LABORATORY OF APPLIED THERMODYNAMICS
MECHANICAL ENGINEERING DEPARTMENT
ARISTOTLE UNIVERSITY THESSALONIKI
P.O. BOX 458 GR 541 24 THESSALONIKI GREECE

Final Report on:

"Impact assessment/Package of New Requirements Relating to the Emissions from Two and Three-Wheel Motor Vehicles"

TENDER No: ENTR/03/066

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LABORATORY OF APPLIED THERMODYNAMICS
MECHANICAL ENGINEERING DEPARTMENT
ARISTOTLE UNIVERSITY THESSALONIKI
P.O.BOX 458 GR-54124 THESSALONIKI GREECE

tel: +30 2310 996047 fax: + 30 2310 996019
http://vergina.eng.auth.gr/mech/lat/lat.html

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Scientific Responsible Prof. Zissis Samaras	
Author(s) Dr. Leonidas Ntziachristos, Athanasios Mamakos, Anastastios Xanthopoulos, Assoc. Prof. Eleytherios Iakovou	

Client/Sponsor

European Commission
Enterprise Directorate – General
Unit F.5
rue d'Arlon, 88
B-1049 Brussels
BELGIUM

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1 Introduction

This document is the final report of the project (ref.: ENTR/03/066) titled:

"Impact Assessment/Package of New Requirements Relating to the Emissions from Two and Three-Wheel Motor Vehicles".

granted to the Laboratory of Applied Thermodynamics / Aristotle University Thessaloniki (LAT/AUTh) by the European Commission – DG Enterprise. The main objective of this study was to provide the European Commission with technical information for developing the regulation of motorcycles at a Euro 3 level. The study calculates the expected environmental benefit from different emission control policies by predicting their effect on the emission levels of motorcycles expected to be introduced in 2006 and later.

The precise – or at least – realistic calculation of the emission effects of different policies requires clarifications on the details of the policy considered for introduction and secondly, description of the vehicle technology expected to be affected. A significant part of the technical information required and the different policy options were provided by the Commission, who has been running a special MVEG ad-hoc group on motorcycle regulation. Additionally the team based its analysis on relevant research and technical work carried out by CITA for an emission roadworthiness procedure for motorcycles, on the ARTEMIS project (DG Transport and Energy) and on the EURO-WMTC related work. To evaluate environmental effects, COPERT III and TRENDS tools were implemented with appropriate technical adaptations to accommodate different policy and technology scenarios.

In order to come up with figures that may assist the Commission in developing an efficient Euro 3 regulation, we calculated the cost-effectiveness of the different policies proposed. Cost figures associated with the implementation of different measures were calculated on the basis of similar studies conducted in US and in Europe in similar fields (e.g. passenger cars), by applying appropriate assumptions where necessary. The cost-effectiveness of each measure was then determined by the ratio of cost invested per total mass of pollutants saved.

Finally, we tried to estimate the potential social impacts of the different measures, which are not necessarily associated with increased costs. For the evaluation of the impact of policy measures on social behaviour in particular, the information drawn from the MVEG meetings has been synthesised and cross-compared with relevant studies in US, to come up with realistic effects.

This report provides the results of our calculations, together with the technical details used in the analysis. The latter should be always considered when examining the extent of application of the different conclusions reached.

1.1 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 was applied concurrently with the implementation of the Directive while the second came into force on June 17, 2002. The same Directive also introduced an emission standard 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 of emission standards, together with emission standards for a Euro 3 regulation.

Currently the Commission seeks for further tightening the emission regulation for both motorcycles and mopeds. With regard to mopeds, the Commission recently finalised a consultancy study placing particular emphasis on the understanding of particulate matter (PM) emissions from small two-stroke engines (Rijkeboer et al. 2002). The outcome of this exercise is currently still under discussion in the MVEG. In the case of motorcycles, Directive 2002/51/EC already requires that the Commission comes forward with proposals for the formulation of future emission regulation, discussing a range of additional issues, further to the implementation of stringent emission standards. In order to respond to this request, the Commission has been running a working group (ad-hoc subgroup of MVEG) where different policy implementation related issues are discussed.

The study presented in this report was launched by the Commission in order to synthesize the views on the different issues and to further enlighten areas which regard the environmental, economic and social impacts of any policy implementation decision. This should provide all necessary information to the Commission Services for constructing an extended impact assessment of its foreseen proposal for new requirements relating to the emissions from two and three-wheel motor vehicles.

1.2 Objectives

The Commission prescribed that the study team would need to evaluate the environmental, social and economic impact of different policy decisions, compared to the "no policy change" baseline scenario. Four general alternatives for policy implementation were foreseen:

- **Policy 1:** The Commission's proposal structured in the special group of the MVEG.
- **Policy 2:** The range of options summarised as "best available technology" (BAT).
- **Policy 3:** The options available assuming "minimum economic and social cost" but respecting the need for environmental benefit over the baseline.

- **Policy 4:** The transfer and adoption of legislative measures from different parts of the world or from within the EU, but applied to different vehicle sectors.

The different policies available were examined for a number of issues considered by the Commission. Those were:

- A procedure to check the durability of emission control systems.
- A procedure to check the in-use conformity of motorcycles.
- The technical provisions for the type-approval with respect to CO_2 emission and fuel consumption.
- New particulate emission limits for compression ignition and 2-stroke engine equipped vehicles.
- The impact of compliance with new Year 2006 emission standards.
- The introduction of OBD systems.
- The control of evaporative emissions.
- Procedures for type-approval of replacement and retrofit catalytic converters.
- The introduction of the World Motorcycle Test Cycle (WMTC).
- A procedure for the roadworthiness of two and three-wheel motor vehicles.

1.3 Methodology

We tried to extend our analysis to cover different aspects of the different policies. In particular we tried – where possible – to analyze the impacts of different policies in terms of:

- Their economic, social and environmental consequences.
- Including other additional effects and describe them in qualitative terms (or even quantify them).
- Distinguish between impacts over short and medium term.
- Distribute economic impacts with respect to enterprise size (effects on SMEs).
- Spread of possible impacts on social groups or other economic sectors, with special reference to SMEs.

Following the guidelines outlined for a preliminary impact assessment from COM(2002)276, the methods used comprise:

- Information collection and analysis: The different stakeholders (the Commission, vehicle manufacturers, associations, etc.) were approached and their positions were reflected (as much as possible) in developing the policy options and the scenarios for each measure considered. The study team focused with priority on the background information that was refined through the two-wheeler MVEG subgroup and constituted the basis for the formulation of the first policy option. This was complemented by information on the legislation in other parts of the world, regarding the emission regulation of two wheelers (in particular the Far East, US and California). Finally, the "best available technology" was clarified for each work-task, collecting the latest information that was available in the technical documentation and with exchange of information with the motorcycle industry. Alternative options which could formulate a cost-effective third policy option (minimum economic and social cost) were also derived in this process.

- Clarification of the policy options (synthesis): The four different policy options were structured based on the information collected. Additionally, we synthesized the information available to develop a baseline scenario. We consider that this baseline scenario reflects the emission evolution if no additional emission control measures are introduced. Hence, we consider that the baseline scenario reflects the evolution of emissions adopting Directive 2002/51/EC, i.e. Euro 2 for mopeds and the reduced Euro 3 emission standards for motorcycles. The additional measures considered for inclusion in the Euro 3 motorcycle regulation and the mopeds Euro 3 emission standards were considered as separate scenarios over the baseline.

- Simulation: The different scenarios considered were modelled with special software applications. The COPERT III tool, developed on behalf of the European Environment Agency (EEA), was modified to reflect new information and was applied to calculate the emission levels from different vehicle technologies. Also, COPERT was used to simulate the effect of roadworthiness tests, durability requirements, CO_2 related policies, Year 2006 emission standards, evaporation control, etc. on the actual emission performance of fleet vehicles. The fleet and activity evolution of PTWs was simulated with TRENDS, which was developed on behalf of DG TrEn with support from DG Eurostat and EEA to project the emissions of transport in the future. LAT/AUTh was responsible for the development of the road-transport module, which was revised to include the latest statistical data on PTW fleet size from Eurostat.

- Impact assessment/cost-effectiveness: The environmental benefits of each policy option were combined with a cost estimate associated with the introduction of the particular policy. This made possible the calculation of useful figures, expressed in €/ton of pollutant saved, which can be used to evaluate the cost involved versus the expected environmental benefit.

- External review: The study team felt that the study conducted would greatly benefit from a more qualitative view of the different aspects, based on experience from the past. Hence we welcomed the collaboration of Mr. Rudolf Rijkeboer from TNO who provided his input in developing this draft final report. His contribution will continue with his review of this manuscript.

1.4 Structure of this report

Further to this introductory chapter, this draft final report includes 5 additional chapters:

- Chapter 2 (Simulation) describes all technical details that were used to simulate emission evolution in the future. This includes emission factors, fleet and age distributions, new registrations, activity data, fuel and ambient conditions, etc.
- Chapter 3 (Emission Standards Effectiveness) presents the total emissions predicted and the cost-effectiveness of the baseline scenario. The emissions projected are compared to the emissions from all other vehicle sources to provide the overall and relative contribution of power two wheeler emissions in the road transport sector. Finally we compare the cost-effectiveness of the Euro 3 emission standards with Euro 1 and 2.
- Chapter 4 (Effectiveness of Additional Measures) provides the policy options for each of the tasks considered (1.2), their technical details, their expected environmental benefits and the cost-effectiveness for each of them.
- Chapter 5(Summary and Conclusions) summarizes the main findings of this study.

1.5 Meetings

In order to address the different issues discussed in this report, the study team met in the course of this study with the following bodies/organisations:

- ACEM (Mr. Vitale, Mr. Segers, Mr. Mills), 27/2/2004 & 26/3/2004
- AECC (Mr. Bosteels, Mr. Vogt, Mr. May), 24/3/2004
- CLEPA (Mr. Ayral, Mr. Gielen, Ms. Mormont, Mr. Sgatti), 24/3/2004
- FEMA (Mr. Antonio Perlot), 25/3/2004
- JRC (Mr. Bonnel, Mr. Martini, Mr. Krasenbrink), 23/3/2004
- TNO (Mr. Rijkeboer), 6/4/2004

Discussions and decisions from these meeting have been implemented in this final report.

