini-cars are prime emitters of NOx and PM. For mini-cars, the technology to be introduced for emission control will be inherited from the larger passenger cars market. Dimensioning and integration of the emission control devices to these smaller engines will need to be done by the manufacturers. As a result, it is not so much a technological limitation to introduce strict emission limits for these vehicles but mainly a cost and size limit. Therefore, it is difficult to propose an emission standard in the absence of a cost-effectiveness calculation (no cost data available). However, a few thoughts can be done, based on the results of the Scenarios simulation.

A new step of emission control needs to be introduced for mini-cars, taking into account the particularities and the size of the market. Not further controlling NOx and in particular PM will substantially increase their environmental impact. With Euro 5 cars and Euro VI trucks all equipped with diesel particle filters from 2010 and 2015 respectively, diesel minicars will be the only vehicle category still emitting black-smoke exhaust plumes. This will sooner or later not be accepted by the society, especially since the operation of these vehicles is focussed in environmentally concerned areas (congested areas, schools, areas with elderly population, etc.). Further to the environmental benefits that several of the scenarios proposed can introduce, maintaining a "green" image will be potentially good for the market growth of these vehicles.

Table 3-25: Summary of the effectiveness of the emission limits scenarios proposed for PTWs

Scenario	Pollutant	Total [tn] (2007-2020)	2009 [tn]	2020 [tn]	Percentage reduction over baseline in 2020	Percentage of total road transport in 2020
Baseline		4.01E+05	2.75E+04	3.05E+04		1.06%
Scenario 1		3.01E+05	2.75E+04	1.71E+04	44.1%	0.59%
Scenario 2		2.16E+05	2.75E+04	5.83E+03	80.9%	0.20%
Scenario 3		2.42E+05	2.75E+04	9.19E+03	69.9%	0.32%
Scenario 4		2.29E+05	2.75E+04	4.33E+03	85.8%	0.15%
Other road	**CO**	7.50E+07	7.70E+06	2.88E+06		
Baseline		5.47E+06	3.73E+05	4.19E+05		0.05%
Scenario 1		5.47E+06	3.73E+05	4.19E+05	0.0%	0.05%
Scenario 2		5.47E+06	3.73E+05	4.19E+05	0.0%	0.05%
Scenario 3		5.47E+06	3.73E+05	4.19E+05	0.0%	0.05%
Scenario 4		5.47E+06	3.73E+05	4.19E+05	0.0%	0.05%
Other road	**CO_2**	1.16E+10	8.08E+08	8.75E+08		
Baseline		9.29E+04	6.40E+03	7.05E+03		1.65%
Scenario 1		7.38E+04	6.40E+03	4.43E+03	37.2%	1.03%
Scenario 2		5.76E+04	6.40E+03	2.32E+03	67.1%	0.54%
Scenario 3		6.72E+04	6.40E+03	3.57E+03	49.4%	0.83%
Scenario 4		5.03E+04	6.40E+03	5.45E+02	92.3%	0.13%
Other road	**HC**	1.03E+07	1.04E+06	4.28E+05		
Baseline		2.47E+04	1.61E+03	1.95E+03		0.16%
Scenario 1		2.44E+04	1.61E+03	1.91E+03	1.9%	0.16%
Scenario 2		1.93E+04	1.61E+03	9.66E+02	50.5%	0.08%
Scenario 3		2.01E+04	1.61E+03	1.12E+03	42.7%	0.09%
Scenario 4		1.96E+04	1.61E+03	8.95E+02	54.1%	0.07%
Other road	**NO_x**	3.30E+07	3.25E+06	1.23E+06		
Baseline		6.84E+03	4.91E+02	5.03E+02		1.63%
Scenario 1		6.10E+03	4.91E+02	3.78E+02	24.9%	1.23%
Scenario 2		4.94E+03	4.91E+02	1.73E+02	65.6%	0.56%
Scenario 3		5.67E+03	4.91E+02	2.78E+02	44.7%	0.90%
Scenario 4		5.14E+03	4.91E+02	1.74E+02	65.4%	0.57%
Other road	**PM**	9.71E+05	1.04E+05	3.08E+04		

Note: In comparison to Table 3-6, other road transport in this case includes baseline PTW emissions as well.

The same more or less also holds true for ATVs Although the contribution of these vehicles to total road transport emissions is small, high emitting or white-smoke vehicles in natural environments, and the exposure of following riders to the white-smoke exhaust of the front ones, when riding in trails will sooner or later be a limiting factor in the promotion of these vehicles. Similar to mini-cars, a new step for such vehicles may be considered beneficial not only for the environment but also for the environmental image of these vehicles.

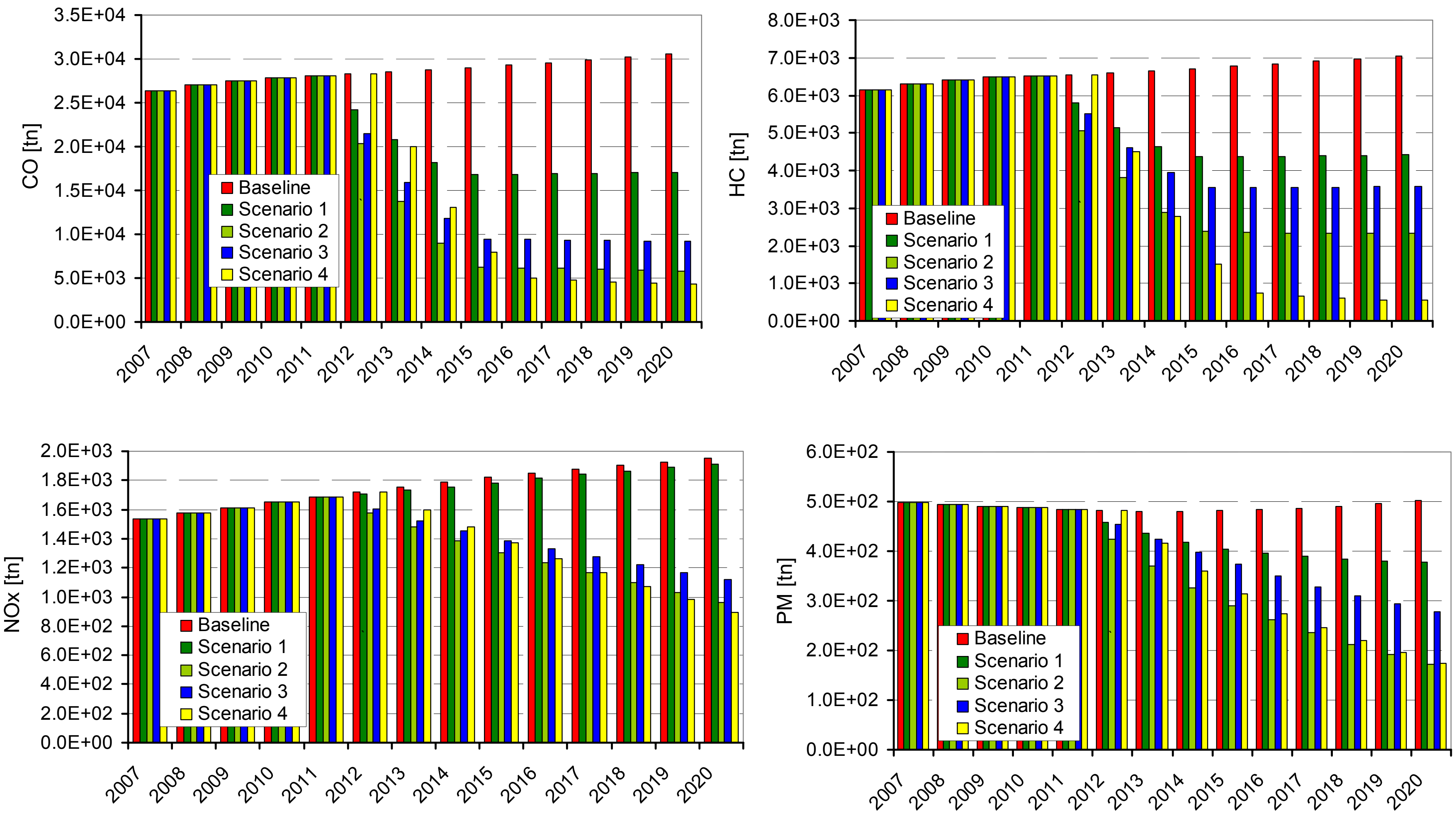


Figure 3-31: Estimated evolution of regulated pollutants and PM from tri- and quadricycles in EU15 according to the different scenarios

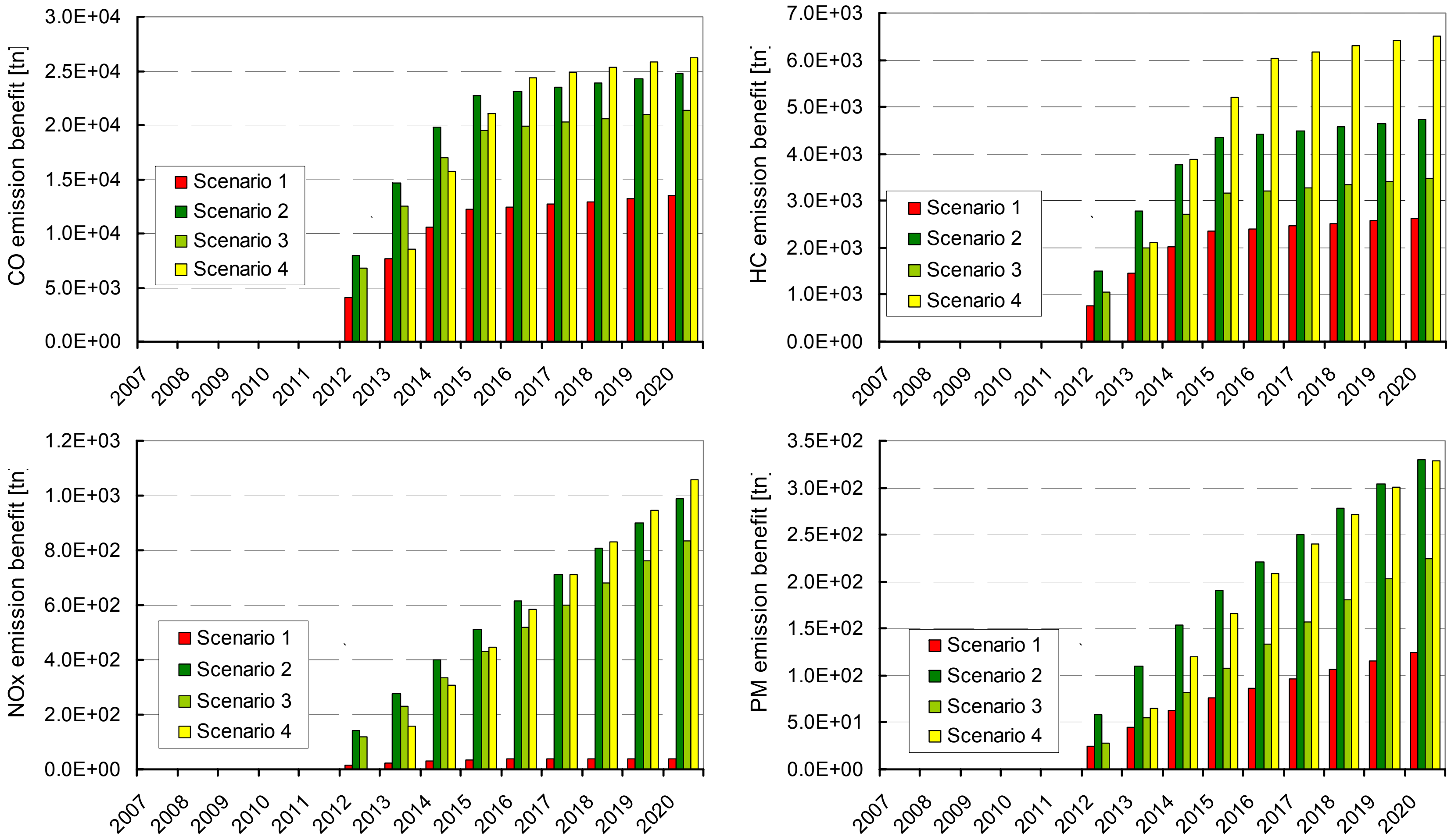


Figure 3-32: Estimated emission benefit of regulated pollutants and PM from tri- and quadricycles in EU15 according to the different scenarios

4 Framework for the emission regulation of PTWs

4.1 Impact of European regulation in other parts of the world

4.1.1 Stock sizes

Although motorcycles in Europe are an important contributor to total annual veh.km conducted by road vehicles, the stock of such vehicles is rather small compared to the numbers in several Asian countries. Just to put it into perspective, Table 4-1 shows the fleet of PTWs in different parts of the world. We need to clarify that, for Asian countries, these are best-guess estimates by experts in the individual countries as significant uncertainties exist with regard to actual number of two-wheelers. In particular, the stock of mopeds may be significantly underestimated in the table, as registration data are scarce. However, the table should more or less accurately represent the order of magnitude of stock size.

Table 4-1: Stock size of PTWs in different parts of the world (Acronyms: VMEW stands for the Vietnam Motorcycle Emissions Workshop, March 6, 2007; AISI is the The Indonesian Motorcycle Industries Association, NHTSA is the National Highway Transport and Safety Authority in USA and Abraciclo is the association of Brazilian motorcycle importers association).

Country	Stock size (mil)	Source
China	51	VMEW
India	48	VMEW
EU	31	ACEM
Indonesia	29	AISI Indonesia
Thailand	18	VMEW
Vietnam	16	VMEW
Japan	13	JAMA
Brazil (>50 cc)	12.5	Abraciclo
Malaysia	6	VMEW
US	4.5	NHTSA
Pakistan	2	VMEW

However, further to absolute level of stock sizes, some additional quality factors give the dimension of the importance of power-two-wheelers in some of the Asian countries:

- There is far higher PTWs than passenger car ownership;
- In some Asian cities (e.g. Anoi) there are more than one mopeds, at an average, per household;

- PTWs are responsible for 50-60% of the total annual veh-km, followed by bicycles and then by other means of transportation;

- There has been a strong growth in the number of PTWs, which is actually centrally promoted to avoid high energy costs of passenger car operation.

The growth of the PTWs market is expected to continue in the future due to the strong GDP increase rates in these countries. This big potential is mostly served by low-cost local manufacturers and Japanese models. Few (mainly high-end) European manufacturer models are available. These observations demonstrate the importance of the PTW sector and emission contribution to local air quality in Asian cities. Effective legislation of moped and motorcycle emissions is therefore even more necessary in these parts of the world, compared to the European conditions, to preserve adequate air quality levels in these countries.

The situation in the American continent is different and rather diverse compared to the North and South American countries. In USA and Canada, motorcycles are rarely used for urban commuting but are rather used for leisure on highway and rural roads. There has been some tendency in some of the US cities (e.g. New York) to promote scooters for commuting within the city but still the contribution of two-wheelers to the total mobility activity is negligible. As a result, the importance of PTWs in urban air quality is limited.

On the other hand, PTWs are more important in South America. Although again detailed data on stock size are rather scarce in these countries, Table 4-1 shows the example of motorcycles (>50 cc) in Brazil, which reach about 12.5 mil. vehicles. The situation in these countries is not as severe as in Asian cities but PTWs do have an important share of total activity, much more than the average European conditions. As a result, again the need for effective regulation is prominent to retain acceptable air quality conditions.

Looking at the perspectives for the stock size evolution in the rest of the world, this is considered to further increase in the future. Just to give an example of PTW stock increase rate, Figure 4-1 shows the growth of PTW stock in Vietnam. The fleet has been quadrupled within 10 years as a result of the recovering GDP. Although it is difficult to imagine that the same growth rate will continue in the future (this would bring significant congestion problems even for motorcycles), PTWs are a very suitable means of transportation for the ambient and social conditions in Asian cities. Therefore, there are clear indications hat the stock will continue to grw, increasing the importance of PTWs on local emission inventories.

4.1.2 Legislation

While most countries currently refer to EU test methods and standards, there are several countries that have developed and implemented alternative legislation. But even in the countries where EU standards are applied different PTW legislation with regard to exhaust limits as well as additional measures could possibly be effective. Therefore data about the present and notably the future legislation applied in other countries or regions of the world are of importance – with particular interest for USA, Japan, India, and China – when considering future actions on European level.

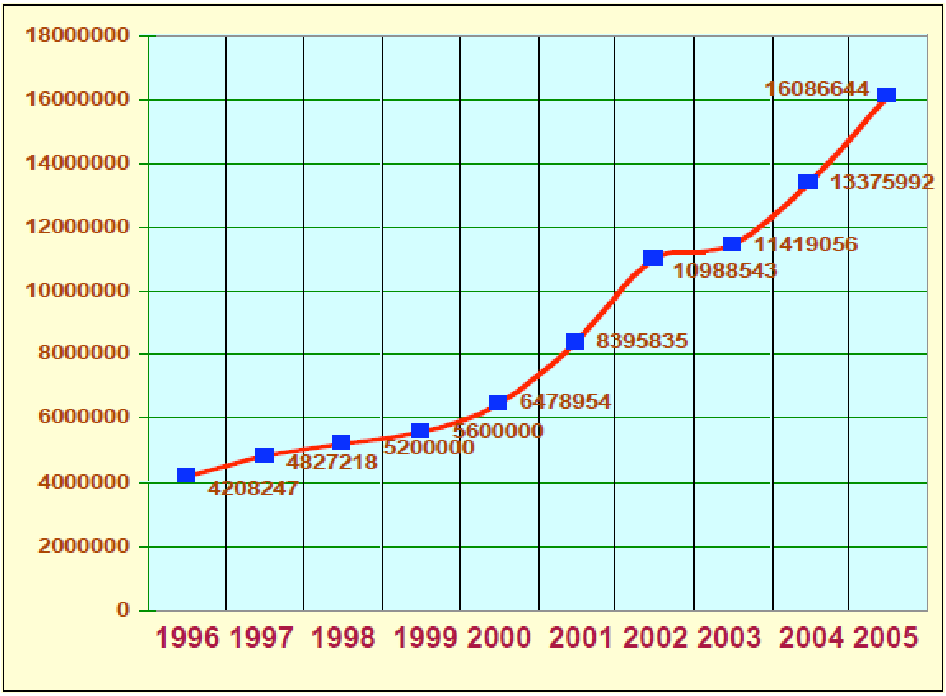


Figure 4-1: Growth of PTW stock size in Vietnam (Source: Le, 2007. Urban Air Pollution caused by transportation and Motorcycles Emissions Control solutions for major cities, Vietnam Motorcycle Emissions Workshop)

These data – based on information coming from manufacturers, associations and national or international organisations as well as from a literature research – are summarised in Table 4-3 and Table 4-4, together with the data concerning the European Union. The first table reflects the situation in the European Union, USA, California and Japan, whereas the second table shows the status in India, China, China Beijing, Thailand, Taiwan, Korea and Singapore.

Although there is a significant number of more or less different PTW emission legislation throughout the world with partly dissimilar test requirements concerning for instance limit values or driving cycles of mopeds or motorcycles only few countries have implemented one or a small number of the available supplementary measures in their current or foreseen motorcycle legislation programmes.

In the case of China for example, in addition to emission regulation China has enforced fuel economy limits (GB/T 15744-1995, GB/T 16486-1996). The test procedure consists of a combination of a driving cycle (ECE-R47, Test 1) and a constant speed test (Test 2) and the fuel consumption is weighted 60% over the driving cycle and 40% over the steady speed test. Then, depending on the PTW size, fuel consumption should not exceed the values of Table 4-2. Moreover, China has introduced durability requirements distinguished in three motorcycle categories (<150cc, >150cc and 130 km/h, and >150cc and >130 km/h), The durability distances concerned have been 12000 km, 18000 km, and 30000 km, respectively. Moped durability is also estimated at 10000 km. Finally, China has also introduced evaporation control of motorcycles with a total HC value of 2 g/test.

Table 4-2: Fuel consumption limits for motorcycles in China. Top row is engine capacity (in ml) and bottom row is fuel consumption limit in l/100 km.

排量 mL	>50~100	≥100~150	≥150~250	≥250~400	≥400~650	≥650~1000	≥1000
限值 L/100km	2.5	2.8	3.2	3.8	5.8	7.0	8.0

India has also introduced strict emission standards, based on the Indian driving cycle. In addition to this, a roadworthiness verification, including CO and HC emission control is required every six months for each PTW. Although this would be a very effective measure to control emissions, several real-world problems have appeared in its application. These problems are associated with the frequency of the test as well as with the education of the drivers and the technical personnel in running the test. The use of good quality (JASO-FC synthetic) lube oil is also mandated for all 2S vehicles.

In Indonesia, the ECE-R40 cycle is used for type-approval, using more relaxed emission standards compared to Europe (4.5 g/km of CO and 3 g/km of HC since Jan 2006). There are some thoughts to introduce a roadworthiness procedure with a limit value of 4.5% CO at idle. Japan also uses the Trias driving cycle, which is the ECE-R40 driving cycle with modified gear-shift points. The emission limits which are applicable in Japan since 2008 for motorcycles follow the Euro 3 emission limits albeit a modified driving cycle and a stricter HC limit for small (<125 cc) motorcycles.

Summarising, 'evaporative emissions' are controlled in California, Thailand, Taiwan and Singapore with a limit of 2 g/test (status: 2008). Test details may differ from country to country. Durability requirements have also been established both for mopeds and/or motorcycles. The durability distances differ with the region and the motorcycle size concerned, but generally range between $10\text{-}30\times10^3$ km, increasing with engine capacity. Durability requirements have been established in California, China, federal USA, India, Japan, Korea, Taiwan, and Thailand.

4.1.3 Conclusions on the impact of European regulation

The conclusions that can be reached from a look on global developments of PTW regulation, can be summarized in the following points:

1. Regulations in most Asian countries (>80% of global stock) are generally based on the European legislation, with regard to driving cycle and emission standards.

2. The same applied to Latin America as well.

3. In most cases, there is a time delay in the introduction of emission standards for a few years, compared to the European implementation date. Lately, countries have started catching up, as the European regulatory measures beyond Euro 3 emission standards have not been implemented yet.

4. Most countries use some version of the ECE-R40 cycle for type approval testing. Different versions of the driving cycle (gear change, cold-start, motorcycle class distinction, etc.) lead to some confusion with regard to the correspondence and equivalency of the emission standard values.

5. Some countries have further advanced compared to Europe in some areas (examples):

   - India & Taiwan have already introduced a durability test procedure and a roadworthiness procedure based on idle CO and HC measurement.

   - China has introduced a fuel economy certification test.

   - Taiwan and Thailand have introduced an evaporation test

Therefore, the impact of the European on global regulation may be summarized to the following points:

- European motorcycle legislation has strong impacts on Asian markets with respect to emission standard values and procedures
- Delays in integrating additional measures leads Europe in loosing the lead of emission regulation
- Complicated / advanced measures may not work in Asian countries due to organisation and mentality particularities. This refers in particular to:
  - OBD effectiveness, as limited respect to MIL warnings is expected, as long as the vehicle is fully operational. Therefore the effectiveness of OBD to identify malfunctions will not be followed by an effective procedure to repair these malfunctions.
  - In-use conformity ill be difficult to enforce as several vehicles are expected to operate on various fuels after their registration. Hence, collecting a sample which is within the manufacturer specifications may be difficult to achieve.
- Measures at manufacturer-level which require minimum user intervention (e.g. durability requirements) are expected to be more effective from a practical (real-world) point of view.
- Based on the history of global emission regulation evolvement, complementation of the current Euro 3 emission standards with additional measures but also proposal of standards at Euro 4 level are expected to also exert more pressure on Asian authorities to control national fleets.

Region	Category [cc]	Cycle Strokes	No. of Wheels	Emission Standards [g/km] Stage	CO	HC	NO_X	PM	Driving Cycle	Cold Start	Idle Test CO[%]	Idle Test HC [ppm]	Durability Test [km]	IUC	EVAP [g/test]	CO_2/FC	OBD
EU	< 50	2&4	2	2002	1.00	1.20			ECE-R47	no	4.5						
		2&4	3&4	2002	3.50	1.20											
	50-149	2&4	2	2006	2.00	0.80	0.15		ECE-R40	yes							
		2&4 SI	3&4	2003	7.00	1.50	0.40			no							
		2&4 CI	3&4	2003	2.00	1.00	0.65										
	≥ 150	2&4	2	2006	2.00	0.30	0.15		ECE-R40+ EUDC	yes				m	m	m	m
		2&4	2[a]	2006	2.62	0.75	0.17		WMTC	yes							
		2&4	2[b]	2006	2.62	0.33	0.22										
		2&4 SI	3&4	2003	7.00	1.50	0.40		ECE-R40	no							
		2&4 CI	3&4	2003	2.00	1.00	0.65										
USA 49 states	< 50	2&4	2&3	2006	12.00	1.00			Modified FTP-75	yes			6 000				
	50-169	2&4	2&3	2006									12 000				
	170-279	2&4	2&3	2006					FTP-75				18 000				
	> 280	2&4	2&3	2006		1.40							30 000				
		2&4	2&3	2010		0.80							30 000				
USA Calif.	50-169	2&4	2&3	1982	12.00	1.00			Modified FTP-75	yes			12 000		2		
	170-279	2&4	2&3	1982					FTP-75				18 000				
	> 280	2&4	2&3	2008		0.80							30 000				
Japan	< 50	2	2&3	1998	8.00	3.00	0.10		ISO 6460	no	4.5		6 000				
		4	2&3	1998	13.00[c] 20.00[d]	2.00[c] 2.93[d]	0.33[c] 0.51[d]			no	4.5		6 000				
	50-125	2	2&3	1999	8.00	3.00	0.10			no	4.5	2 000	8 000				
		4	2&3	1999	13.00[c] 20.00[d]	2.00[c] 2.93[d]	0.33[c] 0.51[d]			no	4.5		8 000				
	125-250	2	2&3	1999	8.00	3.00	0.10			no	4.5	2 000	12 000				
		4	2&3	1999	13.00[c] 20.00[d]	2.00[c] 2.93[d]	0.33[c] 0.51[d]			no	4.5		12 000				
	> 250	4	2&3	1999	13.00[c] 20.00[d]	2.00[c] 2.93[d]	0.33[c] 0.51[d]			no	4.5						
				09/2008	2.00[c] 2.70[d]	0.3[c] 0.4[d]	0.15[c] 0.20[d]		ECE-R40+ EUDC	no	4.5						

Table 4-3: PTW emission standards in the European Union, USA 49 States, USA California and Japan (corresponding legend see Table 4-4)

Region	Category [cc]	Cycle Strokes	No. of Wheels	Emission Standards [g/km]: Stage	CO	HC	NO_X	PM	Driving Cycle	Cold Start	Idle Test: CO[%]	Idle Test: HC [ppm]	Durability Test [km]	IUC	EVAP [g/test]	CO_2/FC	OBD
India	all	2&4	2	2005	1.50[e]	1.50[e]			IDC	yes	3.5	6 000[h] 4 500[i]	30 000				
		2&4	2	2008/10	1.00[e]	1.00[e]					3.5						
		2&4 SI	3	2005	2.25[e]	2.00[e]					3.5						
		2&4 SI	3	2008/10	1.25[e]	1.25[e]					3.5						
		2&4 CI	3	2005	1.00[f]	0.85[f]		0.10[f]			3.5						
		2&4 CI	3	2008/10	0.50[f]	0.50[f]		0.05[f]			3.5						
China	≤ 50	2&4	2	2005	1.00	1.20			EC-R47	no			10 000	l	l	yes	
		2&4	2	07/2008	1.00	1.20				no			10 000				
		2&4	3	2005	3.50	1.20				no			10 000				
		2&4	3	07/2008	3.50	1.20				no			10 000				
	> 50	2&4	2	2004	5.50	1.20	0.30		ECE-R40	no			10 000				
		2&4	3	2004	7.00	1.50	0.40			no			10 000				
	50 - 149	2&4	2	07/2008	2.00	0.80	0.15		ECE-R40				12 000				
	≥ 150	2&4	2	07/2008	2.00	0.30	0.15		ECE-R40 + EUDC	yes			18 000[a] 30 000[b]				
China Beijing	all	2		2004	3.50	2.00			ECE-R40		1.5	3 000	15 000				
		4		2004	3.50	2.00					1.5	300	15 000				
Thailand	< 150	2&4	2&3	2008	2.00	0.80	0.15		ECE-R40	no			j	yes	2		
	≥ 150	2&4	2&3	2008	2.00	0.30	0.15										
Taiwan	< 150	2&4	2	2007	2.00	0.80	0.15		ECE-R40 + EUDC	yes	1.5	3 000	15 000		2	yes	
	> 150		2	2007	1.43[g]	0.21[g]	0,11[g]			yes	1.5						
Korea	< 50	2&4			8.00	4.00	0.10		ECE-R47	no			6 000				
	> 50	2			8.00	4.00	0.10		ECE-R40				6 000				
	> 50	4			13.00	3.00	0.30						6 000				
Singapore	all				12.00	5.00			FTP						2		

[a] $V_{max} <$ 130 km/h
[b] $V_{max} \geq$ 130 km/h
[c] Mean Value
[d] Max. Value
[e] Incl. Deterioration Factor of 1.2
[f] Incl. Deterioration Factor of 1.1
[g] Incl. Deterioration Factor of 1.4
[h] 2-stroke
[i] 4-stroke
[j] 50-169 cc: 12 000; 170-269 cc: 18 000; >270 cc: 30 000
[l] foreseen
[m] under discussion in MVEG motorcycle subgroup

SI = Spark Ignition
CI = Compression Ignition

Table 4-4: PTW emission standards in India, China, China Beijing, Thailand, Taiwan, Korea and Singapore

4.2 New WMTC correlation factors

4.2.1 EU vehicle classification and driving schedule

With directive 2002/51/EC (July 19, 2002) a second stage of emission limits for motorcycles was established as amendment of directive 97/24/EC, together with emission standards for a Euro 3 regulation. From EURO 2 stage onwards the vehicle classification is purely based on engine capacity and covers just 2 classes:

Class 1: < 150 cm³,

Class 2: >= 150 cm³

The driving schedule for class 1 is the urban driving cycle (UDC) as shown in Figure 4-2, the driving cycle for class 2 has an additional extra urban part (see Figure 4-3). The measurements of exhaust emissions start right at the beginning of the cycles with the vehicle in cold condition. The average speeds, max. speeds and max. acceleration values are shown in Table 4-5. It can be stated that these cycles do not represent typical motorcycle driving behaviour, even for class 1 vehicles.