2 Simulation

This section provides the technical details of the methodology followed to calculate total emissions from the fleet of motorcycles and mopeds, introducing the effect of different policy measures. Figure 2-1 shows the general scheme followed, assuming that each policy option has an impact on three different modules related to total emissions, namely the fleet evolution, the emission performance (main module) and the vehicle activity. Also, any policy measure is associated with an additional cost (see Chapter 2). Combination of the total cost and total emissions, provides the cost-effectiveness of any policy measure.

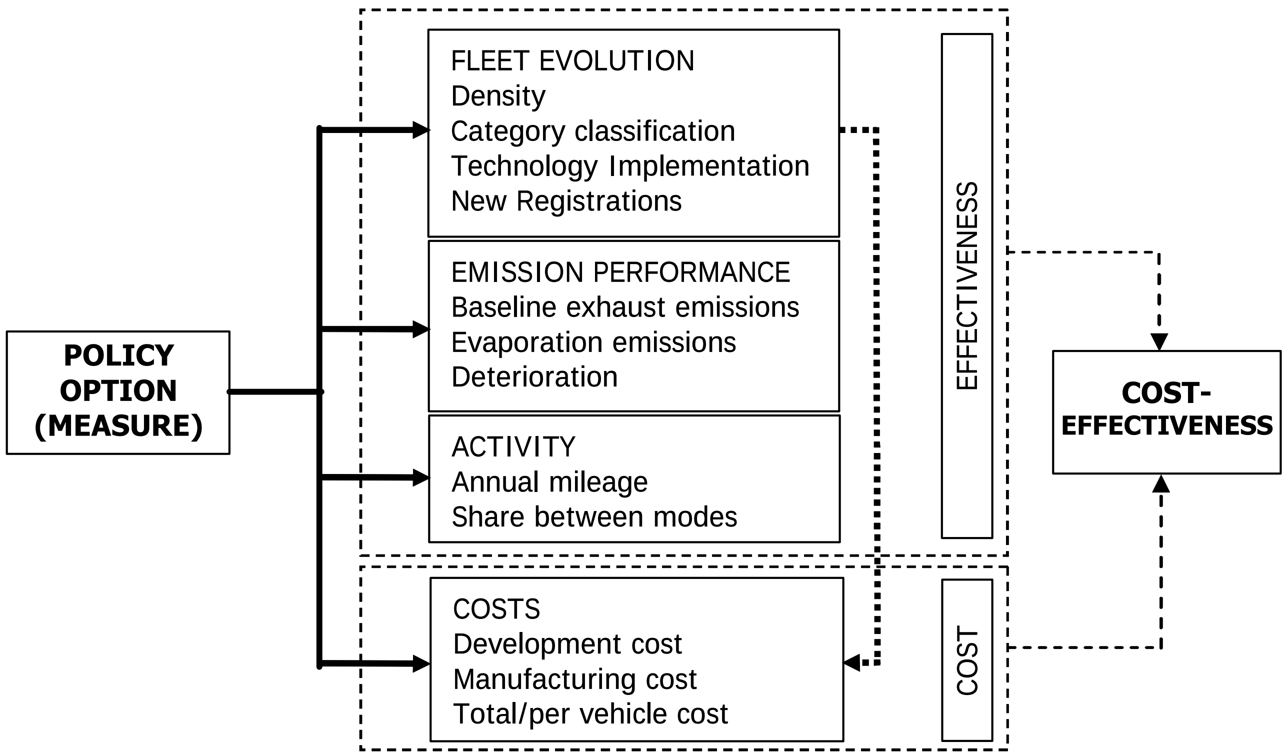


Figure 2-1: Schematic of the methodology adopted to calculate emission effects, costs and cost-effectiveness of different policies (scenarios).

2.1 Fleet evolution

The motorcycle populations and the corresponding age distributions for each EU15 country (from 1970 to 2020), were estimated using the TRENDS model (TRENDS 2003), with appropriate modifications following the latest data from Eurostat and ACEM.

2.1.1 Category Classification

It was decided to classify PTWs into 6 categories to better reflect emission performance:

- Mopeds (i.e. scooters with engine capacity less than 150 cc)
- 2 stroke motorcycles
- 4 stroke motorcycles with engine capacity smaller than 150 cc (Class 1)
- 4 stroke motorcycles with engine capacity between 150 and 750 cc (Class 2)
- 4 stroke motorcycles with engine capacity greater than 750 cc (Class 3)
- 3 & 4 Wheelers, further distinguished as compression ignition and spark ignition

2.1.2 Vehicle Population

Figure 2-2 to Figure 2-3 compare the total motorcycle fleet estimated using the TRENDS model with statistical data from EUROSTAT and ACEM for 12 of the EU15 countries. Two PTW fleet projections of the TRENDS model are shown in these figures. The first (Old projection) results from available statistical data in the period 1970-1997, and correspond to the baseline TRENDS scenario. The second estimation (Updated projection) is the one produced after taking into account the latest EUROSTAT and ACEM data (up to 2001). This projection is the one used in the calculations of the present study. It is obvious that the projections change as new information becomes available. We left both estimations on these figures to show the reliability and sensitivity of the projections. It is obvious that for countries with a significant population of motorcycles (such as France, Italy and Germany), the two projections do not differ significantly. There are three European countries for which ACEM data are not available (Belgium, Greece, Ireland) and no charts are shown for them. However, TRENDS also includes projections for these countries and they have been taken into account in the calculations. Additionally, Table 2-1 shows the fleet evolution (but not projections) in different new member states and neighbouring countries.

Table 2-1: Motorcycle fleets in new member states and neighbouring countries (EUROSTAT)

Total	AC-12*	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Malta	Poland	Romania	Slovak Republic	Slovenia	Turkey**
1990	2 482 039	281 270	14 487	#N/A	#N/A	168 817	#N/A	7 685	1 356 553	105 444	#N/A	15 842	531 941
1991	2 245 439	282 137	14 824	#N/A	#N/A	#N/A	#N/A	#N/A	1 235 640	108 006	#N/A	14 344	590 488
1992	2 455 922	282 792	14 093	#N/A	#N/A	162 761	#N/A	#N/A	1 134 366	108 737	84 258	13 568	655 347
1993	2 880 822	284 000	13 356	400 968	#N/A	157 693	8 970	#N/A	1 067 634	113 651	81 263	9 967	743 320
1994	2 896 118	284 600	13 090	402 882	2 200	157 407	11 100	17 179	1 008 410	121 205	80 473	8 786	788 786
1995	2 861 048	285 900	13 003	404 393	3 300	159 152	15 729	17 411	929 269	122 692	81 847	8 430	819 922
1996	2 829 669	286 800	12 112	405 110	4 680	151 019	18 444	11 663	875 663	122 527	79 479	8 022	854 150
1997	2 847 719	288 690	11 876	409 880	5 300	138 029	19 267	13 881	842 358	123 913	81 062	8 342	905 121
1998	2 830 628	281 749	11 918	407 256	6 100	97 073	19 409	14 847	819 902	121 335	100 891	9 213	940 935
1999	2 687 111	281 749	12 659	345 590	6 700	87 573	20 057	11 870	804 000	122 000	44 000	9 978	940 935

* AC12 does not include Lithuania where data are not available
** Turkey fleet also includes mopeds

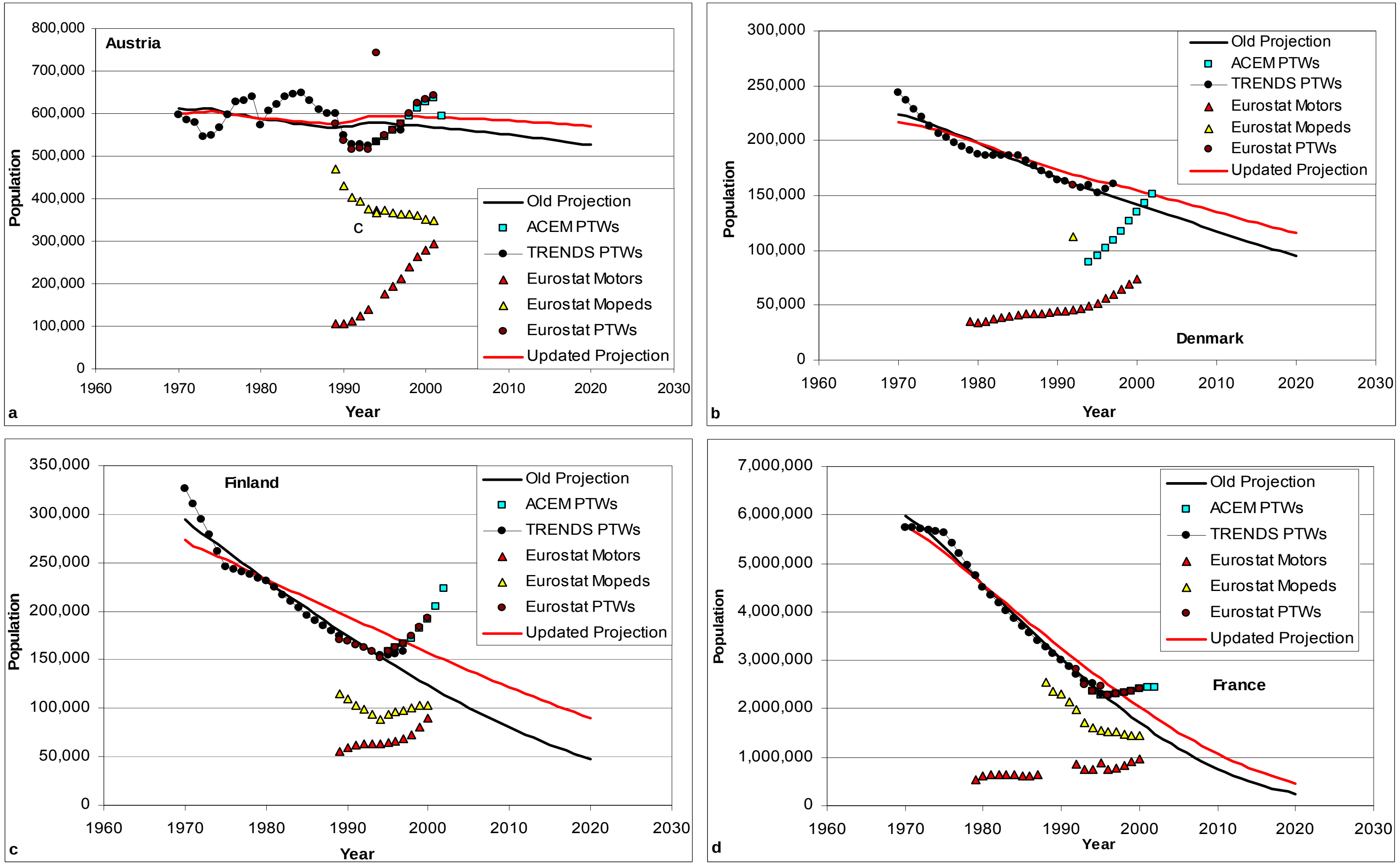


Figure 2-2: Comparison of total vehicle population used in TRENDS with statistical data from EUROSTAT and ACEM. Data for Austria, Denmark, Finland and France.