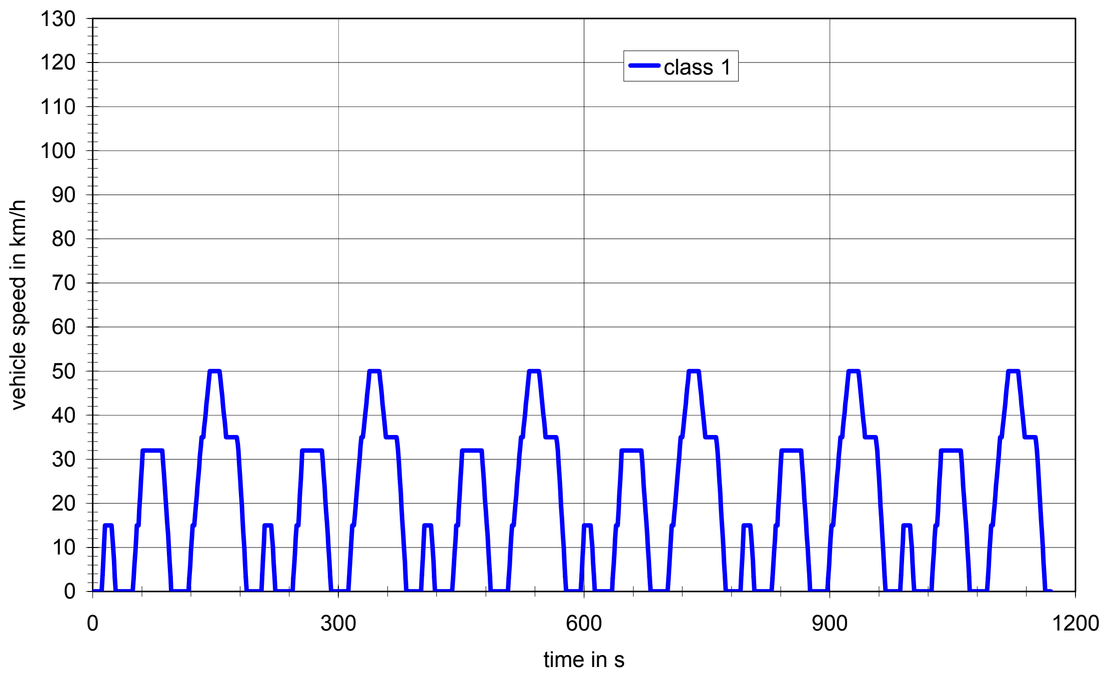


Figure 4-2: European driving cycle for class 1 motorcycles

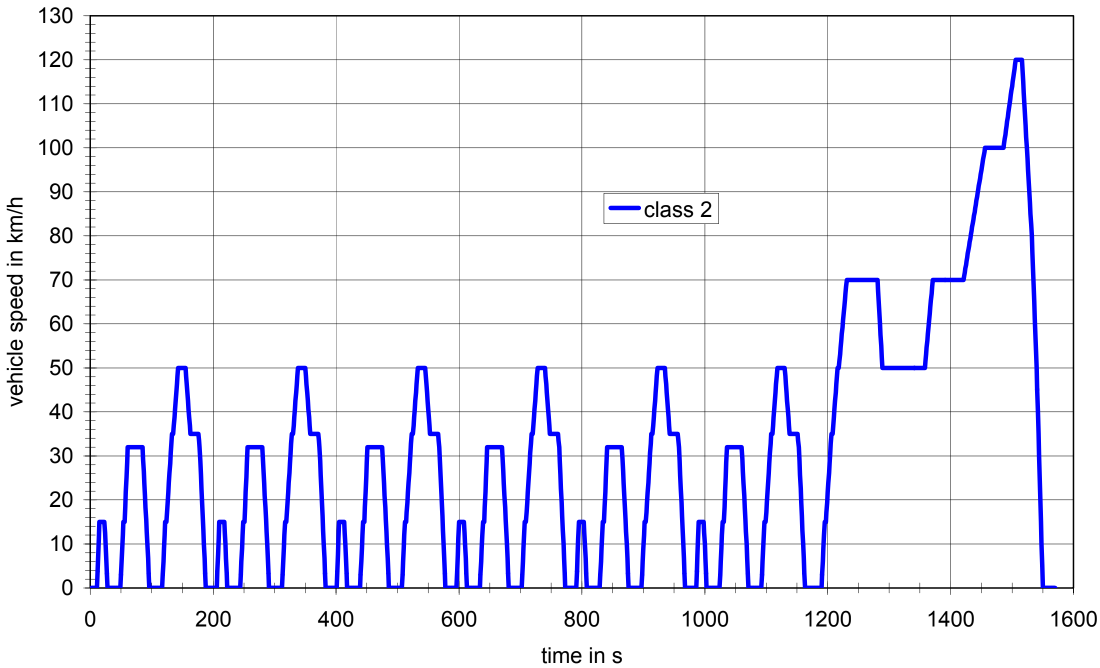


Figure 4-3: European driving cycle for class 2 motorcycles

Table 4-5: Average speed, max. speed and max. acceleration values for the driving cycles of the 2 European motorcycle classes

class	v_ave in km/h	v_max in km/h	a_max in m/s²
1	18.7	50	1.06
2	29.9	120	1.06

4.2.2 WMTC classification and driving schedule

4.2.2.1 GTR 2 from August 2005

Mandated by ECE WP 29 the GRPE working group WMTC developed a new worldwide harmonised motorcycle emissions certification procedure with regard to the emission of gaseous pollutants, the emission of CO2 and fuel consumption. This work resulted in Global Technical Regulation (GTR) 2 and is described in ECE TRANS/180/Add2 from 30. August 2005.

The procedure contains a vehicle classification, a test bench driving schedule divided into 3 parts, gearshift prescriptions and weighting factors for the calculation of the final results. The 3 cycle parts represent urban, rural and fast rural/motorway operation of the vehicles.

The vehicle classification covers 3 classes based on engine capacity and maximum vehicle speed as follows (GTR 2, 08/2005):

- Class 1: Vehicles that fulfil the following specifications belong to class 1

  - subclass 1-1: engine capacity ≤ 50 cm³ and 50 km/h < vmax ≤ 60 km/h,
  - subclass 1-2: 50 cm³ < engine capacity < 150 cm³ and vmax < 50 km/h,
  - subclass 1-3: engine capacity < 150 cm³ and 50 km/h ≤ vmax < 100 km/h, but not including subclass 1-1.
- Class 2: Vehicles that fulfil the following specifications belong to class 2
  - subclass 2-1: engine capacity < 150 cm³ and 100 km/h ≤ vmax < 115 km/h or engine capacity ≥150 cm³ and vmax < 115 km/h,
  - subclass 2-2: 115 km/h ≤ vmax < 130 km/h .
- Class 3: Vehicles that fulfil the following specifications belong to class 3
  - subclass 3-1: 130 ≤ vmax < 140 km/h,
  - subclass 3-2: vmax ≥ 140 km/h.

The test cycle for the Type I test consists of up to three parts (see Figure 4-4 to Figure 4-6). Depending on the vehicle class the following test cycle parts have to be run (GTR 2, 08/2005):

- Class 1:
  - Subclasses 1-1 and 1-2: part 1, reduced speed in cold condition, followed by part 1, reduced speed in hot condition.
  - Subclass 1-3: part 1 in cold condition, followed by part 1 in hot condition.
- Class 2:
  - Subclass 2-1: part 1 in cold condition, followed by part 2, reduced speed in hot condition.
  - Subclass 2-2: part 1 in cold condition, followed by part 2 in hot condition.
- Class 3:
  - Subclass 3-1: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3, reduced speed in hot condition.
  - Subclass 3-2: part 1 in cold condition, followed by part 2 in hot condition, followed by part 3 in hot condition.

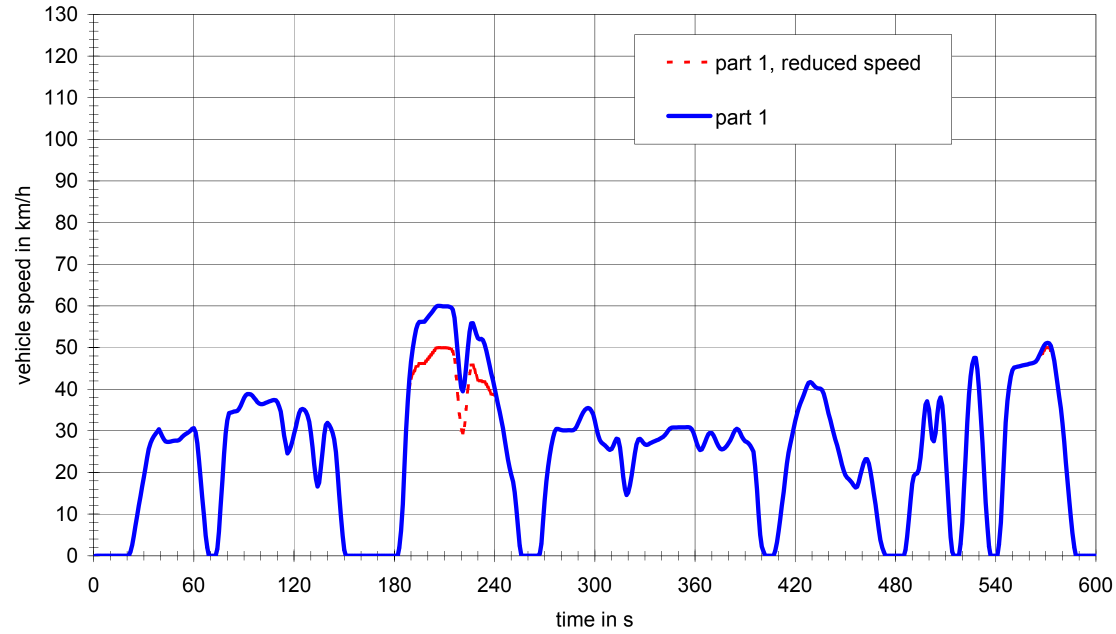


Figure 4-4: Cycle part 1, GTR 2, 08/2005

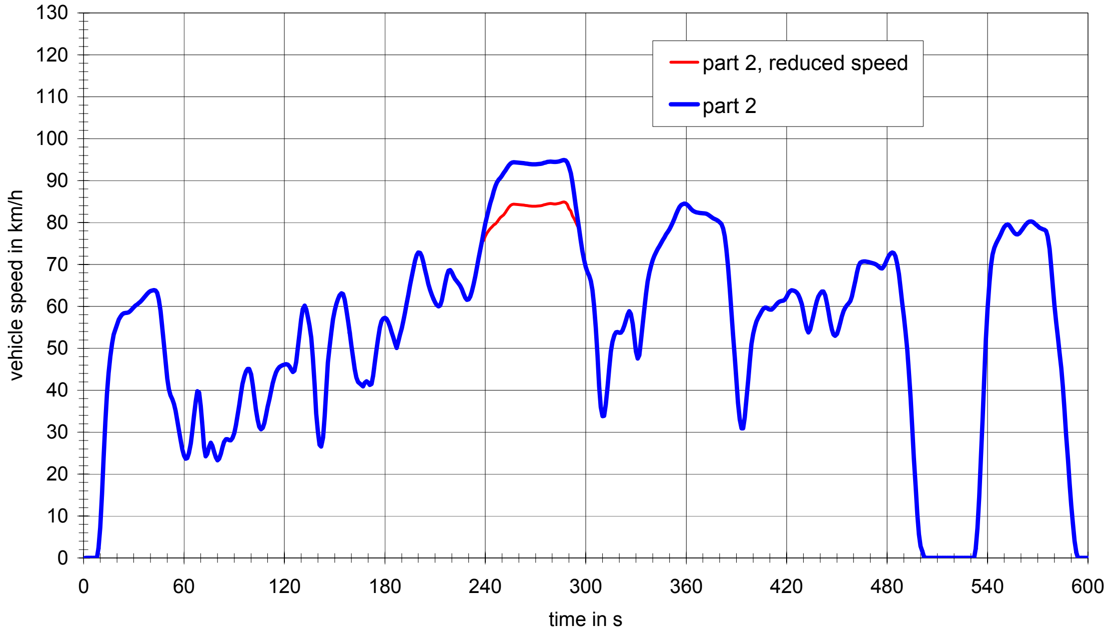


Figure 4-5: Cycle part 2, GTR 2, 08/2005

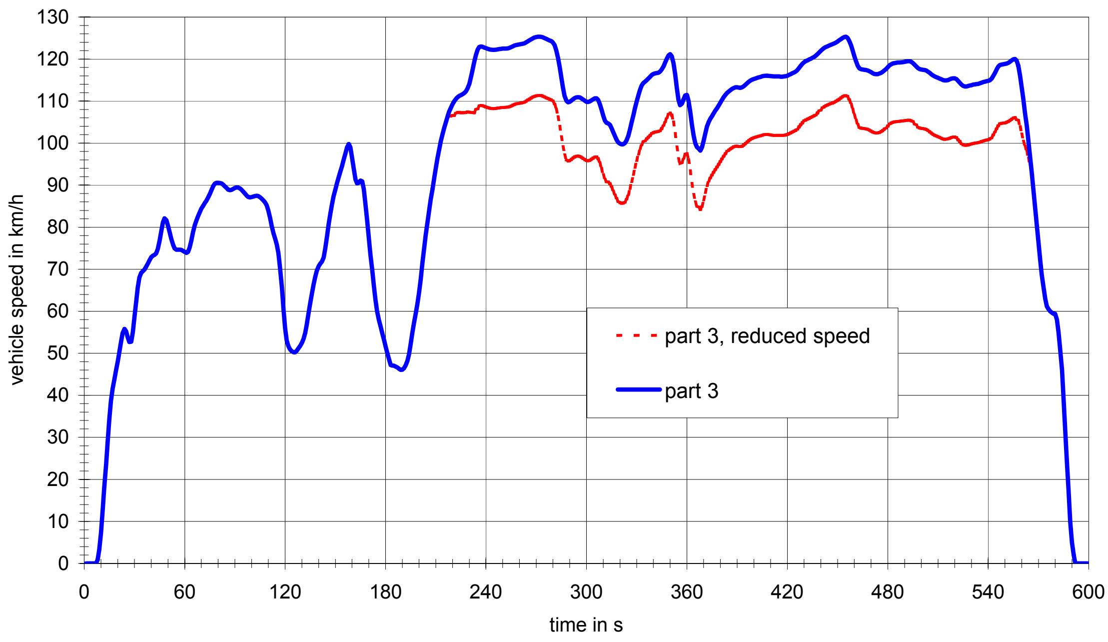


Figure 4-6: Cycle part 3, GTR 2, 08/2005

The weighting factors for the final emission and fuel consumption results are shown in the following table.

Table 4-6: Weighting factors for the calculation of the final emission and fuel consumption results

Vehicle class	Cycle	Weighting	
Class 1	Part 1, cold	w_1	50 per cent
	Part 1, hot	w_{1hot}	50 per cent
Class 2	Part 1, cold	w_1	30 per cent
	Part 2, hot	w_2	70 per cent
Class 3	Part 1, cold	w_1	25 per cent
	Part 2, hot	w_2	50 per cent
	Part 3, hot	w_3	25 per cent

4.2.2.2 Amendment of GTR 2 from January 2008

At its April 2006 meeting, WMTC/FEG (mandated by WP29) agreed to prepare new test cycle proposals and a new vehicle classification for draft amendments to the GTR in order to suit low-powered vehicles, such as commonly used in India and China. The following work resulted in Amendment 1 to GTR No. 2 from January 2008 (ECE/TRANS/180/Add.2/Amend.1) covering the following modifications to the vehicle classification and the driving cycles.

- Class 1:
  - o 50 cm³ < engine capacity < 150 cm³ and vmax < 50 km/h, or
  - o engine capacity < 150 cm³ and 50 km/h ≤ vmax < 100 km/h.

The Classes 2 and 3 remain unchanged.

The test cycles part 1 and 2 were amended as shown in Figure 4-7 and Figure 4-8. Depending on the vehicle class the following test cycle parts have to be run (Amendment 1 to GTR 2, July 2007):

- Class 1:
  - o part 1, reduced speed in cold condition, followed by part 1, reduced speed in hot condition.
- Class 2:
  - o Subclass 2-1: part 1, reduced speed in cold condition, followed by part 2, reduced speed in hot condition.
  - o Subclass 2-2: part 1 in cold condition, followed by part 2 in hot condition.