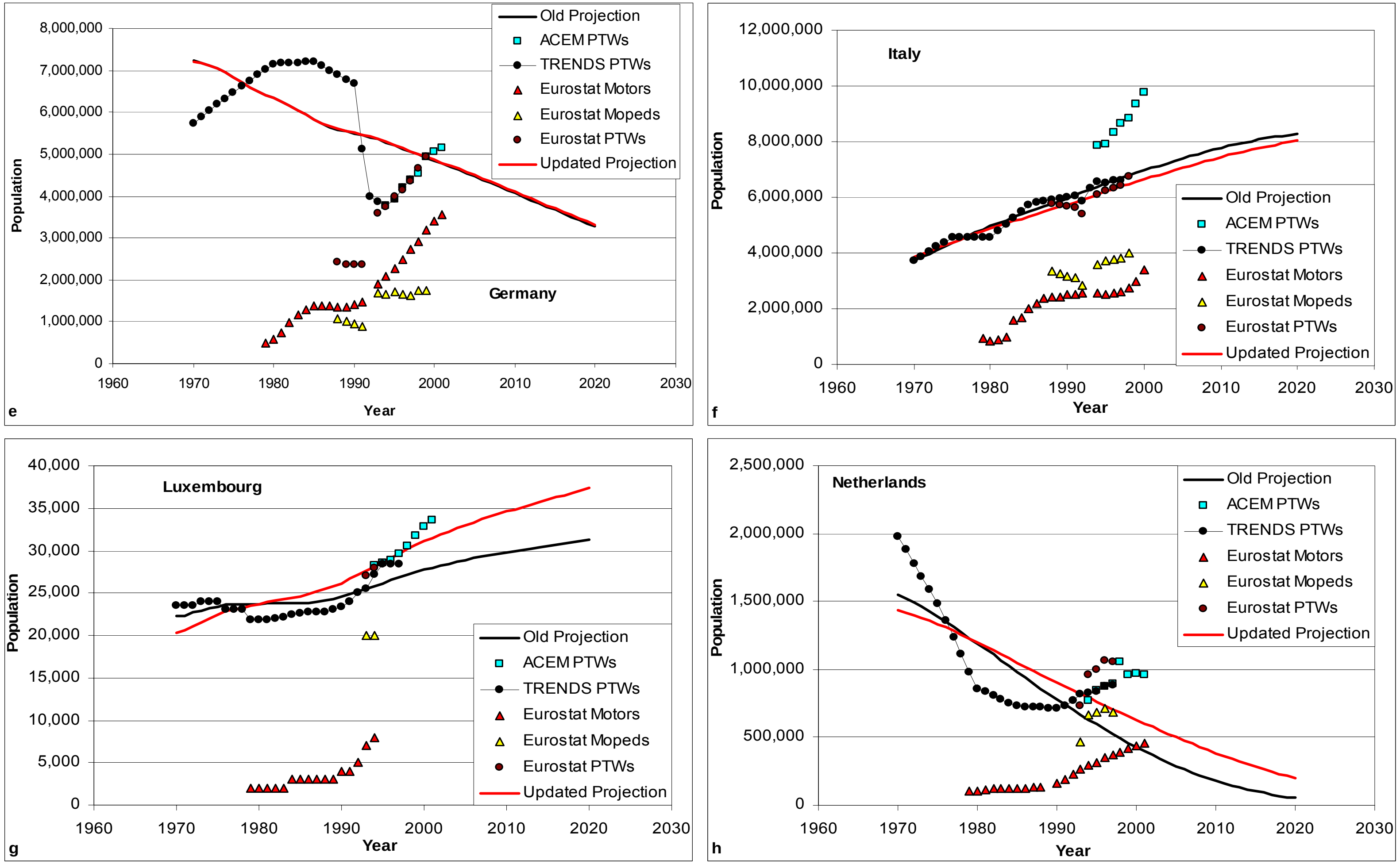


Figure 2-3: Comparison of total vehicle population used in TRENDS with statistical data from EUROSTAT and ACEM. Data for Germany, Italy, Luxembourg and Netherlands.

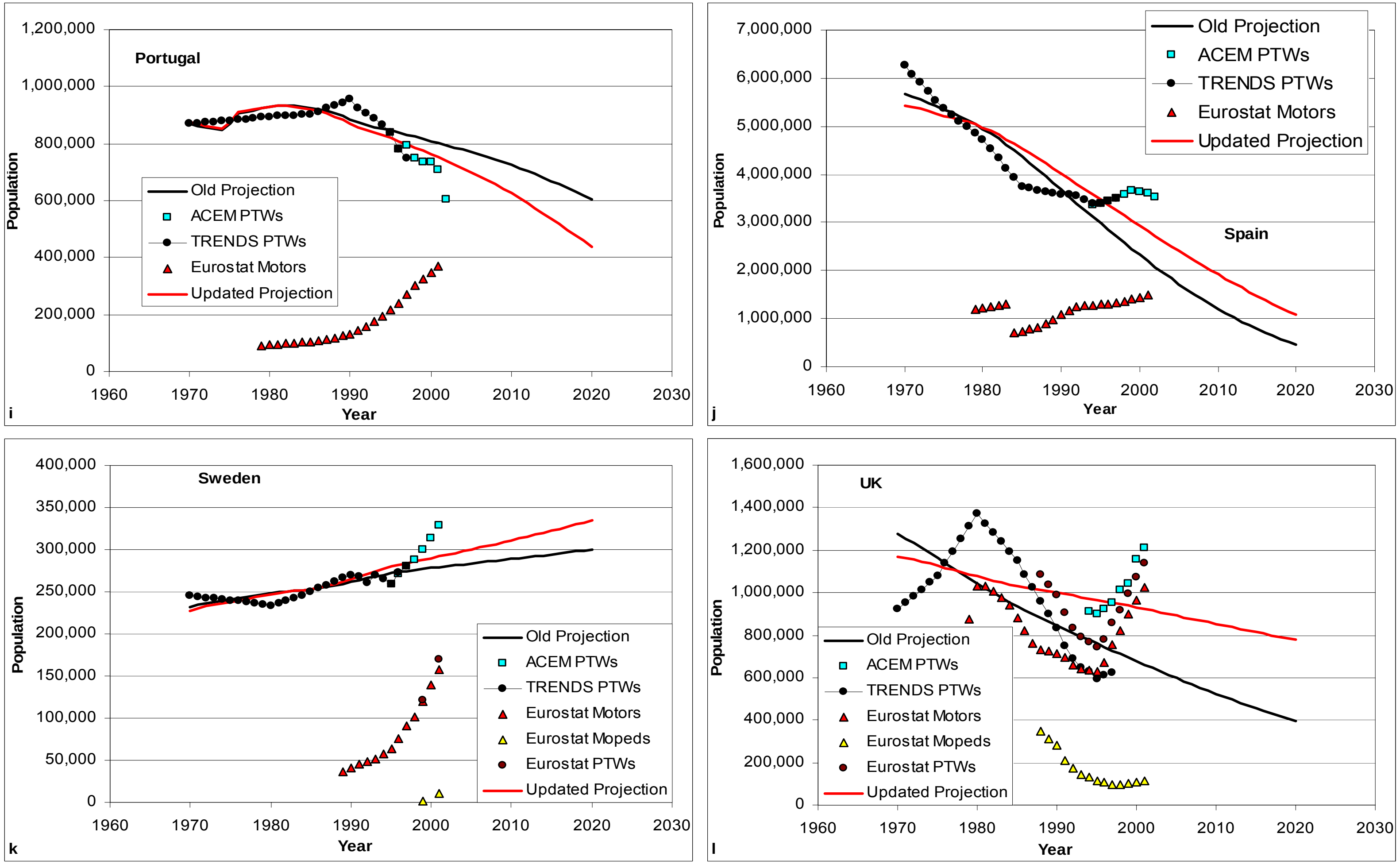


Figure 2-4: Comparison of total vehicle population used in TRENDS with statistical data from EUROSTAT and ACEM. Data for Portugal, Spain, Sweden and UK

Further to calculating total fleet evolution, TRENDS also calculates scrap vehicle rates (vehicles leaving the fleet) and new registrations per year, allowing for the estimation of the vehicle age distribution. In order to demonstrate the results of this methodology, the age distribution of the EU15 vehicle population of 2-stroke and 4-stroke motorcycles <150 cc are shown in Figure 2-6, for each year of the calculations. Figure 2-7 shows the corresponding picture for mopeds. Finally, Figure 2-8 shows the evolution of the total EU15 PTW population.

Using this methodology, the vehicle age distributions of the different PTW categories were made available for each EU15 country. This provided the means to take into account the individuality of each country (activity data and ambient temperature) in the calculation of total emissions. In the calculations, it was assumed that the estimated populations and age distributions will be unaffected from the introduction of different legislative measures, i.e. it is assumed that new policy measures do not affect the market volume. One potential measure that may both affect the internal passenger car market structure and the relative size of passenger car and motorcycle fleets may be the introduction of a CO_2-related taxation, as this is considered by the Commission in their COM(2002)431 communication to the Council. It is however difficult to predict what will be the time scale and extent of application of such a measure, therefore it is not possible to quantify its effect, at least at a confidence level higher than the uncertainty of the total fleet emissions calculations. We therefore decided not to modify the fleet sizes.

In the case of 3 & 4 wheelers, due to the lack of adequate information, a somehow simplified approach was considered. The only available data for the fleet size of these vehicles were their annual sales in EU from 2000 to 2003 (Figure 2-5). Based on these scarce data, a constant number of new registered vehicles, equal to the average of the available data, has been suggested from 1999 to 2012. Moreover, an average vehicle life of 9 years and a uniform age distribution has been applied in order to estimate the total population. This resulted to a constant total population of 67700 vehicles which corresponds to ~0.5% of the total PTW population. Finally, it has been assumed that 30 % of the total 3 & 4 wheeler population will be compression ignition vehicles, while all gasoline vehicles were only assumed to be 2-stroke ones.

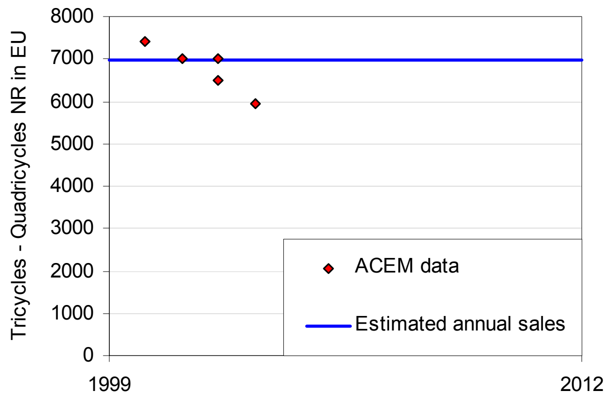
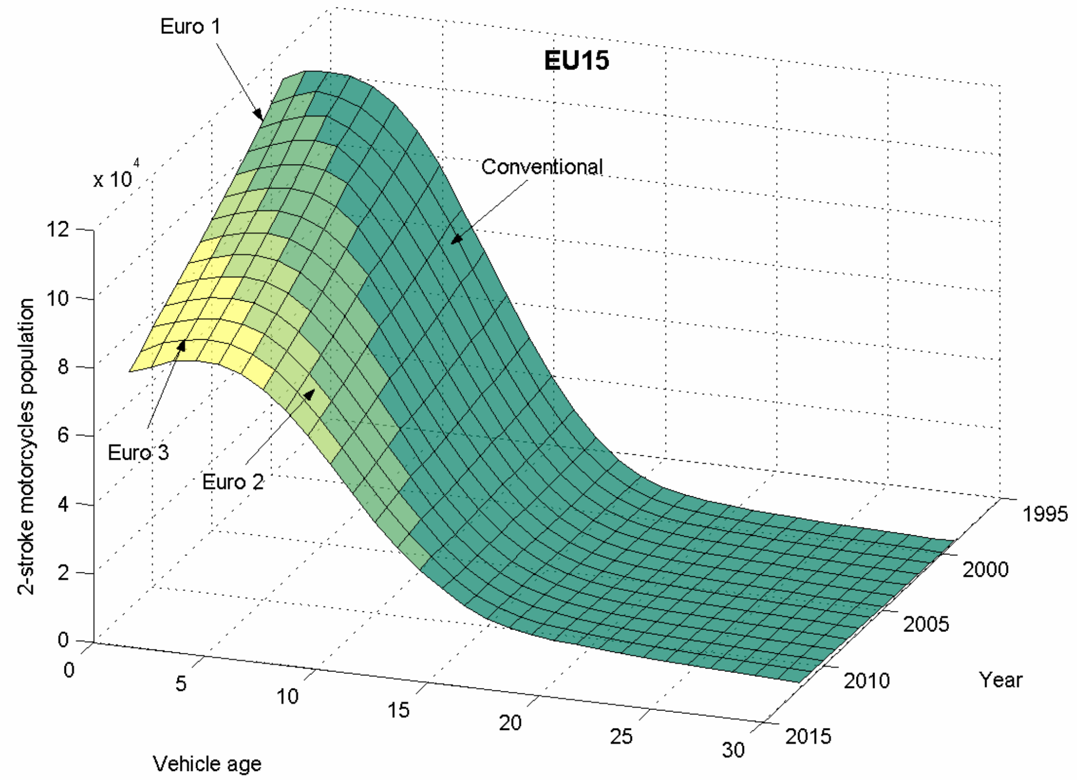


Figure 2-5: Annual sales of 3 & 4 wheelers in EU.



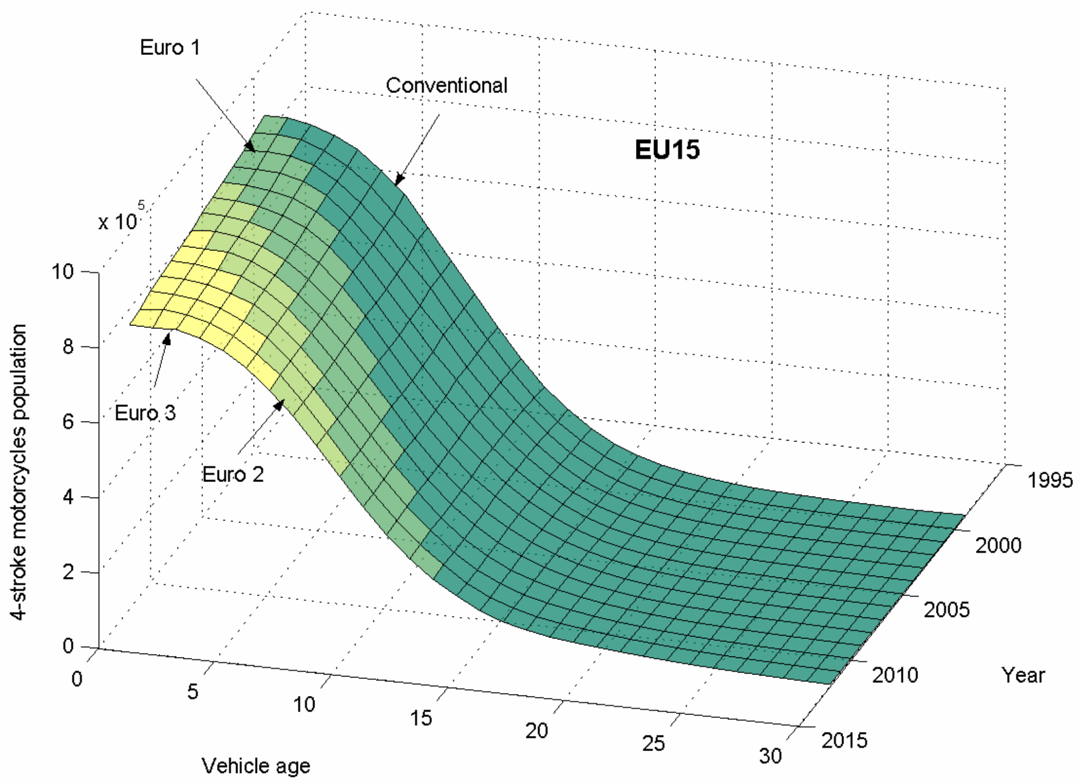


Figure 2-6: Age distribution of the motorcycle fleet in EU15 from 1999 to 2012. The upper picture corresponds to 2-stroke motorcycles and the lower one to 4-stroke ones.

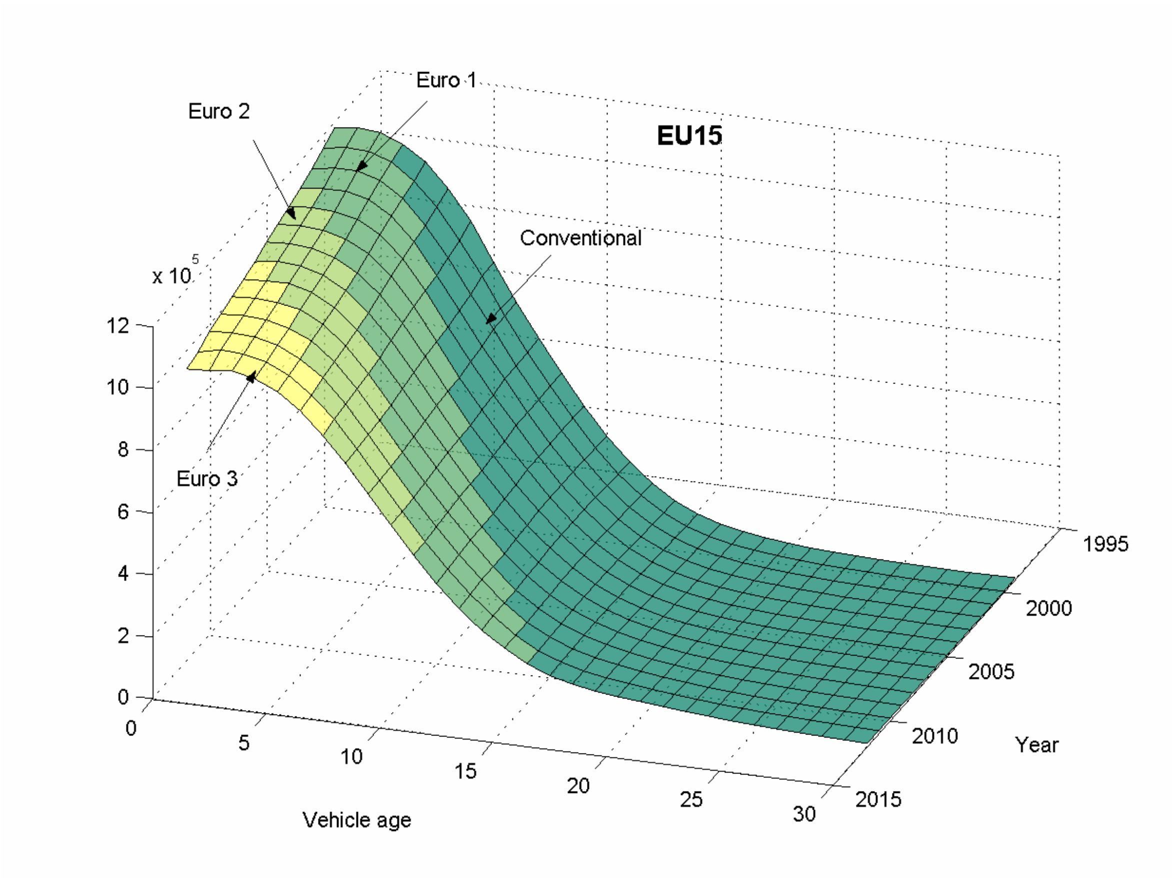


Figure 2-7: Age distribution of the moped fleet in EU15 from 1999 to 2012.