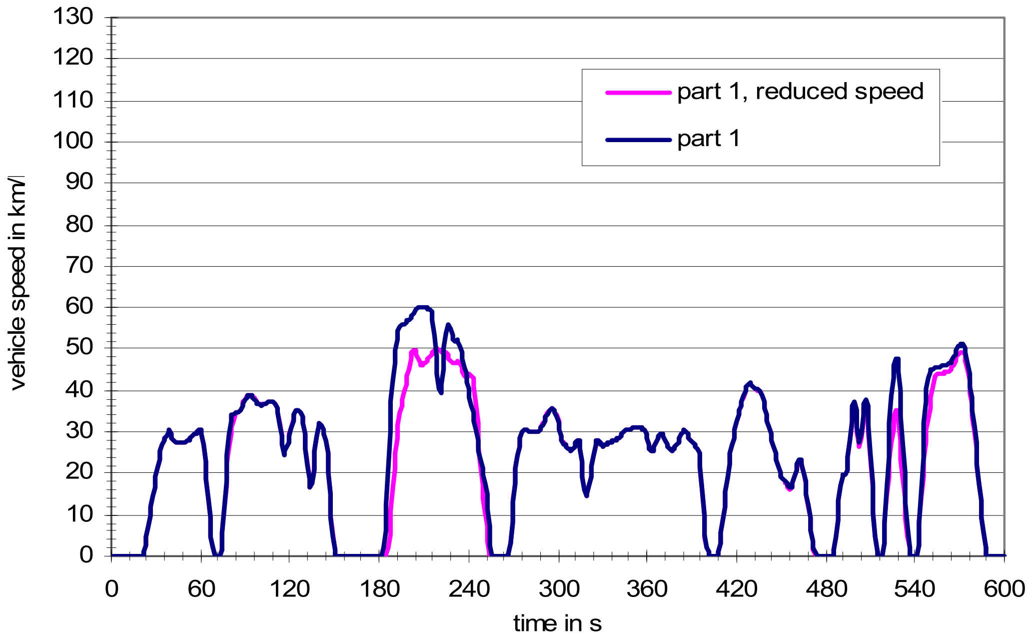


Figure 4-7: Cycle part 1, GTR 2, 01/2008

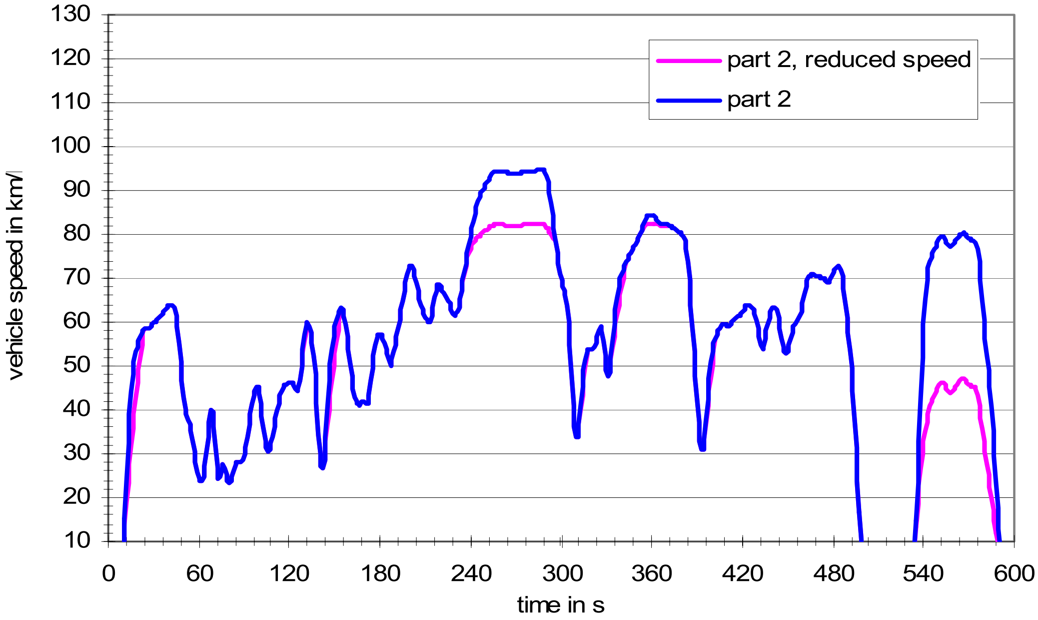


Figure 4-8: Cycle part 2, GTR 2, 01/2008

The requirements for class 3 and the cycles for part 3 remain unchanged. The changes for the cycle parts 1 and 2 are related to the reduced speed versions only. The differences in average and max. speed and max. acceleration are shown in Table 4-7. These cycles are much more representative for motorcycle driving behaviour than the European driving cycles (EDC).

Table 4-7: Average speed, max. speed and max. acceleration values for the different cycle parts and versions of the WMTC

version	part	v_ave in km/h	v_max in km/h	a_max in m/s²
GTR 2, March 2004	1	24.4	60.0	2.51
	1, reduced speed	23.6	50.0	2.51
	2	54.7	94.9	2.68
	2, reduced speed	53.8	84.9	2.68
	3	94.4	125.3	1.56
	3, reduced speed	86.6	111.3	1.56
Amendm. 1, GTR 2, January 2008	1	24.4	60.0	2.51
	1, reduced speed	23.0	50.0	1.72
	2	54.7	94.9	2.68
	2, reduced speed	50.6	82.5	1.77
	3	94.4	125.3	1.56
	3, reduced speed	86.6	111.3	1.56

The weighting factors for the calculation of the final results remained unchanged.

It should also be mentioned that the gearshift prescriptions have been amended. The amendment is mainly related to phase indicators (acceleration, cruise, deceleration) and additional requirements. They are intended to improve driveability and will not significantly influence the emissions results. The amendments are described in the GRPE document ECE-

TRANS-WP29-GRPE-2009-02e. The formal adoption of the amendment by GRPE can be expected for the meeting in January 2009.

4.2.3 Assessment of the correlation factors between EDC and WMTC

4.2.3.1 Correlation factors for EDC and WMTC GTR 2, 08/2005

With directive 2005/51/EC directive 97/24/EC was amended introducing the emission standards EURO 2 and EURO 3 for motorcycles. Limit values and cycles are shown in Table 4-8. With directive 2006/72/EC equivalent limit values were added based on the WMTC cycles of GTR 2, 08/2005. These limit values and the corresponding correlation factors in relation to the EDC are also listed in Table 4-8. It is the manufacturer's choice on which cycles the type approval measurements shall be based. The correlation factors are based on a JRC proposal from 2005 that was elaborated for the discussions in the MVEG ad-hoc group on motorcycles [6]. The table also shows the initial JRC proposal of 2003, which was based on the 2002/51/EC vehicle classification, as summarized in Moto_90 file.

Table 4-8: Pollutant emissions limit values for motorcycles and correlation factors WMTC/EDC

Directive	Emission stage	Motorcycle class	Cycle	Limit values in g/km			Enforcement date
				CO	HC	NOx	
97/24/EC	EURO 1	2-stroke	UDC hot	8	4	0.1	1999
		4-stroke	UDC hot	13	3	0.3	
2002/51/EC	EURO 2	< 150 cm^3	UDC hot	5.50	1.20	0.30	2003
		>= 150 cm^3	UDC hot	5.50	1.00	0.30	
	EURO 3	< 150 cm^3	UDC cold	2.00	0.80	0.15	2006
		>= 150 cm^3	UDC + EUDC cold	2.00	0.30	0.15	
2006/72/EC		v_max < 130 km/h	WMTC	2.62	0.75	0.17	
		v_max >= 130 km/h	WMTC	2.62	0.33	0.22	
			correlation factors	1.310	0.938	1.133	
			WMTC/EDC	1.310	1.100	1.467	
	JRC proposal, 2003	< 150 cm^3	WMTC	2.42	0.74	0.21	
		>= 150 cm^3	WMTC	2.42	0.33	0.21	
			correlation factors	1.210	0.925	1.400	
			WMTC/EDC	1.210	1.100	1.400	

4.2.4 Influence of amendments of GTR 2 (ECE/TRANS/180/Add.2/Amend.1) on the correlation factors

The first point that has to be mentioned is the fact that the vehicle classification of 2006/72/EC and WMTC GTR 2, Amend. 1 are not compatible. The EU-class 1 (< 150 cm^3) covers vehicles of class 1 and class 2 of the GTR 2. The EU-class 2 (>=150 cm^3) covers vehicles of class 2 and 3 of GTR 2.

Data from KBA statistics of type approval data for "Krafträder und Leichtkrafträder" is shown in Table 4-9. It can be concluded that at least for countries having a similar stock distribution as Germany the overlap in class 2 is not so dramatic. The WMTC classes 1 and 2.1 fall completely into EU class 1, the WMTC classes 3.1 and 3.2 completely into EU class 2. Only WMTC class 2.2 has 15% of the vehicle types in EU class 1 and 85% in EU class 2. Furthermore this class has the second lowest frequency and thus is not so important. But this might be different in European regions or member states with different stock distributions.

Table 4-9: Vehicle type distribution fort he different vehicle classification systems

KBA statistics, type appr. Data 2004				
EU_class	**WMTC class, GTR 2, Amend. 1**	**number of vehicles**	**percentage**	
1	1	109	16.4%	
1	2.1	73	11.0%	
1	2.2	7	1.1%	28.5%
2	2.2	39	5.9%	
2	3.1	22	3.3%	
2	3.2	414	62.3%	71.5%
	sum	**664**	100.0%	

The data that is currently available for the assessment of the influence of the amendments of GTR 2 on the correlation factors to the limit values of 2002/51/EC is the IMMA database for the limit value discussions within the ECE WMTC group. This database consists of the data already used in [6] and several new data from 2007 whose measurements are based on the amended cycles and vehicle classification. Unfortunately only 2 new datasets from 2007 are from Europe and can be used for this study. All other datasets from Europe are based on the old cycle versions of GTR 2.

In addition we received the results from 10 vehicles measured in 2007 at EMPA in Switzerland and 4 vehicles from the AECC EURO 3 motorcycle test programme. For these measurements the new WMTC cycles were used. The results were added to the European part of the IMMA database and the data was restructured with respect to the new WMTC vehicle classification. This resulted in the following figures:

WMTC class 1: 5 vehicles, 1 vehicle fulfils EURO 3 limits.

WMTC class 2: 20 vehicles, 10 vehicles in EU class 1 and 10 in EU class 2, no vehicle fulfils EURO 3 limits.

WMTC class 3: 55 vehicles, 37 vehicles with 3way catalyst, 10 vehicles fulfil EURO 3 limits.

Figure 4-9 to Figure 4-11 show the comparison of the results for the 2002/51/EC and the WMTC cycles for NO_x, CO and HC, concerning Class 1 vehicles. The EURO 3 limit values are also indicated on the graphs. The new WMTC cycle was only used for 1 vehicle. The results of this vehicle are shown as yellow circles. They are always below the regression line, so that one can conclude that correlation factors based on the old WMTC cycle are on the safe side. The correlation factors would be 1 for CO, 0.95 for HC, and 1.2 for NO_x. But it must be mentioned that the sample size is still very small.

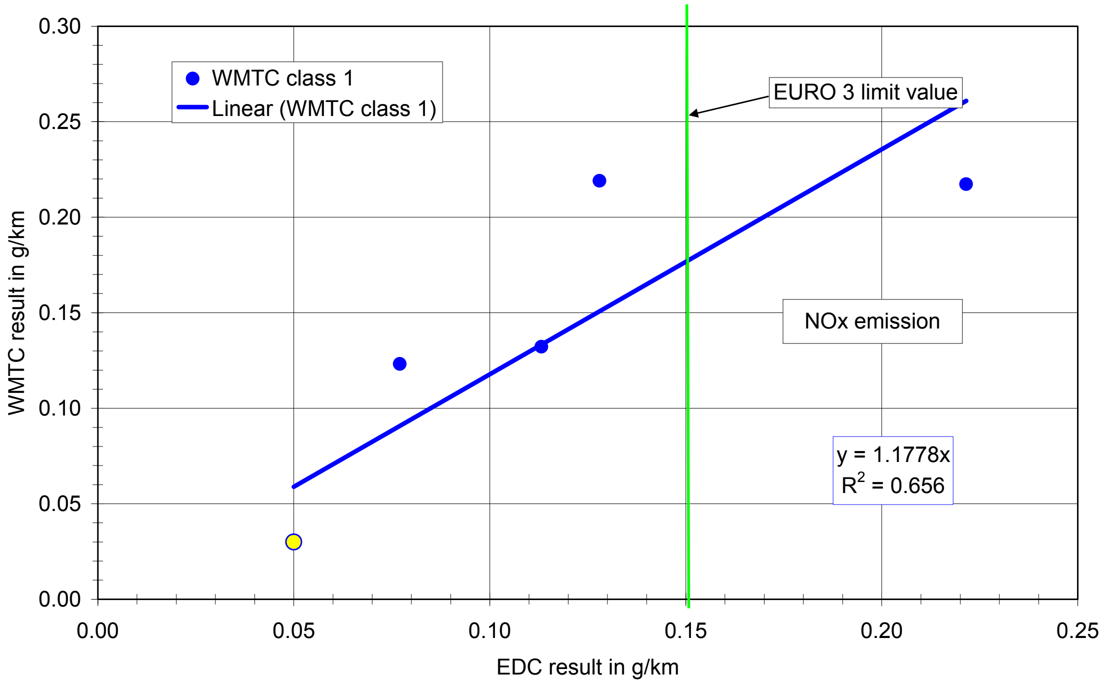


Figure 4-9: WMTC cycle results versus 2002/51/EC cycle (6 UDC cold) results for NO_x, WMTC class 1

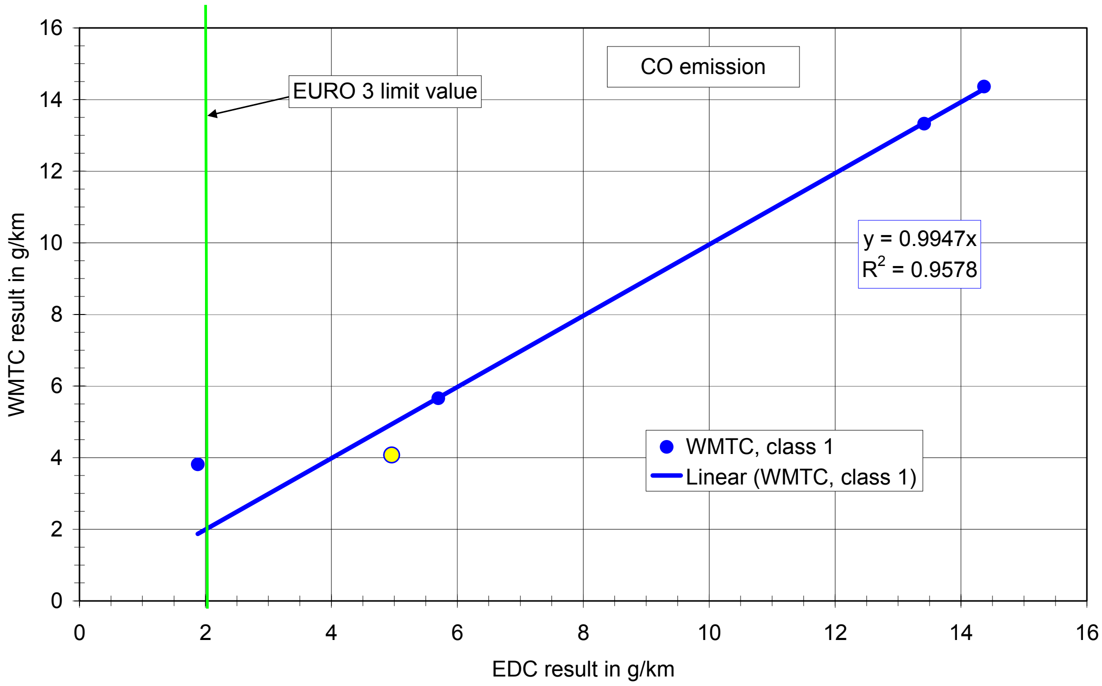


Figure 4-10: WMTC cycle results versus 2002/51/EC cycle (6 UDC cold) results for CO, WMTC class 1