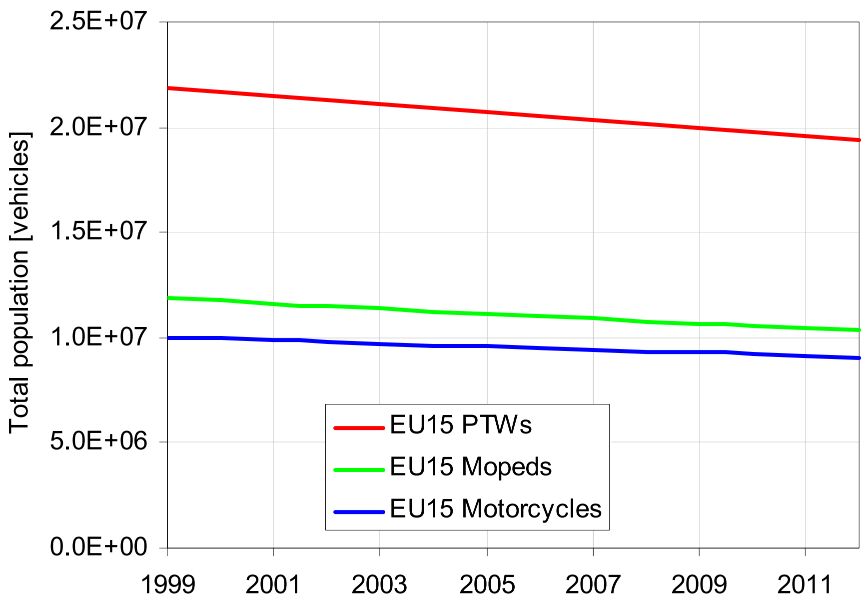


Figure 2-8: Projection of total two wheelers population evolution in Europe.

2.1.3 Technology Implementation

Each vehicle class is further distinguished into emission technologies according to the emission standards introduced in Europe. Historically, it has been observed that some vehicles already satisfy future emission limits before the introduction of the actual emission standard. This benefit is however somehow counterbalanced from the sales of older technology vehicles in the transition period after the introduction of a new emission standard. Therefore, there is always a question mark on which date to set the real-world implementation of a new emission standard. Due to this uncertainty, it has been decided to use the actual implementation dates of the emission standards to discriminate the different technologies, at least for motorcycles.

For mopeds, a somehow earlier introduction of the Euro 1 and Euro 2 technologies has been introduced. The reason for this assumption was the special agreement between the Italian Ministry of Environment and ANCMA. This agreement resulted in an earlier introduction of Euro 1 and Euro 2 mopeds in Italy where most of the mopeds are sold (almost 35 % of the total European moped fleet). Moreover, this has affected the import of improved emission control mopeds in other parts of Europe. Table 1 summarizes the suggested implementation dates for mopeds and motorcycles.

Table 2-2: Implementation dates of the emission standards for mopeds and motorcycles considered in the calculations.

Emission Standard	**Euro 1**	**Euro 2**	**Euro 3**
Mopeds	1997	2002	2006[1]
Motorcycles	1999	2003	2006

[1] Not for the baseline scenario where no moped Euro 3 introduction is considered.

2.2 Emission performance

The basic input sources used for the estimation/development of the emission factors for the different PTW vehicles (category – technology level) were COPERT III, the EURO-WMTC correlation study conducted by JRC (EURO WMTC, 2003), JRC and ACEM in-house testing activities, and finally, the TNO data collected over the CITA – IM project.

COPERT III provided emission factors for conventional and Euro 1 motorcycles, as well as emission factors for up to Euro 2 mopeds. Hence, the more recent studies from JRC and TNO were used to derive emission factors for Euro 2 motorcycles and to estimate emission factors for Euro 3 mopeds and motorcycles. Most of the ~60 motorcycles included in the JRC database were still of a Euro 1 technology and few were Euro 2. Obviously, none was officially type-approved as Euro 3. However, we utilized an emission hardware technology related classification in order to allocate the motorcycles in different emission standards. Therefore, vehicles equipped with an OxCat were considered as Euro 2 motorcycles, while those equipped with a TWC were regarded as Euro 3 ones. The remaining vehicles were regarded as Euro 1. Indeed, it was found that the actual emission performance of the vehicles classified into the different technologies, was mostly fulfilling the emission standard requirement over the corresponding type approval test. Therefore, this distinction was preserved and the development of the emission factors is presented in the next section.

The vehicles tested during the TNO/CITA study were either conventional or Euro 1 certified. The later however, included vehicles equipped with OxCat and TWC which for compatibility with the classification applied to the WMTC data, were also considered as Euro 2 and Euro 3 respectively. As a summary, the distribution of the JRC and CITA vehicle samples to different technology – engine capacity categories is summarized in Table 2-3.

Table 2-3: Classification of the motorcycles included in the EURO-WMTC (JRC) sample and CITA (TNO) sample according to principle type, engine displacement and the suggested type approval class.

	Technology Class	**4-stroke**			**2-Stroke**
		< 150 cc	**150 – 750 cc**	**> 750 cc**	
JRC	Conventional	-	-	-	-
	Euro 1	10	18	6	-
	Euro 2	3	4	4	-
	Euro 3	4	2	16	-
CITA	Conventional	1	2	2	3
	Euro 1	4	13	3	1
	Euro 2	-	-	1	-
	Euro 3	-	2	3	-

2.2.1 Baseline Exhaust Emissions

The pollutants considered in this study are CO, NO_x, THC, PM and "ultimate" CO_2. By considering "ultimate" instead of "tailpipe" CO_2, we refer to all CO_2 produced if we reduce all fuel consumption to CO_2, following the carbon balance. Hence, ultimate CO_2 can be directly associated to fuel consumption and lacks interference from high HC and/or CO emitting vehicles. The sources used for the estimation of the emission levels for each vehicle category were the COPERT III model and the experimental data collected in the EURO-WMTC and CITA studies. The subsequent sections describe in more detail the emission levels chosen for the different categories – emission standards.

2.2.1.1 Gaseous pollutants of 4-stroke motorcycles

Conventional vehicles:

There was no need to update the COPERT III emission factors for conventional vehicles. It was further confirmed that emission levels from the few conventional vehicles included in the JRC and TNO databases matched the emission levels estimated with COPERT. Separate emission factors for CO, HC NO_x are given for the three motorcycles classes (<150 cm³, 150-750 cm³, and >750 cm³), all of them being a 2nd order polynomial of mean travelling speed. In addition, the ultimate CO_2 emissions can be calculated from fuel consumption according to:

$$CO_{2,ultimate}[g/km] = \frac{44.011}{(12.011 + 1.008 \cdot r_{H:C})} \cdot FuelConsumption[g/km] \qquad \text{Eq. 2-1}$$

Where $r_{H:C}$ is the ratio of hydrogen to carbon atoms in the fuel. An $r_{H:C}$ value of 1.8 (typical for gasoline fuels) has been used in the calculations.

Euro 1 vehicles:

Although COPERT III already included emission factors for Euro 1 vehicles, it was suggested to use the relatively large new sample (Table 2-3) to update the calculations. Hence, the emission factors for the Euro 1 vehicles used in this study were derived from the experimental data obtained from the EURO-WMTC and CITA studies. During these studies, the motorcycles were tested under the type approval cycles but also under a number of real world driving cycles (WMTC and Fachhochschule Biel driving cycles) incorporating urban, rural and highway parts and both cold-start and hot engine operation. The actual emission performance of the motorcycles under these different driving cycles provided the means for an estimation of the dependence of emission factors on mean travelling speed. This was done by corresponding the cycle average emissions to the average cycle speed. Table 2-4 displays the cycles considered in this analysis together with the corresponding average cycle speeds.

Figure 2-9 to Figure 2-12 show the cycle average emission levels of the different Euro 1 4-stroke motorcycles tested in the EURO-WMTC and CITA studies and the emission factors derived. Each dot in these charts corresponds to the actual emission of a particular vehicle over the mean cycle speed. The large dots correspond to the mean value of the vehicle sample over a particular cycle, and their polynomial trendline is the suggested emission factor function. The results from both cold start and hot start cycles have been used in this analysis, so the emission factors produced can be considered as a bulk value which also takes into account cold start emissions.

No experimental data were available at speeds higher than 60 km/h for class 1 motorcycles. The extrapolation of the trendline to higher speeds (i.e. highway driving conditions) yielded unreasonable estimations for exhaust HC and ultimate CO_2 emissions.

Therefore, a constant value equal to the corresponding one at 60 km/h was used at higher speeds for exhaust HC emissions. On the other hand, the average relative increase of class 2 and class 3 CO_2 over the corresponding levels at 60 km/h has been applied to estimate the CO_2 levels of these small 4-stroke motorcycles. This was deemed necessary in order to reflect the energy losses associated with the higher speed driving.

Table 2-4: Test cycles used in the EURO-WMTC and CITA studies and corresponding mean speeds.

Cycle	STUDY	Information	Average Speed [km/h]
Euro 1 type approval cycle	CITA/WMTC	Hot start	19
Euro 2 type approval cycle	WMTC	Hot start	19
Euro 3 type approval cycle (motorcycles having engine capacity smaller than 150 cc).	WMTC	Cold start	19
Euro 3 type approval cycle (motorcycles having engine capacity larger than 150 cc).	WMTC	Cold start	30
WMTC1 cold	WMTC	Cold start	24.5
WMTC1 hot	WMTC	Hot start	24.5
WMTC2	WMTC	Hot start	55
WMTC3	WMTC	Hot start	95
cold WMTC1 & hot WMTC1 (Weighting factors: 50%/50%)	WMTC	Cold start	24.5
cold WMTC1 & WMTC2 (Weighting factors: 30%/70%)	WMTC	Cold start	39.5
cold WMTC1 & WMTC2 & WMTC3 (Weighting factors: 25%/50%/25%)	WMTC	Cold start	58
4 UDCs + EUDC	WMTC	Cold start	33.5
Fachhochschule Biel cycle urban part	CITA	Hot start	22
Fachhochschule Biel cycle rural part	CITA	Hot start	29.5
Fachhochschule Biel cycle highway part	CITA	Hot start	50

The ultimate CO_2 emissions were calculated from the measured exhaust CO_2 emissions by adding the mass of CO and HC that will eventually became CO_2 in atmosphere, according to the formula:

$$E_{CO_2ultimate} = E_{CO_2tailpipe} + \frac{44.011}{28.011} \cdot E_{CO} + \frac{44.011}{13.85} \cdot E_{HC}$$ Eq. 2-2

Euro 2 – 3 vehicles:

The real world emission levels of the Euro 2 and Euro 3 4-stroke motorcycles were estimated based on the JRC data and using the CITA data to cross-check these estimations. As already mentioned, the vehicles equipped with an OxCat were regarded as Euro 2 motorcycles, while those equipped with TWC were regarded as Euro 3 ones. Unfortunately, the small datasets produced in this way did not allow to derive an engine displacement dependence for the emission factors.

In any case, the vehicles used to derive the emission factors for Euro 2 and Euro 3 technologies were originally certified as Euro 1 and, as a consequence, there were cases where the actual emissions over the relevant type approval cycle were greater than the corresponding emission standard limits assumed. In order to overcome this, we considered that the real-world emission factor corresponds to the WMTC driving behaviour. Hence, when the actual emission level of a particular vehicle over the Type-Approval cycle (TA) is lower than the emission standard (ES) considered, then the emission factor (EF) is the emission level over the WMTC cycle, i.e.:

$$E_{TA} \leq ES \rightarrow EF = E_{WMTC}$$ Eq. 2-3

On the other hand, when the vehicle emission level over the TA is higher than the ES considered, then we scale the WMTC emission value with the ratio of the emission standard over the actual emission level. That is:

$$E_{TA} > ES \rightarrow EF = E_{WMTC} \cdot \frac{ES}{E_{TA}}$$ Eq. 2-4

With this method, we emphasize on the behaviour of the different technologies in different driving situations, while the absolute emission level is adjusted to the expected emission standard levels. We believe that this is the best approximation possible, given the lack of emission information from actual Euro 3 vehicles.

In order to estimate emission factors separately for urban, rural and highway driving conditions we utilized the emission values over the WMTC1 cold, WMTC2 and WMTC3 subcycles as approximations of the actual driving performance. We used the WMTC1 cold results instead of the WMTC1 hot ones, to account for the cold start emissions that occur mainly under urban driving conditions.

This approach was applied for HC, CO and NO_x emissions. Ultimate CO_2 emissions were left equal to the Euro 1 case. Unfortunately, there are no reliable data to estimate whether any particular change in the efficiency of 4-stroke engines has taken place, at least at a magnitude that could have a positive effect on CO_2 emissions (the situation is different for 2-stroke engines). In a similar question, no particular trend has been observed for CO_2 emissions in gasoline passenger cars, where any improvement in the drivetrain efficiency is counterbalanced or even exceeded by the increase in fuel consumption due to the increase in average vehicle weight. Whether this will also be the situation for motorcycles where the performance increase is the major requirement, is presently not known.

Based on these considerations and approaches, Figure 2-13 to Figure 2-16 summarize the 4-stroke motorcycle emission factors used in this study for typical speeds of urban, rural and highway conditions (25, 55 and 95 km/h respectively).

2.2.1.2 Gaseous pollutants of 2-stroke motorcycles

Conventional & Euro 1 vehicles:

The original emission factors incorporated in COPERT III have been used for the conventional and Euro 1 2-stroke vehicles. This provided the means for a speed dependency of the emissions, since the emission factors are given as a 2nd order polynomial of mean travelling speed.

Euro 2 vehicles:

Neither the EURO-WMTC nor the CITA studies included sufficient information to deduce the emission behaviour of later than Euro 1 2-stroke motorcycles. Hence, as a best approximation, we decided to deduce the HC and CO emission levels from the Euro 1 emission factors, using the ratio of the corresponding emission standard limits as a scaling parameter, i.e.:

$$EF_{Euro2} = EF_{Euro1} \cdot \frac{ES_{Euro2}}{ES_{Euro1}} \qquad \text{Eq. 2-5}$$

It was not considered appropriate to calculate NO_x and CO_2 emissions on the same principle though, due to the particularity in the performance of DI motorcycles, introduced for some types of 2-stroke Euro 2 motorcycles. Based on limited experimental evidence (Rijkeboer et al. 2002, EURO WMTC 2003) which in any case replicates the trends expected, it has been assumed that DI vehicles will exhibit 10 times higher NO_x emissions and will consume 30 % less fuel than their carburettor equipped counterparts. This is the outcome of the much leaner operation of DI engines (higher NO_x), and the increase in their efficiency due to limited scavenging losses. For non-DI vehicles, no particular shift of CO_2 and NO_x emissions over their Euro 1 predecessors has been assumed, because CO_2 and NO_x emissions have not been targeted by the regulation. A 30% share of DI over carburettor Euro 2 2-stroke motorcycles was considered, after oral exchange of information with ACEM. This share is expected to increase for late model Euro 2 vehicles but in any case the sensitivity of the final emissions to this ratio is small and hence it was not further researched. Based on these assumptions, the mean NO_x and CO_2 emissions for 2-stroke Euro 2 motorcycles were calculated as:

$$CO_{2,Euro2} = CO_{2,Euro1} \cdot \left(70\% + 30\% \cdot 0.7\right) \quad \text{Eq. 2-6}$$

and:

$$NO_{x,Euro2} = NO_{x,Euro1} \cdot \left(70\% + 30\% \cdot 10\right) \quad \text{Eq. 2-7}$$

Euro 3 vehicles:

A similar approach to the one used for Euro 2 vehicles was also introduced for Euro 3 levels. However, since the Euro 3 type approval cycle is different from the Euro 2 one, the application of **Eq. 2-5** was not straightforward but equivalent Euro 3 emission limits that would correspond to the Euro 2 type approval cycle should be first estimated. Both the Euro 2 and Euro 3 type approval cycles include 6 repetitions of the UDC cycle (it has been assumed that all 2-stroke motorcycles have an engine capacity lower than 150 cc) but the Euro 2 standard requires sampling from the 4 last UDCs while the Euro 3 requires sampling from the beginning of the procedure. It has been assumed that the averaged HC and CO emissions over the first two UDCs are 200% and 150% higher than those over the last four UDCs . These values were deduced from engineering judgment taking into account estimations of ACEM (ACEM 2002a) and experimental data (EURO-WMTC 2003) on 2-stroke mopeds, and reflect the cold-start effect on the catalyst (all Euro 3 vehicles are considered catalyst equipped). Therefore, the Euro 3 limit values that would correspond to a Euro 2 type approval cycle would be:

$$ES_{Euro3(\text{Euro 2 type approval})} = \frac{ES_{Euro3}}{\frac{2}{3} + \frac{1}{3} \cdot \frac{Cold}{Hot}} \quad \text{Eq. 2-8}$$

where: Cold/Hot is 300% for HC and 250% for CO.

For the case of NO_x and ultimate CO_2, it has been assumed that all Euro 3 vehicles will be DI 2-stroke ones emitting the same levels of NO_x and ultimate CO_2 with their Euro 2 DI 2-stroke predecessors. That is:

$$CO_{2,Euro3} = 0.7 \cdot CO_{2,Euro1} \quad \text{Eq. 2-9}$$

and:

$$NO_{x,Euro3} = 10 \cdot NO_{x,Euro1}$$ Eq. 2-10

Although, these assumptions are rough approximations, it should be reminded that the share of 2-stroke motorcycles to post-2006 fleets is quite low (about 13 % of the total motorcycle fleet), therefore any uncertainties in the estimations of the emission factors are translated to a very small variation of the final emission result.

2.2.1.3 Gaseous pollutants for mopeds

Conventional, Euro 1 and Euro 2 mopeds:

COPERT III included emission factors for conventional, Euro 1 and Euro 2 mopeds. However, since the Euro 2 values were rather rough approximations, we decided to update these figures using emission information from 3 mopeds measured by JRC and included in the EURO-WMTC database. The sample included a conventional 2-stroke vehicle, a 2-stroke moped equipped with oxidation catalyst and a DI 2-stroke moped, all tested over the type approval cycle (ECE 47). These vehicles were regarded as representative of conventional, Euro 1 and Euro 2 mopeds respectively (based on their technology).

The emission factors for the regulated pollutants of the different moped technologies were estimated according to the formula:

$$EF_{EUROx} = EF_{ECE47} \cdot \left(70\% + 30\% \cdot \left(\frac{Cold}{Hot} \right)_{EUROx} \right)$$ **eq 2-11**

where E_{ECE47} is the actual emission over the hot part of the ECE 47 cycle (4 last repetitions of the base driving cycle) and Cold/Hot is the estimated contribution of cold start emissions. Table 2-5 shows the estimated cold start effect for the different moped technologies. These values were deduced taking into account the ACEM suggestions (ACEM, 2002a) and experimental data from the EURO-WMTC database.