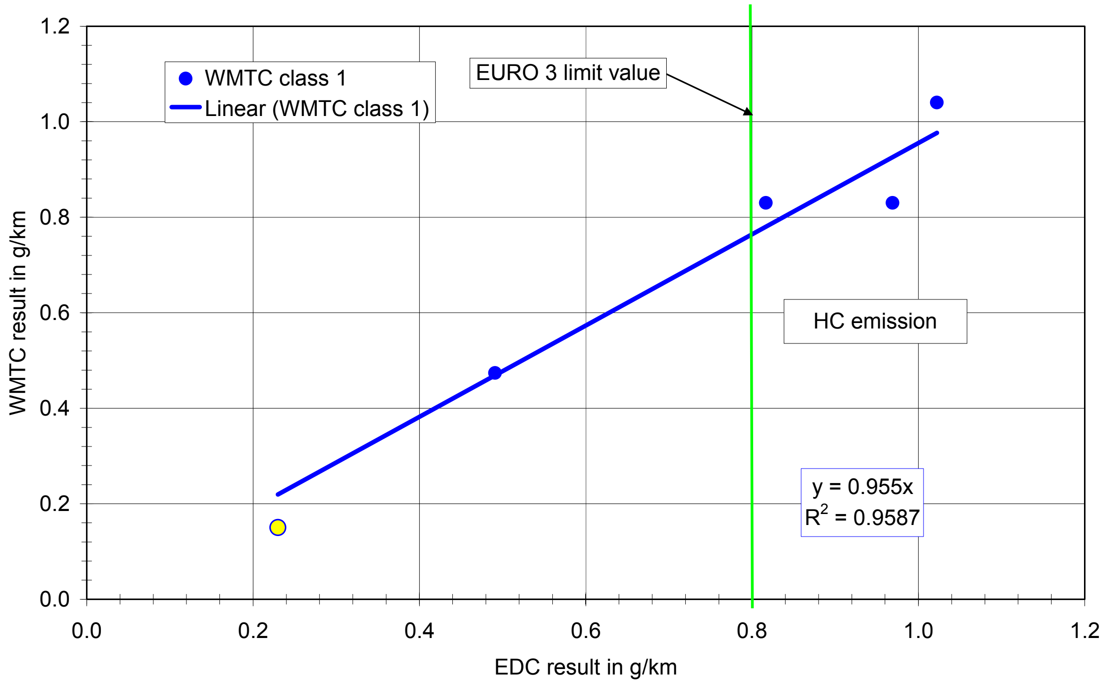


Figure 4-11: WMTC cycle results versus 2002/51/EC cycle (6 UDC cold) results for HC, WMTC class 1

Figure 4-12 to Figure 4-14 show the results for WMTC class 2. In this class all vehicles were measured using the old WMTC cycles. The sample is separated into the 2 EU vehicle classes. Only 4 vehicles fulfil the EURO 3 limit for NO_x, all are in EU class 1. The results for CO show very high emission values (see Figure 4-13). One can conclude that a substantial part of the sample do not fulfil the EURO 2 requirements.

In order to get a clearer picture the results are shown in Figure 4-15 to Figure 4-17 again, but without the high CO emitters. In this case the scatter of the results for NO_x and HC is significantly reduced, but not for CO itself. The correlation factors would be 1.05 for NO_x, 1 for HC and 1.25 for CO if the high WMTC values are not considered.

Figure 4-18 to Figure 4-20 show the results for WMTC class 3. In this case the database is up to date because the WMTC cycles were not modified. But as for WMTC class 2 the sample contains a lot of high emitters. For that reason a second series of pictures was drawn considering only vehicles with 3 way catalysts (see Figure 4-21 to Figure 4-23), which at the same time led to the deletion of the high emitters. The corresponding correlation factors are 1 for HC, 1.4 for NO_x and 1.15 for CO.

The analysis of the results without high CO emitters leads to correlation factors as shown in Table 4-10.

Table 4-10: Correlation factors for the WMTC cycles over the ECE40+EUDC, based on data analysis without high CO emitters

WMTC class	EU class	Correlation factors for		
		CO	HC	NOx
1	< 150 cm³	1.00	1.00	1.20
2	< 150 cm³	1.10	0.80	1.05
2	>= 150 cm³	1.10	1.00	1.05
3	>= 150 cm³	1.15	1.00	1.40

In 2006/72/EC the limit values and thus the correlation factors are defined in relation to maximum vehicle speed classes (< 130 km/h, >= 130 km/h). With respect to the vehicle sample that means that one can put together WMTC classes 1 and 2 for the lower maximum speed class, while WMTC class 3 represents the higher speed class. If a rounding to one digit behind the decimal point is applied this leads to correlation factors as shown in Table 4-11. These values are not so different than the initial JRC values, values resulting from 2006/72/EC.

Table 4-11: Correlation factors for the max. vehicle speed classes defined in 2006/72/EC, based on data analysis without high CO emitters

	Correlation factors for		
v_max	CO	HC	NOx
< 130 km/h	1.1	0.9	1.1
>= 130 km/h	1.2	1.0	1.4

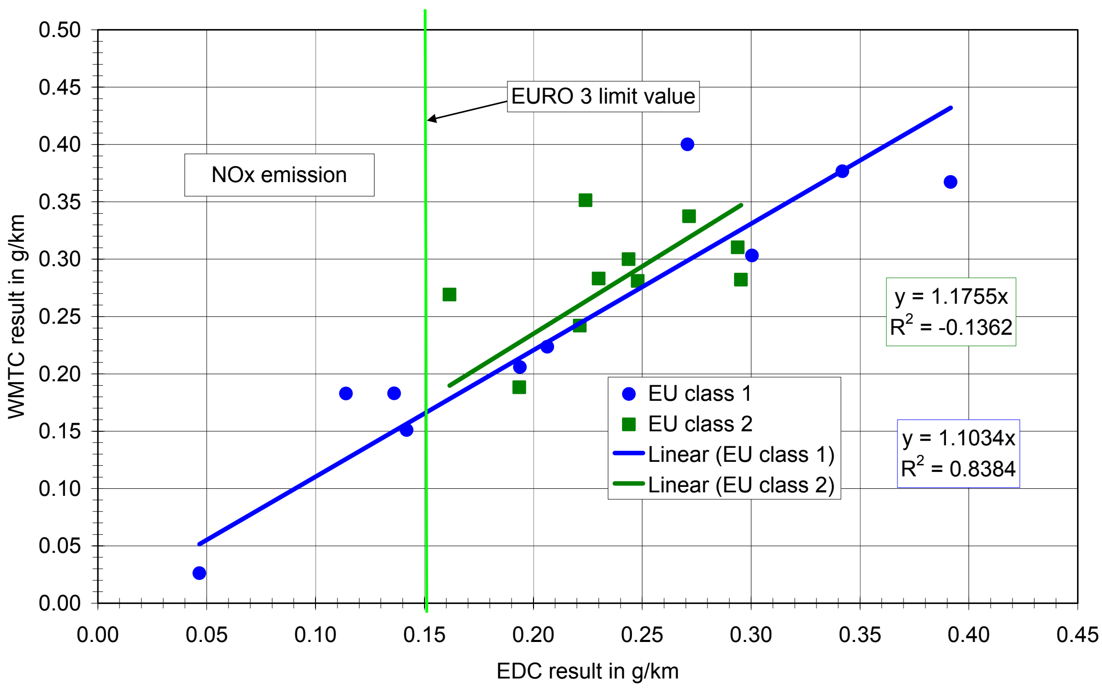


Figure 4-12: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for NO_x, WMTC class 2

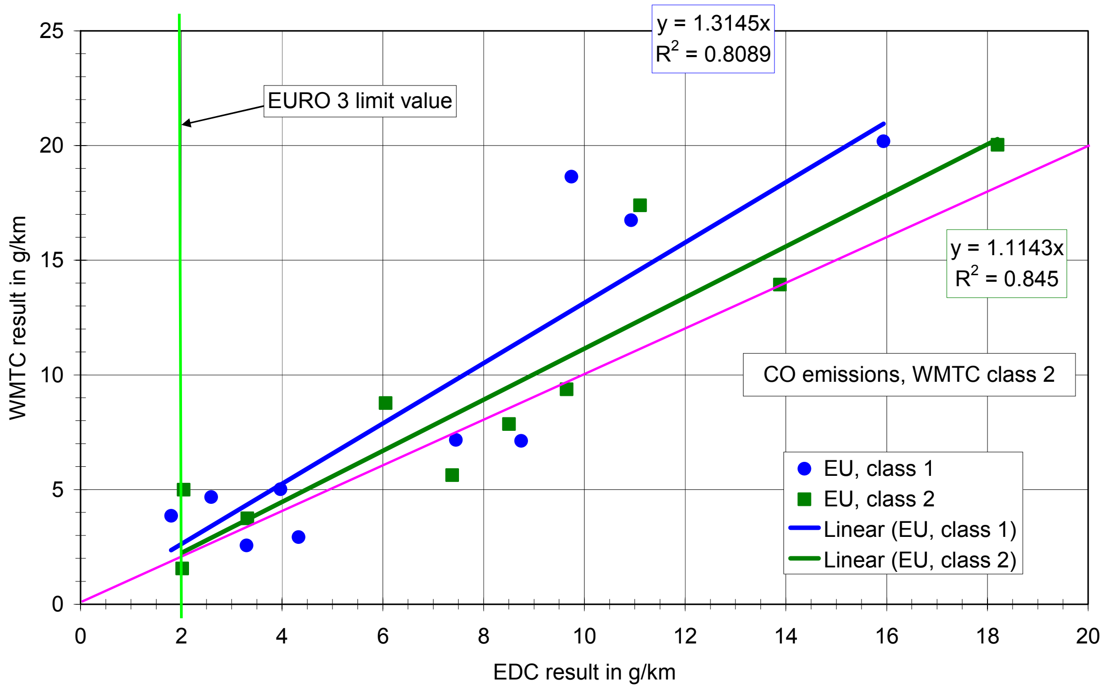


Figure 4-13: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for CO, WMTC class 2

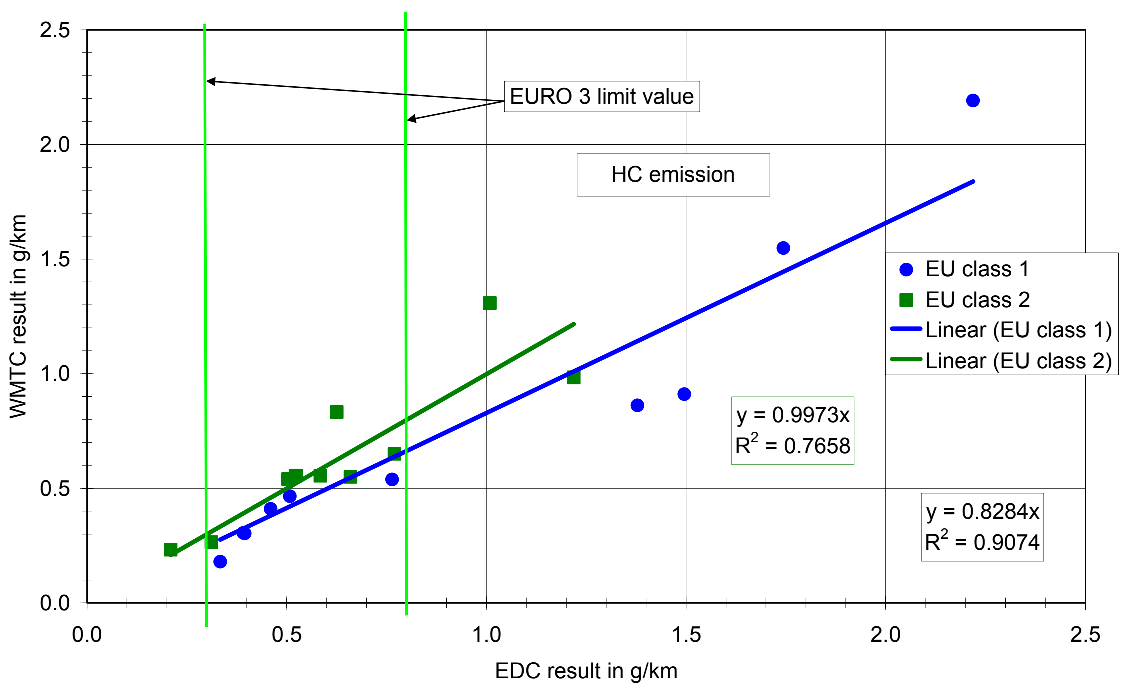


Figure 4-14: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for HC, WMTC class 2

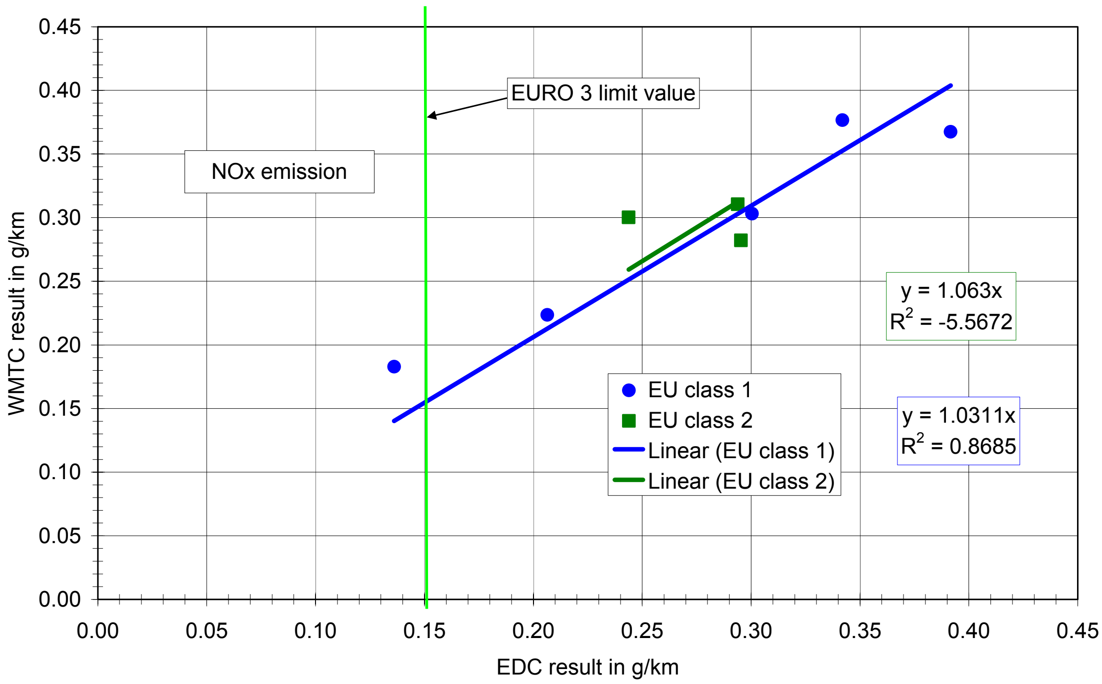


Figure 4-15: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for NO_x, WMTC class 2 without high CO emitters

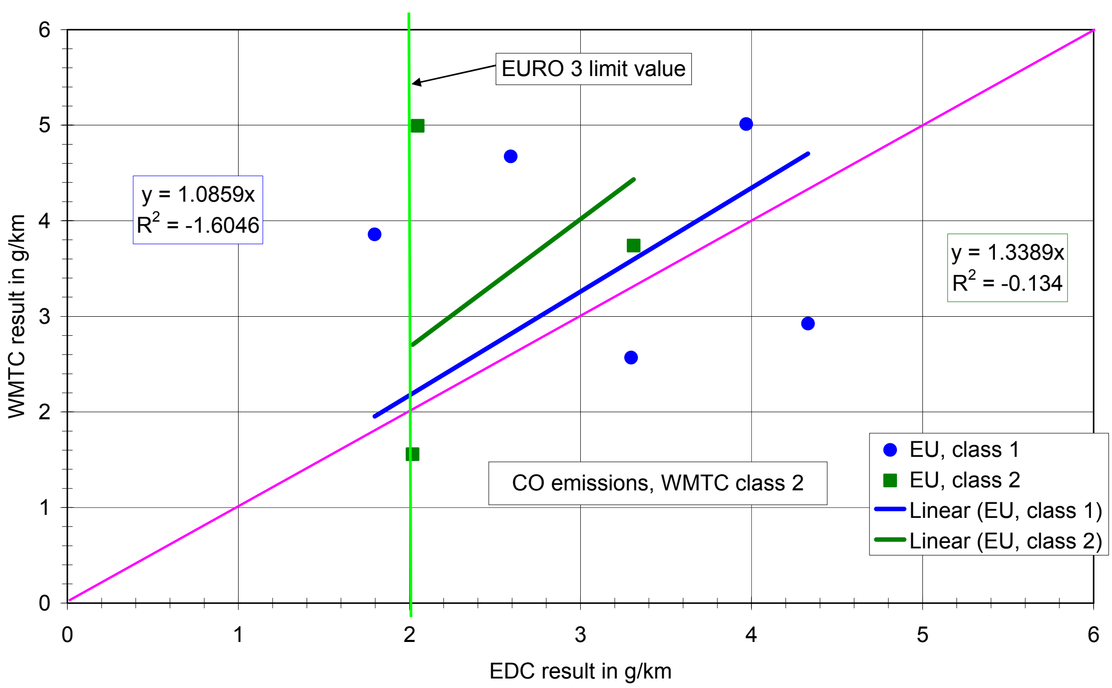


Figure 4-16: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for CO, WMTC class 2 without high CO emitters