Table 2-5: Estimated cold start effect for the mopeds of different emission standard (technology).

Cold/Hot	CO	HC	NOx
Euro 0 - Conventional (2-Str)	150%	200%	90%
Euro1 (2-Str+OxCat)	300%	200%	90%
Euro2 (2-Str+DI/4Str)	200%	200%	95%

No information on the CO_2 emissions or fuel consumption was available for these 3 mopeds and COPERT III included emission factors up to Euro 1. For Euro 2 vehicles, it has been assumed that 50 % of the vehicles will be 4-stroke, 15 % DI 2-stroke and 35 % will be 2-stroke equipped with carburettor and OxCat. 2-stroke carburetted vehicles were assumed to exhibit the same levels of CO_2 emissions with their Euro 1 predecessors while a 30 % lower fuel consumption has been assumed for the other two moped categories.

2.2.1.4 Gaseous pollutant emissions of 3 & 4 wheelers

There have been no experimental data on the emission performance of 3 and 4 wheelers available to the study team. Therefore, their emission behaviour has been solely based on the emissions of 2-wheelers. For 2-stroke 3 and 4 wheelers, 50 % higher emission factors than 2-stroke motorcycles of the corresponding emission standard were used, based on the manufacturers' proposal for 3 and 4 wheelers emission standards. Similarly, for diesel 3 and 4 wheelers, 50% higher emissions than diesel passenger cars of the corresponding technology (COPERT III 2000) were assumed, to reflect the less advanced engine and aftertreatment technology used in these vehicles. This applies to all gaseous pollutants except CO_2 where emissions of diesel 3 & 4 wheelers were assumed at 50% of the passenger cars level in order to reflect the smaller vehicle size. The emission factors of diesel and gasoline 3 & 4 wheelers are shown in Figure 2-19 and Figure 2-20 respectively.

2.2.1.5 Gaseous pollutants summary

The actual approach applied for the estimation of the emission factors of the gaseous pollutants for each PTW category is summarized in Table 2-6. Moreover, Table 2-7 shows the technology assumed necessary to reach the different emission standards.

2.2.1.6 PM emission factors

The PM emission factors used for each vehicle category are summarized in Table 2-8. The source for these values has been the evaluation of a number of available experimental studies (Ntziachristos et al., 2003; Rijkeboer et al., 2002; EURO-WMTC, 2003; ANCMA, 2002; RICARDO/ACEM, 2002; Rijkeboer 2002b) and engineering judgment on the PM emission evolution for upcoming vehicle technologies. Also, different emission factors were used for the 2-stroke vehicles, depending on the type of lubricating oil used (synthetic or mineral). In principle it is assumed that use of a fully synthetic oil reduces PM emissions by 20% over mineral oil levels. There is no solid experimental basis for this estimation. However, the range of PM emissions from 2-stroke motorcycles has been fully explored by Rijkeboer et al. (2002), where it was found that 50-95% of total PM may consist of semi-volatile material due to lubricant and fuel, escaping combustion. An ACEM/Ricardo study showed that an even higher share of total PM emissions is due to lubricant consumption (70% of total PM at an average). The use of synthetic oil is expected to reduce this contribution, first because a lower mixing ratio may be used, and secondly, because synthetic oil can be more efficiently combusted in the combustion chamber.

We estimated that the oil contribution in PM is reduced by 30% when using a synthetic oil which is reflected to a 20% total PM reduction (assuming that 70% of PM is due to oil). We believe it may be possible to achieve even larger reductions in reality, especially for white-smoke emitters, by reducing the mixing ratio when using synthetic oils. However, we had no experimental information to base such an argument.

2.2.2 Emissions Deterioration

The aforementioned emission levels correspond to the emission performance of relatively new vehicles. In order to take into account the effect of vehicle age in emission performance we may apply appropriate deterioration factors. USEPA in a previous work (USEPA 2002) suggested deterioration factors in the range of 5-65% per 10000 km for pre Tier 2 on-highway motorcycles. In this respect, an increase of 20 % per useful life in THC and CO emissions is suggested for all PTWs up to Euro 2. The corresponding deterioration factors for the Euro 3 PTWs are assumed to be 10 % per useful life, which for the case of 4-stroke vehicles extend to NO_x emissions as well. This has been decided to reflect the MVEG discussions on motorcycle durability requirements. Table 2-9 displays the estimated useful lifetimes for the different PTWs categories (according to the USEPA).

The deterioration concerned so far corresponds to the natural performance decrease of the emission control system and it is expected to occur even for well maintained vehicles. Additional deterioration of the mean fleet emissions may occur due to malfunctioning of the emission control devices for some vehicles. Finally, the mean emission performance may be degraded if the real-world emissions of a whole vehicle family fail to comply with the type approval limits for any reasons (defective components, errors in the production line, etc.). In order to simulate the emission degradation due to reasons, we have introduced appropriate deteriorations in our baseline scenario. Since these deteriorations are lifted when some additional policies are introduced (i.e. in-use compliance, OBD, etc.), we examine them in detail in the relevant sections (sections 4.2, 4.6 and 4.10).

In order to have a picture of the mean deterioration, Figure 2-21 shows the evolution of the emission factors for 4-stroke motorcycles >750cc (taking Italy as an example). The emission factors shown in these figures were calculated as the ratio of the total annual emissions from the vehicle fleet of a particular technology level (Conventional, Euro 1, etc.) over the annual total mileage driven by these vehicles.

Table 2-6: Sources and type of emission factors produced for the different PTW categories considered.

		Type	HC	CO	NOx	Ultimate CO_2
4-stroke	Conventional Class 1 - 2 - 3	f(V)	COPERT III			
	Euro 1 Class 1 - 2 - 3	f(V)	WMTC & CITA			
	Euro 2 All classes	U - R - H	WMTC (scaling with EF)			Euro I EF
	Euro 3 All classes	U - R - H	WMTC (scaling with EF)			Euro I EF
2-stroke	Conventional	f(V)	COPERT III			
	Euro 1	f(V)	COPERT III			
	Euro 2	f(V)	Euro 1 (Scaling with ES)		30 % DI	
	Euro 3	f(V)	Euro 1 (Scaling with ES)		100 % DI	
mopeds	Conventional	Single value	WMTC + Cold start			COPERT III
	Euro 1	Single value	WMTC + Cold start			COPERT III
	Euro 2	Single value	WMTC + Cold start			65 % DI + 4-str
Gasoline 3 & 4 Wheelers	Conventional	f(V)	1.5 · EF 2-stroke Conv			
	Euro 1	f(V)	1.5 · EF 2-stroke Euro 1			
	Euro 2	f(V)	1.5 · EF 2-stroke Euro 2			
	Euro 3	f(V)	1.5 · EF 2-stroke Euro 3			
Diesel 3 & 4 Wheelers	Conventional	f(V)	1.5 · EF Diesel PC Conv			0.5 · EF Diesel PC Conv
	Euro 1	f(V)	1.5 · EF Diesel PC Euro 1			0.5 · EF Diesel PC Euro 1
	Euro 2	f(V)	1.5 · EF Diesel PC Euro 2			0.5 · EF Diesel PC Euro 2
	Euro 3	f(V)	1.5 · EF Diesel PC Euro 3			0.5 · EF Diesel PC Euro 3

Table 2-7: 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	10%		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%
	Euro 3	30%	30%	70%

Table 2-8: PM emission factors for the different PTW categories.

PM EF [mg/km]		Mineral Oil	Synthetic Oil
2-stroke PTWs	Conventional	200	160
	Euro 1	80	65
	Euro 2	40	32
	Euro 3	12	10
4-stroke PTWs	Conventional	20	
	Euro 1	20	
	Euro 2	5	
	Euro 3	5	
Compression Ignition	Conventional	250	
	Euro 1	150	
	Euro 2	150	
	Euro 3	100	

Table 2-9: Useful life considered in the baseline scenario for different vehicle classes.

Vehicle Category	Mopeds	2-stroke	4-stroke			3 & 4 Wheelers
			<150cc	150-750cc	>750cc	
Useful life [km]	10000	12000	12000	30000	30000	12000