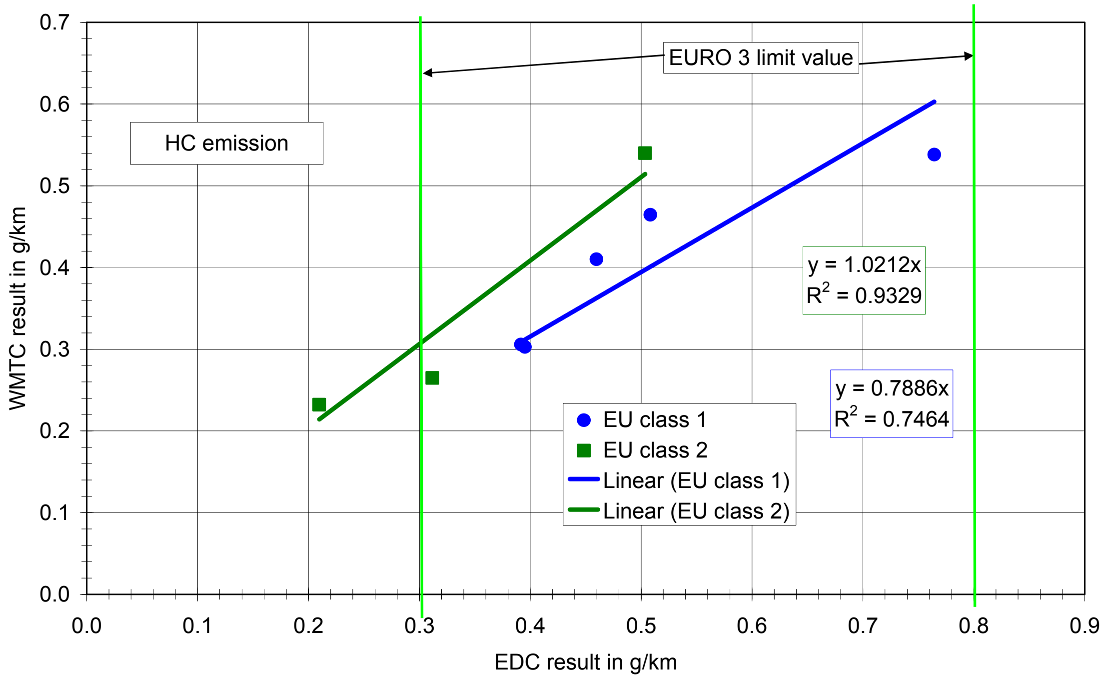


Figure 4-17: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for HC, WMTC class 2 without high CO emitters

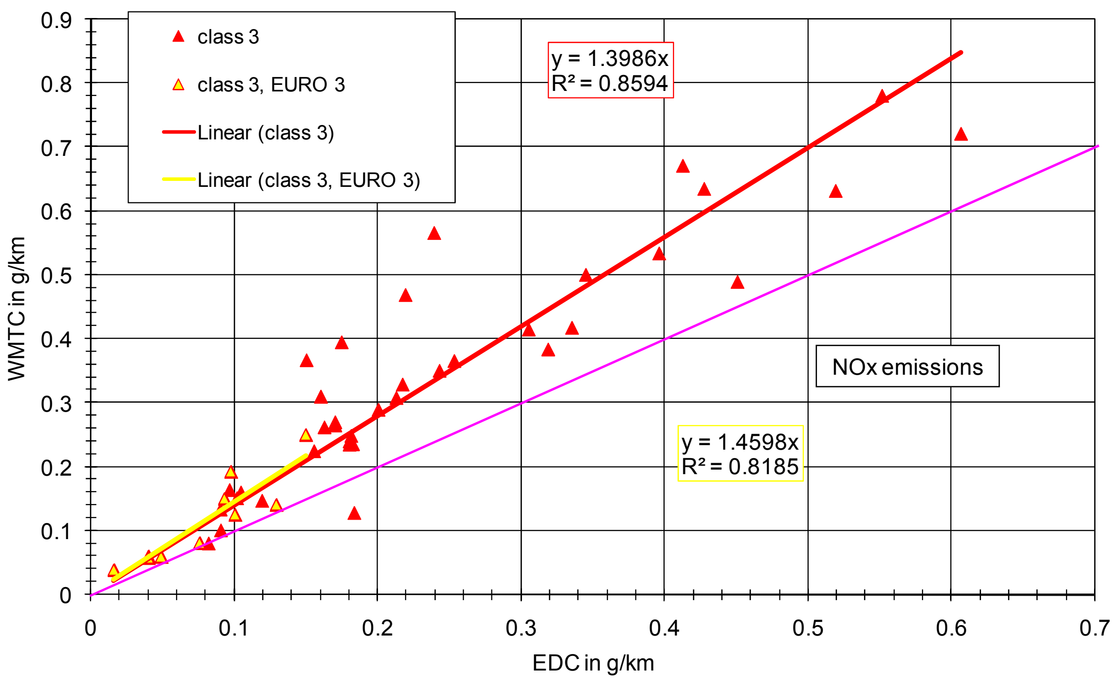


Figure 4-18: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for NO_x, WMTC class 3

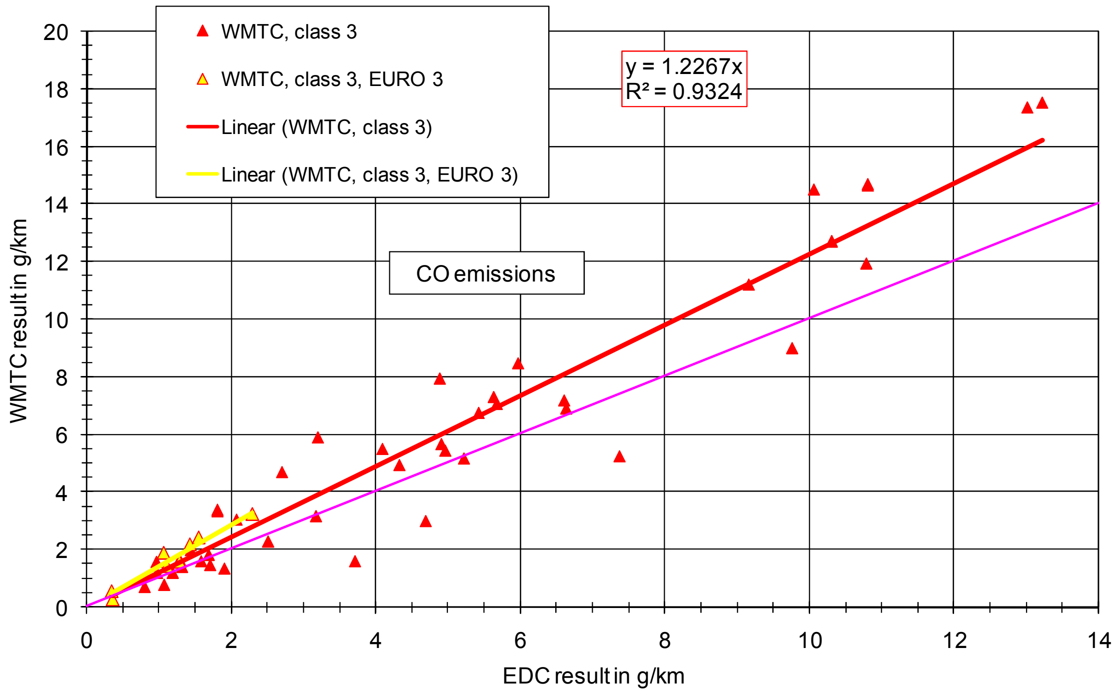


Figure 4-19: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for CO, WMTC class 3

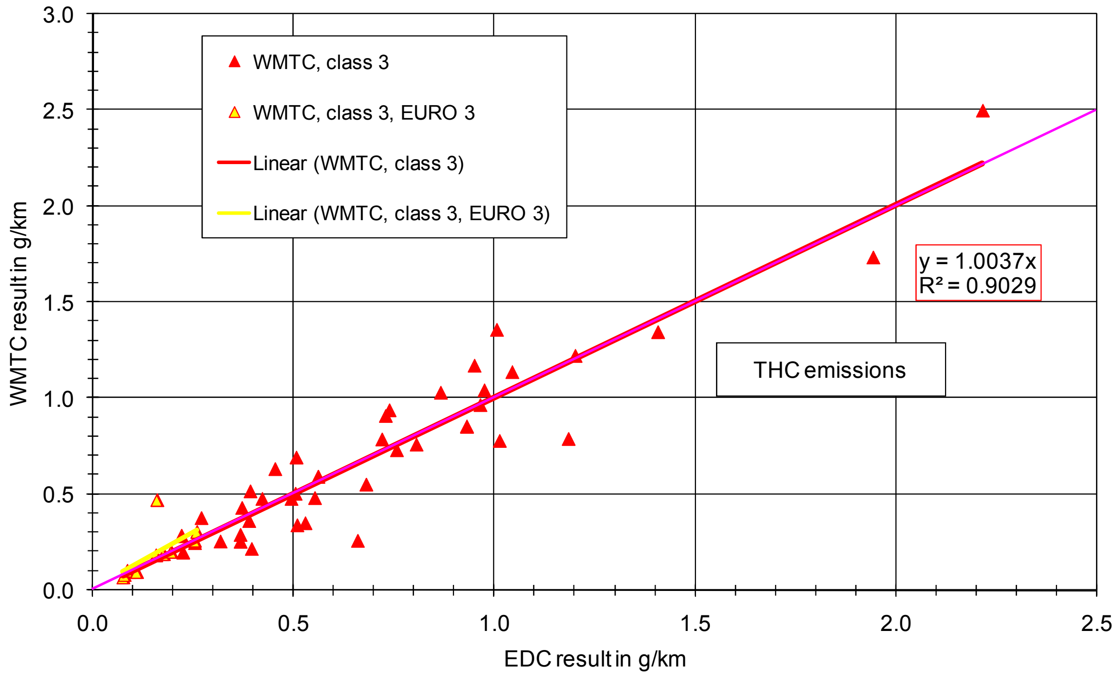


Figure 4-20: WMTC cycle results versus 2002/51/EC cycle (ECE40+EUDC) results for HC, WMTC class 3

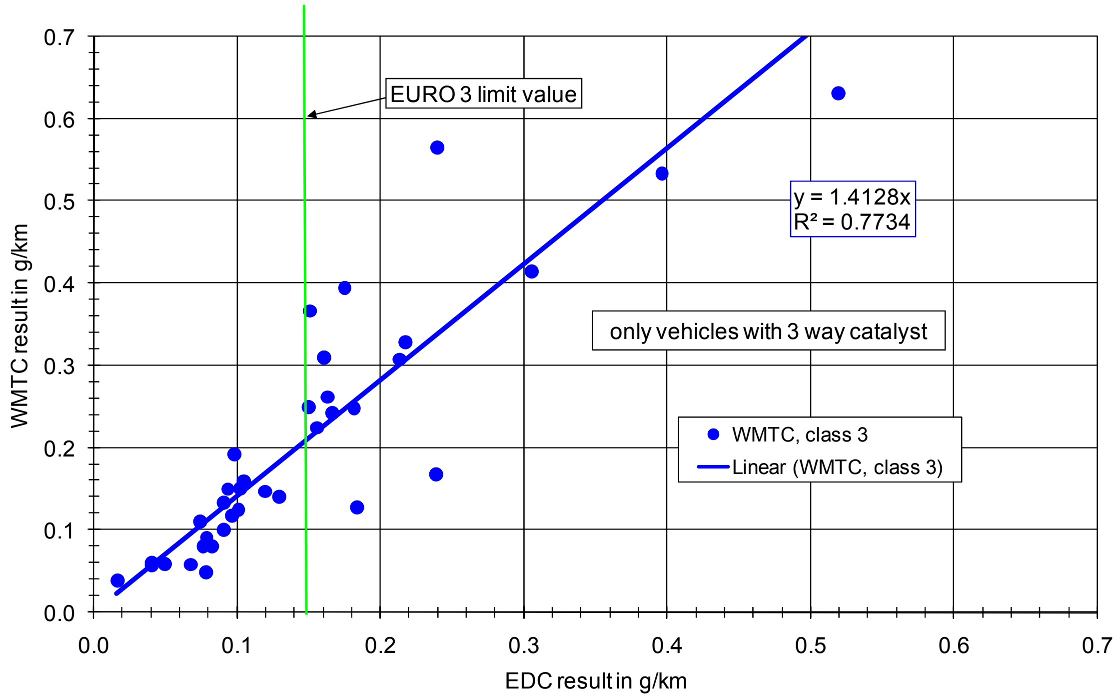


Figure 4-21: WMTC cycle results versus 2002/51/EC cycle (6 UDC + EUDC cold) results for NO_x, WMTC class 3, only vehicles wit 3 way catalyst

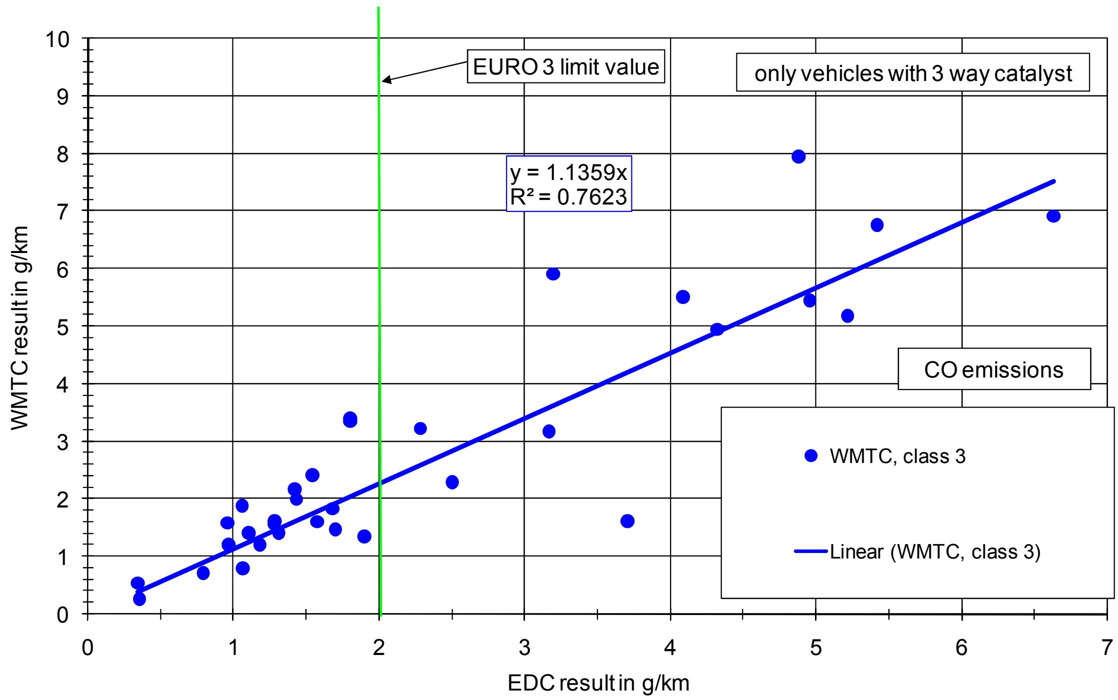


Figure 4-22: WMTC cycle results versus 2002/51/EC cycle (6 UDC + EUDC cold) results for CO, WMTC class 3, only vehicles wit 3 way catalyst

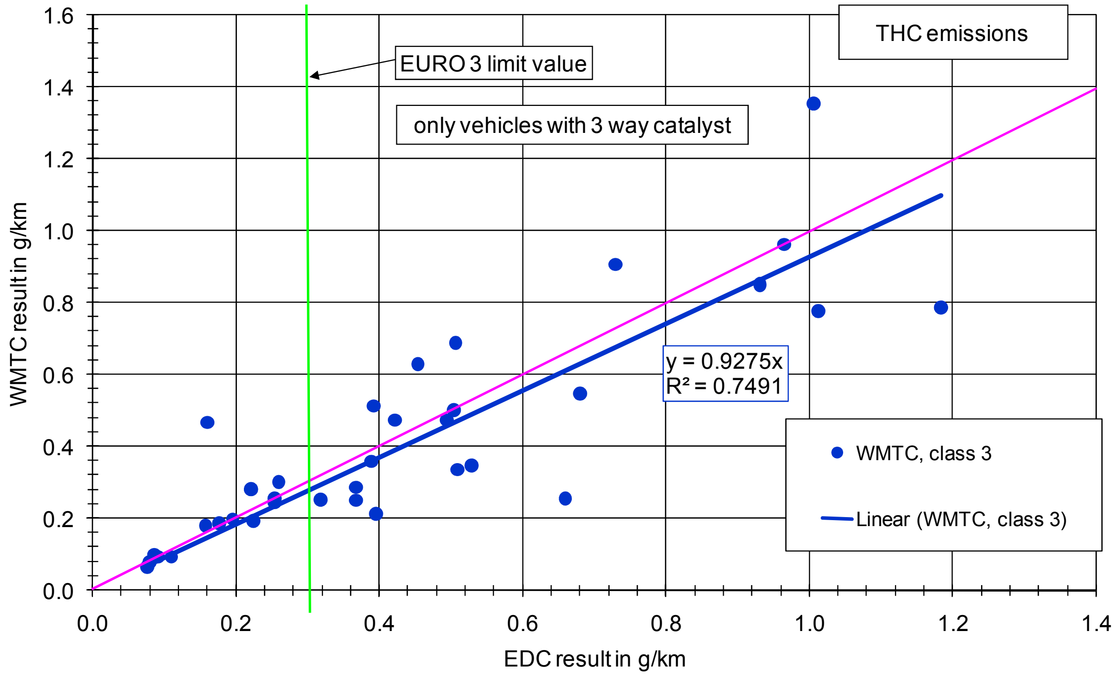


Figure 4-23: WMTC cycle results versus 2002/51/EC cycle (6 UDC + EUDC cold) results for HC, WMTC class 3, only vehicles with 3 way catalyst

4.3 Impact of PTWs on local air-quality

In Chapter 3.1.1 it was attempted to provide an estimate of the contribution of PTWs to total road transport emissions. As in similar previous studies it was concluded that PTWs are and will continue to be important contributors to HC and CO emissions (with shares expected to reach 55% and 35% by 2020 respectively), while they are minor contributors to total road traffic NO_x and PM emissions (2% and 5% by 2020 respectively).

However, there are strong indications that the above shares do not represent the real need to control the emissions from this vehicle category, since the main driver for emission standard setting is air quality and in particular urban concentrations of the major pollutants. This is also reflected to the Technical Annex of our study that stated that "*The analysis will also focus on the contribution of motorcycles in the air pollution of urban areas, particularly in Mediterranean countries, where there is a high density of motorcycles*".

Already in a previous study for the European Commission [15] it was attempted to estimate the contribution of PM emissions from mopeds in an urban inventory, using two different sources of information comparatively. This was done for the year 2002, for France and Greece, two countries with high and very low dieselization respectively. The results indicate that despite the significant uncertainties in the estimation of activity data and emission factors, urban PM contributions from mopeds cannot be neglected even for significantly dieselised countries like France (where urban PM from mopeds can be in the range of 15 to 30% of diesel PC emissions) and can exceed the diesel PC's contribution in special cases as in Greece (1.8 to almost 4 times the diesel PC urban PM emissions).

While the above was an attempt to approximate the significance of PTW emissions in the urban context in a top-down manner, a study by WHO European Centre for Environment and Health (Rome Office) [16] attempted to do a similar approximation in a bottom-up way. The study that has been commissioned by the Ministry of Environment of Italy, tried to perform an initial assessment of the specific contribution of mopeds to the health effects associated to transport focusing on Rome as a specific case study. This feasibility study investigated five distinct areas (a) the contribution by mopeds to air pollution in the city of Rome (b) accidents involving mopeds (c) health effects on the population of Rome attributable to the air pollution generated by mopeds (d) the social costs of accidents and (e) noise exposure.

One of the study's most important conclusions is that mopeds play a considerable role in producing Rome's urban pollution. Each of the city's estimated 443 000 mopeds covers an average of about 6 000 km annually for a total of 2.58 billion km. These 443 000 mopeds are responsible for 20% of the carbon monoxide and 21% of the PM10 concentrations measured by monitoring stations and represent 17% of the total circulating vehicles in Rome (about 2 600 000). PM emissions from mopeds are considered to be responsible for about 350 premature deaths annually, which comprise 1.4% of deaths of people aged 30 years or older in the City of Rome; about 450 people are admitted to hospital for respiratory illnesses (2.2%

of total admissions) and 660 for cardiovascular problems (1.0% of total admissions), in addition to other minor health problems.

For accidents, Rome has more than 4 000 accidents involving mopeds annually, resulting in more than 6 000 injured people. Seventeen percent of the accidents caused by mopeds in urban areas are severe and involve hospitalization. Fatal urban accidents involving motorcycles and powerful scooters number about four times those involving mopeds. In 2000, insurance companies spent an average of €2 100 per claim for mopeds, 64% related to personal injury. The cost in health care expenses and lost work time owing to urban accidents was estimated to be €36 million in Rome for 2000. Research on noise exposure has not supplied quantitative data for Rome.

The need to better assess the sources of urban air quality and to abate it via both technical and non technical measures is also expressed by recently launched studies that attempt to measure and evaluate pollution at the very local street level. Particular emphasis is put on PM emissions.

In this framework, a Dutch study (financed by the Ministry of Housing, Regional Development and the Environment) published in April 2008 [17] reports on measurements of air quality when cycling and driving in 11 Dutch towns. A test car and a test bicycle were used for approximately 35 km in each city measuring near real time particle concentrations as fine particles ($PM_{2.5}$ measured with TSI's DustTrak) and ultra fine particles ($PM_{0.1}$ measured with TSI's CPC 3700). The main objective of the study was to collect hard data in order to support the analysis of various aspects of the cycling climate in the Netherlands (a project framework called Fietsbalans). The main conclusion of the study was that on average the exposure to ultrafine particles is somewhat higher in a car than on a bicycle, with significant differences in the exposure pattern though: cyclists are found to be subjected to very high particle peaks of very short duration, while car drivers encounter lower peaks that last longer.

Interestingly but not unexpectedly, the study reports that the concentration of ultrafine particles measured was strongly dependent on encounters with certain "much pollution-emitting, overtaking or stationary vehicle". Exposure of cyclists to high concentrations of ultrafine particles generally occurs in several situation the most important of which was found to be hindrance by overtaking mopeds. As compared to the average situation without hindrance, there is a more than 90% increase in ultrafine particles and almost 7 times higher chance for an ultrafine peak. In contrast, hindrance by overtaking car leads to more than 23% increase in ultrafine particles, with 3 times higher chance for a peak.

Similarly the Belgian Government has launched the study SHAPES (Systematic analysis of Health risks and physical Activity associated with cycling Policies) with main objective to analyze the risks and benefits of a modal shift from passenger cars to cycling. The first results of this study are expected in the beginning of 2009.

Based on the above, it can be concluded that PTWs and mopeds in particular are important contributors to local air pollution, in particular as regards HC and PM emissions. Top down and bottom up approximations indicate that this contribution is in the range of a couple of decades of percent Since the emissions of passenger cars are expected to decrease substantially, it is expected that mopeds and PTWs contribution will rise even further. Public awareness also rises, since a number of studies are commissioned that look closely to the issue of street level air quality and identify PTWs as an important source at his scale. Evidently, the recent developments at regulatory level with emission standards limiting not only the mass but also the number of particles and addressing also some categories of gasoline powered vehicles introduce new directions and boundary conditions in the PTWs regulations as well.

Nevertheless, it should be reminded that it is not clear whether PM emissions from PTWs and in particular two-stroke mopeds pose equivalent health risks to the diesel PM emissions, due to the different particle nature.

4.4 Type-approval based on the engine-family concept

The type-approval of PTWs on the basis of the "family concept" is a potential beneficial approach for certification of vehicles. For this reason the GTR No 2 initially endorsed the idea, because it would allow extension of conformity to vehicles with similar characteristics and thus reduce the cost and time demand for type approval. Nevertheless, the discussions on this issue were not fruitful and no family concept was incorporated. However in order to provide insight to the Commission on this issue, a brief review was conducted regarding similar approaches within the EU and US regulatory framework. Additionally a family concept proposed by the manufacturers in Moto 105 [14] is analysed and commented as a potential future development of the legislation.

4.4.1 GTR n°2 Family concept status

During the review performed for this study no specific proposal for a family concept was retrieved from GTR n°2. In the GTR n°2 documents (Appendix to Amendment 1 to gtr No. 2 - Proposal to develop Amendment 1 to GTR No. 2) and particularly in the ECE/TRANS/180/Add.2/Amend.1/Appendix 1 issued on 29 January 2008 the following statement was found (section D), referring to a family concept: *"Some legislation of Contracting Parties already includes a family concept (e.g. United States of America) or the extension of type approval (e.g. the European Union (EU)). The introduction of a family concept in GTR n°2 is proposed by IMMA. An engine or vehicle family is characterized by design parameters. These shall be common to all vehicles within the family. The engine manufacturer may decide which vehicles belong to a family, as long as the membership criteria are respected. The engine family shall be approved by the type approval or certification authority."* In addition in paragraph 14 of the same document it is stated that *"A proposal introducing the family concept will be prepared during 2007."*.

After investigating the status of the family concept proposal in the GTR n°2 discussion, it was concluded that the engine family concept was a very difficult subject for contracting parties to understand and accept given that only the USA has truly embraced this as a concept. Despite IMMA 's efforts to reach a consensus with the WMTC-FEG group no agreement was achieved. Consequently, the FEG agreed to leave the issue for each contracting party to decide and no proposal was issued.

4.4.2 Family concept approaches - Europe

4.4.2.1 Heavy duty engine family concept

Directive 88/77/EEC regarding the type approval of heavy duty engines introduces the family concept for granting extension of conformity to all members of a heavy duty engine family. According to the directive, approval of an engine (engine family) means the approval of an engine type (engine family) with regard to the level of the emission of gaseous and particulate pollutants. The legislation in this case defines the "engine family" as the manufacturer's grouping of engines which, through their design, have similar exhaust emissions characteristics. All members of a family must comply with the applicable emission limit values. Furthermore the directive introduces the criteria for classifying engines within a family. Essential characteristics of a heavy duty engine family are:

- Combustion cycle
- Cooling medium
- Number of cylinders
- Individual cylinder displacement
- Method of air aspiration
- Combustion chamber design/pre-design
- Valve and porting-configuration, size, number
- Fuel system
- Ignition system
- Miscellaneous features
    - Charge cooling system
    - Exhaust gas recirculation
    - Water injection emulsion
    - Air injection

It becomes clear that in this case the regulatory framework refers specifically to a family of engines, not vehicles, defining also the classification characteristics that should be present across the members.

The scope here is to ensure that all engines comply with the current standards and through this procedure attempt to control the final vehicle's actual emissions as well. This approach is introduced due to the inherent difficulty in testing the final vehicle-engine configuration in a predefined, controllable and repeatable test driving cycle as performed for passenger cars and light duty trucks. The fact that heavy duty trucks present multiple vehicle-engine configurations (according to the application), operate under various loading conditions together with their size, would make vehicle testing for each individual configuration a complex and technically difficult option.

4.4.2.2 N1 Vehicles

The idea of vehicle family is introduced in the case of light duty trucks in Europe through Directive 2004/3/EC amending Directive 80/1268/EEC related to fuel consumption and CO_2 emissions monitoring of road vehicles. The Directive introduces fuel consumption and CO_2 emissions reporting for light duty trucks and emphasizes particularly on aspects that affect vehicle energy efficiency rather than pollutant emissions.

Regarding vehicle classification and extension of type approval, the legislation foresees the extension of type approval for certain vehicle groups that comply with specific rules. N1 vehicles may be grouped together into a family for the purposes of type approval if certain parameters are identical or within the specified limits shown in Table 4-12.

Table 4-12: Vehicle family criteria (2004/3/EEC Section 12.1)

Identical parameters	Similar parameters
Manufacturer and type	Transmission overall ratios (no more than 8 % higher than the lowest)
Engine capacity and type	Reference mass (no more than 220 kg lighter than the heaviest),
Emission control system type	Frontal area (no more than 15 % smaller than the largest)
Fuel system type	Engine power (no more than 10 % less than the highest value).

N1 vehicles can be approved within a family as defined in Table 2-1 using two alternative methods described in paragraphs 12.2 and 12.3 of the directive. The first alternative provides that a vehicle family can be approved with CO_2 emission and fuel consumption data that are common to all members of the family. The technical service must select for testing the member of the family which the service considers to have the highest CO_2 emission and the results are used as type-approval values that are common to all members of the family. The second alternative is to establish a different CO_2 emissions/fuel consumption factor for all family members. However, the manufacturer has to prove if the factor is within the limits made up of those two vehicles in the family that have the lowest and the highest fuel consumption, respectively. If the factor complies with this criterion, for each family member its individual CO_2/fuel consumption factor may be used.

An interesting point in this type approval procedure is that paragraph 11.2.1 allows extension of the type approval to other vehicles provided that they comply with certain criteria. In this case type approvals may also be extended to vehicles which:

- are up to 110 kg heavier than the family member tested, provided that they are within 220 kg of the lightest member of the family,
- have a lower overall transmission ratio than the family member tested due solely to a change in tyre sizes and
- conform with the family in all other respects

It is clear that, in the way this family concept is established, it aims at fuel consumption monitoring and potentially provides a mechanism for future CO_2 emissions control of vehicles, not engines in this regard. Vehicles members are grouped with respect to the heaviest vehicle or the member that has the largest frontal area. This way the legislation covers the worst in terms of energy efficiency case and allows for the manufacturers to identify whether a separate type-approval test for vehicles with better fuel economy performance is cost effective. Pollutant emissions are expected to remain at the same levels for all family members.

4.4.3 Motorcycle family concept - The US approach

Regarding motorcycles the US regulation has already incorporated a family concept [18]. Vehicle and engine classification in engine families is one of the early major steps in the type approval procedure.

According to the regulation an engine family is the basic unit used in the US by EPA / CARB to issue a certificate for highway motorcycles. By definition an engine family refers to the basic classification unit of a manufacturer's product line used for the purpose of the test fleet selection. According to the regulation, emission certification must be obtained by every model year, regardless of whether engine families change or not.

Vehicles are grouped into engine families in a two step procedure. Initially the vehicles are grouped with respect to engine displacement. Four different engine displacement classes are distinguished.

Table 4-13: Motorcycles engine families according to engine displacement according to US legislation

Class I-A	Less than 50cc (CARB exempted)
Class I-B	50cc to <170cc
Class II	170cc to <280cc
Class III	280cc and above

Once vehicles are classified with respect to engine displacement, then criteria are applicable to define a vehicle family. Family members are expected to have similar exhaust and evaporative emission characteristics throughout their useful life. In order for a number of vehicles to be grouped in the same family, they should be the same in all of the following aspects:

1. Combustion Cycle
2. Cooling system type (liquid cooled – air cooled)
3. Cylinder configuration
4. Number of cylinders
5. Engine displacement class
6. Method of air aspiration
7. Number, location, volume and composition of catalytic converters
8. Thermal reactor characteristics
9. Number of carburettors (or fuel injectors)
10. Pre chamber characteristics

It is clear that although the US law refers to vehicle families, the characteristics considered for the classification are in all cases associated with the engine and the pollutant emissions aftertreatment system, and not the vehicle design and characteristics as such. Therefore this approach is comparable to the EU approach for heavy duty engines rather than that of N1 vehicles. Considering the family criteria established in the US for the classification, it is expected that in terms of pollutant emissions the vehicles may present the same performance. In terms of CO_2 and fuel consumption however, it is expected that characteristics related to the vehicle configuration and not only the engine are of significance and therefore such a system would most likely be insufficient for monitoring energy efficiency and controlling CO_2 emissions from 2 and 3 wheelers.

4.4.4 The European Industry's proposal on PTW (Moto 105)

Vehicle manufacturers propose a family concept scheme in Moto 105 [14]. More specifically in section 8.3 of the document it is proposed that approval granted to a vehicle type should be possible to extend to different vehicle types provided that the engine/pollution control system combination is identical to that of the vehicle already approved. The text continues by defining the parameters that need to be identical or remain within the tolerance bands for fulfilling the aforementioned criterion (same engine/pollution control system combination). The following parameters are suggested:

- Engine:
  - Number of cylinders
  - Engine capacity (± 30%)
  - Configuration of the cylinder block, number of valves, fuel system
  - Type of cooling system
  - Combustion process
  - Cylinder bore centre-to-centre dimensions
- Pollution control system:

- Catalytic converters:
    - Number of catalytic converters and elements
    - Size and shape of catalytic converters (volume of monolith ± 10%)
    - Type of catalytic activity (oxidising, three-way, etc)
    - Precious metal load (identical or higher)
    - Precious metal ratio (+/- 15%)
    - Substrate (structure and material), cell density
- Type of casing for the catalytic converter(s)
- Location of catalytic converters (position and dimension in the exhaust system, that does not produce a temperature variation of more than 75°K at the inlet of the catalytic converter). Where a catalyst position differs, this temperature variation shall be checked under stabilised conditions at a speed according to the highest value in km/h in the test cycle and at the dynamometer load setting of type I test.

➢ Air injection:
- With or without
- Type (pulsed, air pumps, etc.)

➢ EGR:
- With or without.

➢ Oxygen Sensor
- With or without

The parameters named are more or less similar to those considered in the US regulation for defining an engine/vehicle family, with additional characteristics such as EGR being also considered. Again in this case the scheme provides a good basis for ensuring that all family members are equivalent in terms of pollutant emission but needs to incorporate additional features prior to being used for energy efficiency monitoring and control purposes.

4.4.5 Discussion

As presented in the previous sections, either vehicles or engines families can be given certification according to a "family" type-approval concept. The initial GTR n°2 proposal refers to either an engine or a vehicle family concept. Although both definitions are related to the same procedure, i.e. the classification of vehicles or engines in such a way that extension of type approval between various motor vehicle types becomes possible, it is noted that there is a distinctive character between the requirements to group vehicles or engines within a family concept.. Therefore, the two terms should not be used interchangeably within the regulatory framework, as this may lead to confusion and regulation gaps.

In the same direction, any future regulations should be clear as to whether the scope of a family approach is to ensure conformity with respect to pollutant emissions or simplification of the CO_2 and fuel consumption monitoring procedure.

If aim of the regulation is to simplify the type-approval procedure with regard to conventional pollutants, then the "engine family" concept should be adopted, which is reflected by both the US regulations and the European Industry proposal in Moto 105 [14]. This is because the identical (or very similar) engine and aftertreatment setup may be used on a variety of motorcycle realisations (e.g. two and three wheel vehicles). The exact technical details of the regulation can be discussed. It is proposed that the industry comes up with typical examples of similar engine and aftertreatment realisations used in different models, together with the type-approval values of these motorcycles. This can facilitate a thorough technical discussion on which engine and aftertreatment concepts need to be standardized within an engine family.

If the simplification of the CO_2 emissions monitoring procedure is sought, and particularly in view of a possible future emission limit introduction for passenger cars, then a broader approach should be investigated and adopted. In this case, vehicle related criteria should be taken into account and a vehicle family approach, as the one of the N1 regulation, should be considered. A vehicle family should then be defined using, at a minimum, the following criteria:

- Vehicle mass
- Number of wheels,
- Power output,
- Transmission type.

5 Summary and conclusions

5.1 Current status of PTW emissions (Status 2009)

- Motorcycle emissions are responsible for 0.7% of total road transport NO_x emissions, while the contribution of mopeds is 0.2%. A 5% fraction of total PTW emissions is due to quadric-cycles and, in principle, mini-cars alone. Although this appears as a negligible fraction, one should not forget that such small vehicles operate basically in urban areas, compared to trucks where emissions largely occur in highways.

- The contribution of motorcycles to CO_2 emissions is similar to NO_x (~1.0%) and moped CO_2 is 0.2% of total road transport emissions. The contribution of tri-cycles and quadric-cycles is ~0.04% of total road transport, equally distributed between the two categories. As there is no point in distinguishing between urban and highway conditions for GHGs (as in the case of NO_x), PTWs appear as negligible contributors of total CO_2.

- Mopeds emit ~2.0% of total PM and motorcycles some 1.3% of total PM from road transport. The share of tri- and quadric-cycles is 0.47%, with 80% of this originating from diesel vehicles. Given the small fleet of such vehicles and the low annual mileage, this contribution appears disproportionally high.

- Mopeds are responsible for some 25% and motorcycles for~15% of HC emissions, while evaporation alone is ~1% of total road transport emissions. Tri- and quadricycles are responsible for 0.6% of total road transport, with 90% of this share attributed to gasoline vehicles. This confirms the common understanding, that small PTWs are responsible for a large share of urban HC emissions. This higher percentage (compared to the 2004 LAT/AUTh study) mainly comes as a result of the improved HC emission factors of other vehicle categories.

- PTWs are also important contributors of CO. In particular motorcycles are responsible for 17.3% of total road transport emissions and mopeds are responsible for another 3.8% of total CO. Tri-cycles and quadricycles emit 0.36% of total road transport CO emissions, with 90% of this originating from gasoline vehicles.

5.2 Future evolution of PTW emissions

Assuming that no further measures over Euro 2 mopeds and Euro 3 motorcycles are taken, the following are expected to occur with respect to the evolution of their contribution total road transport emissions.

- NO_x emission contribution will continue to increase in the future, rather exponentially. In 2020, it is expected that PTWs, including tri- and quadric-cycles will be responsible for 3.6% of total road transport NO_x.

- The contribution of PTWs to total CO_2 is not expected to change in the future, despite the growth of their stock, both because their CO_2 performance increases but also as emissions from other sectors are projected to grow faster than PTWs.

- PM emission contribution follows a curvy pattern. Initially it decreases as the Euro 2 moped and the Euro 3 motorcycle regulations lead to effective control of PTW emissions. However, as diesel particle filters appear later for cars and trucks, the share of PTWs increase again and collectively reaches some 8% of total PM emissions. About 16% of total PTW emissions is projected to originate from quadricycles and, in principle, diesel mini-cars. This calls for additional regulation from such vehicles.

- HC emission contribution of PTWs (including evaporation and tri-cycles and quadric-cycles) will continue to increase in the future and it is projected to reach 62.4% of total road transport emissions by 2020. An efficient policy is therefore necessitated to further control emissions of, primarily mopeds, and motorcycles.

- CO emission contribution will also increase and PTWs are projected to contribute to some 36% of total CO by 2020. Although CO is not a priority pollutant in Europe, more strict control of CO emissions would be required to control the contribution of motorcycles to same to today levels.

5.3 Emission limit scenarios

Four emission limit scenarios were simulated. Scenario 1 considered the introduction of Euro 3 mopeds in 2010. Scenario 2 considered introduction of Euro 3 mopeds and Euro 4 motorcycles in 2012, and Euro 4 mopeds and Euro 5 motorcycles in 2015. Scenario 3 simulated the introduction of best available technology in 2010. Scenario 4 considered the same emission standard steps with Scenario 2, but with more stringent limits and introduction one year later than Scenario 2 (2013 instead of 2012 and 2016 instead of 2015). Details on the technical measures and the emission factors introduced are given in sections 2.4 and 3.2. Based on the simulation, the scenarios achieve the following reductions over the baseline in 2020:

- Scenario 1 achieves 1.5%, 6.5%, and 27% reduction in CO, HC, PM, and CO_2 respectively. NOx marginally increases (by +0.24%).
- Scenario 2 leads to 16.3%, 15.3%, 37%, 1.77%, and 26.9% reductions in CO, HC, PM, CO_2, and NOx, respectively.
- Scenario 3 achieves reductions of 15%, 2.3%, 9.7%, and 22% for CO, HC, CO_2 and NO_x, respectively. No PM reduction could be assessed based on the available experimental data.
- Finally, Scenario 4 achieves 18.5%, 28.2%, 40.1%, 0.88%, and 36.7% reductions in CO, HC, PM, CO2, and NOx, respectively.

The cost-effectiveness of the introduction of the different technical measures in each scenario has been assessed until 2020, regardless of the date of introduction of each emission standard. This has led to the following conclusions:

- With regard to HC and PM Scenario 1 appears as the most cost-effective one, followed by Scenario 2 and 4. Scenario 3 appears much less cost-effective for HC as it practically requires the same technology with Scenario 2 but with more relaxed emission limits. No effectiveness could be calculated for Scenario 3 and PM.
- Scenario 1 achieves no NOx reductions and therefore no cost-effectiveness could be assessed. From the remaining scenarios, Scenario 3 appears as the most cost-effective demonstrating the potential of the best available technology to reduce NOx.
- With regard to CO_2, cost-effectiveness is not a direct product of technology introduced specifically to decrease CO_2, as no CO_2 emission limits were introduced by any scenario. However, CO_2 benefits occur as a positive side-effect of the technology introduced to limit other pollutants. In this respect, Scenario 3 appears as the most cost-effective one, followed by Scenario 1, 2, and 4 in degrading order, in terms of cost-effectiveness.

5.4 Effectiveness of additional measures

A number of additional measures were examined in this study with respect to their effectiveness in reducing emissions and the associated costs. Based on this analysis, the final conclusions can be drawn:

1. Regulations for durability need to be introduced to effectively control emissions over the useful life of the vehicle. It is today very difficult to estimate the current degradation level of motorcycles but there is evidence that certain models may emit much beyond the emission limits at relatively short mileage after their type-approval. This situation needs to be remedied. As long as durability requirements have been introduced, the actual distance that will be used as a useful life is of secondary importance.

2. Regulations to monitor the CO_2 and energy consumption of PTWs can be put in place to monitor the performance of such vehicles. PTWs appear as much more energy efficient means of transportation than passenger cars and their activity should be promoted as a measure to further control GHG emissions from road transport. The energy efficiency labelling regulation should be formulated in a way that will not affect the sensitive PTW market. A solution would be to classify vehicles within the same market segment.

3. One measure that was found very cost-effective in the previous LAT/AUTh study was the establishment of a periodic road-worthiness test. Although this was not reassessed

in the current study, it is repeated that road-worthiness testing is a very suitable measure in controlling emissions from motorcycles.

4. With respect to HC emissions, a number of measures can be classified with respect to the effectiveness and cost. IUC is both low cost and a low effectiveness measure that rather has a precautionary character. From the other measures, the evaporation control of motorcycles appears as the most cost-effective solution, while emission limit Scenario 4 appears as the most effective one. Interestingly, OBD measures appear more cost-effective than emission limit Scenario 3 for. In general, OBD appears more cost-effective than what was presented in the 2004 version of the report.

5. For NO_x emission control, the available options are located along a straight line on a log-log scale. Again, IUC appears as a low-cost, low-effectiveness measure. Then OBD options appear more costly and more effective. Finally, the higher effectiveness, but also cost, appears from the further tightening of the emission standards.

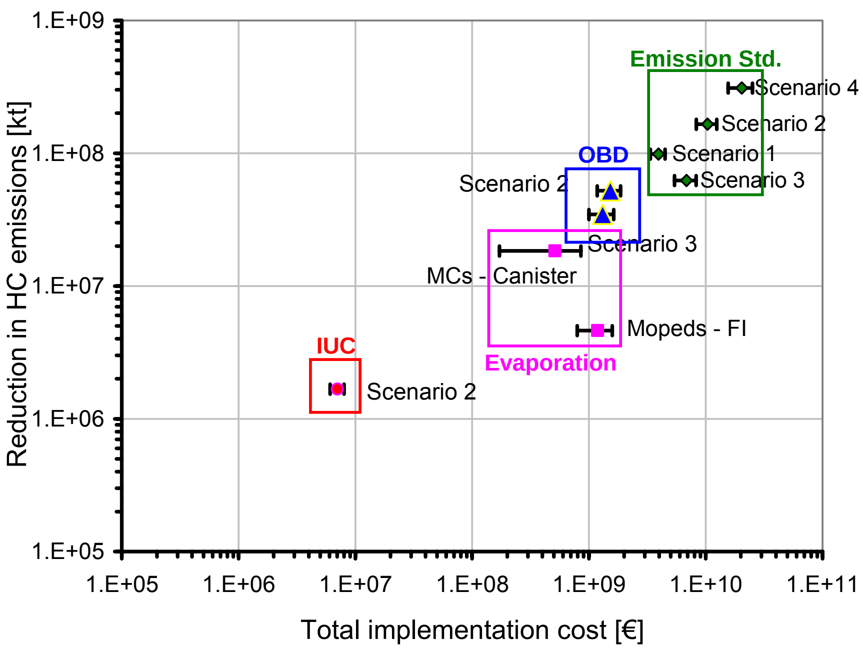


Figure 5-1: Evaluation of the cost effectiveness of control measures for HC emissions

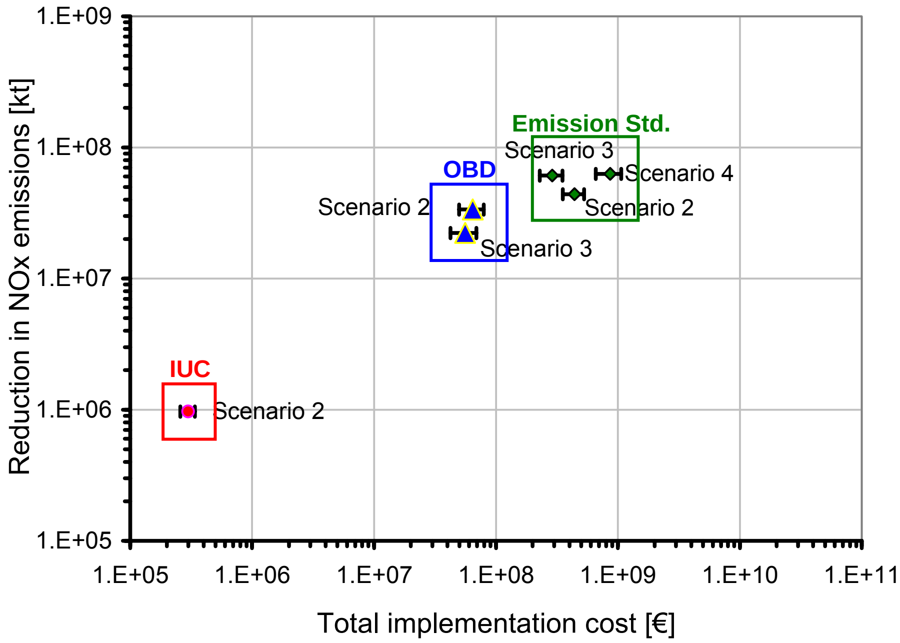


Figure 5-2: Evaluation of the cost effectiveness of the control measures for NO_x emissions

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