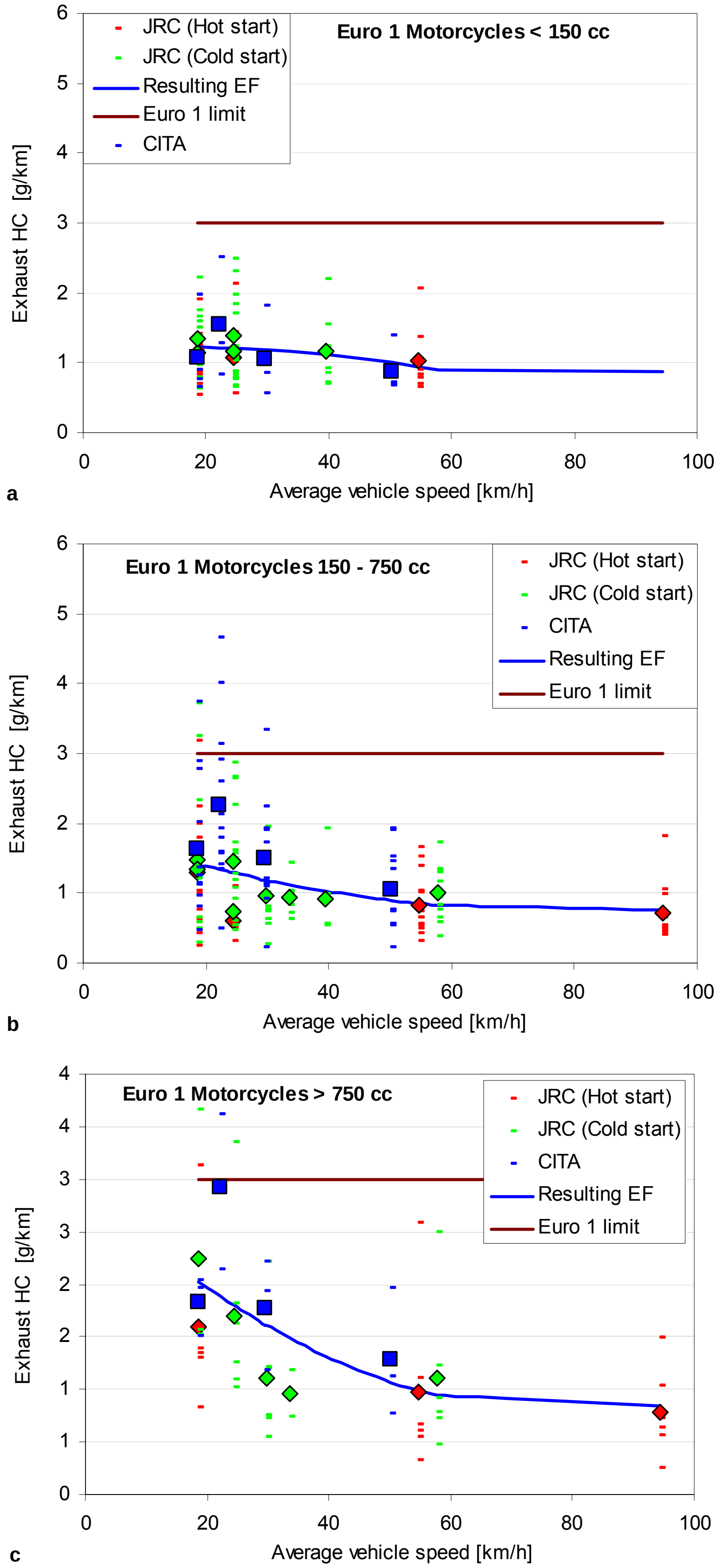


Figure 2-9: Derivation of the Euro 1 emission factors from the experimental data obtained from the JRC and CITA studies. Results for exhaust HC emissions.

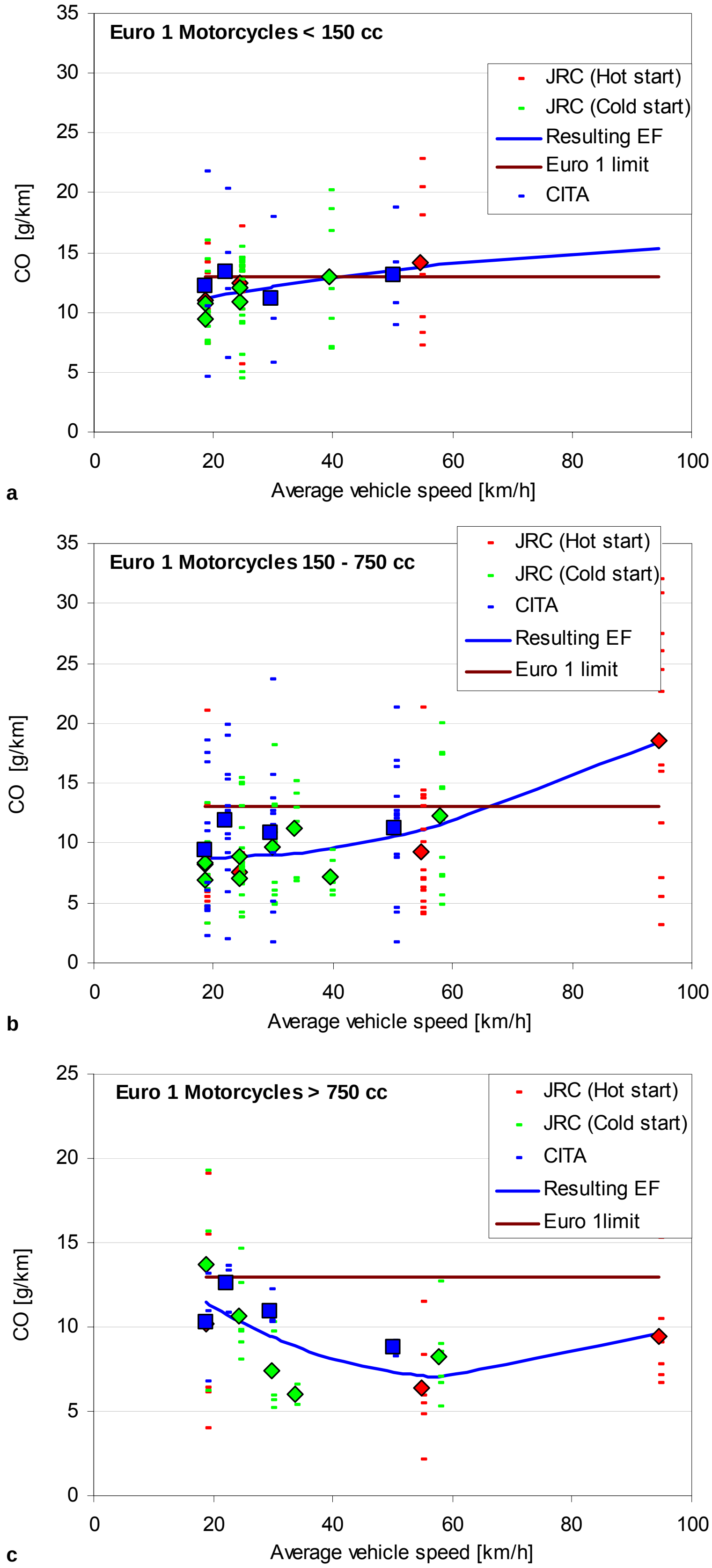
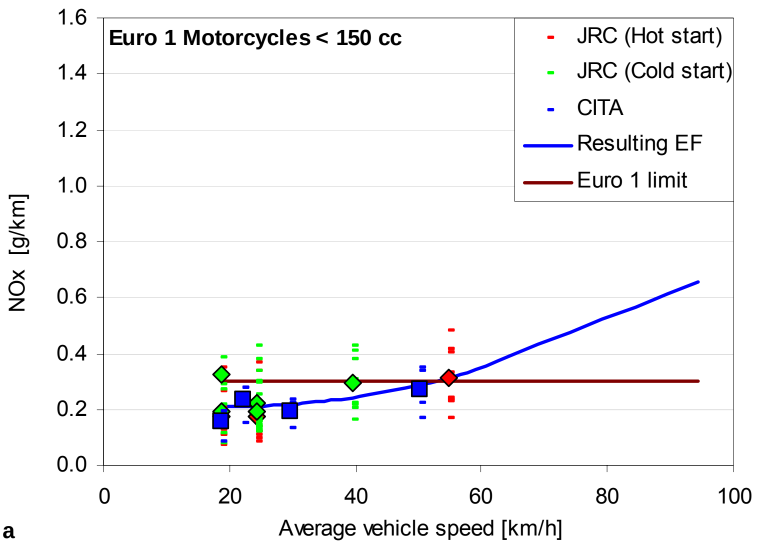


Figure 2-10: Derivation of the Euro 1 emission factors from the experimental data obtained from the JRC and CITA studies. Results for CO emissions.



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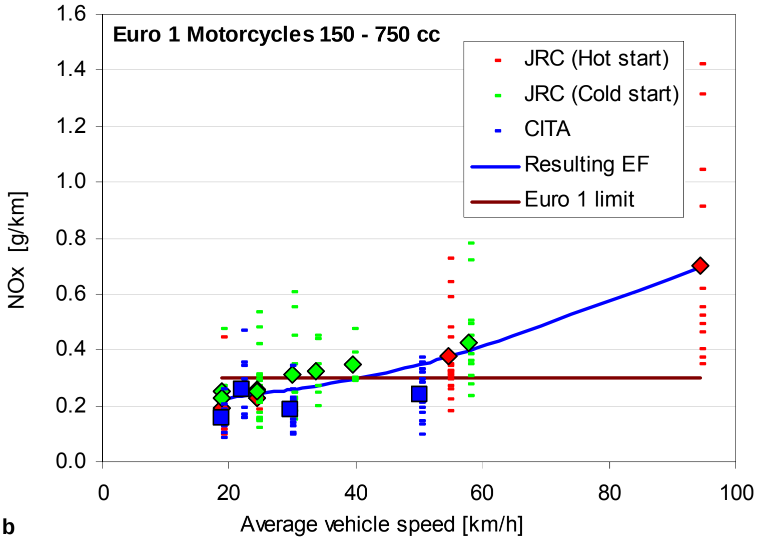

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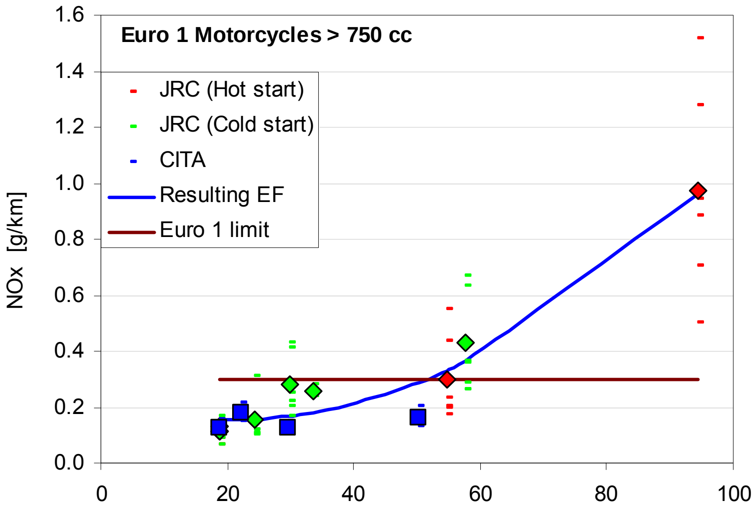


c

Figure 2-11: Derivation of the Euro 1 emission factors from the experimental data obtained from the JRC and CITA studies. Results for NO_x emissions.

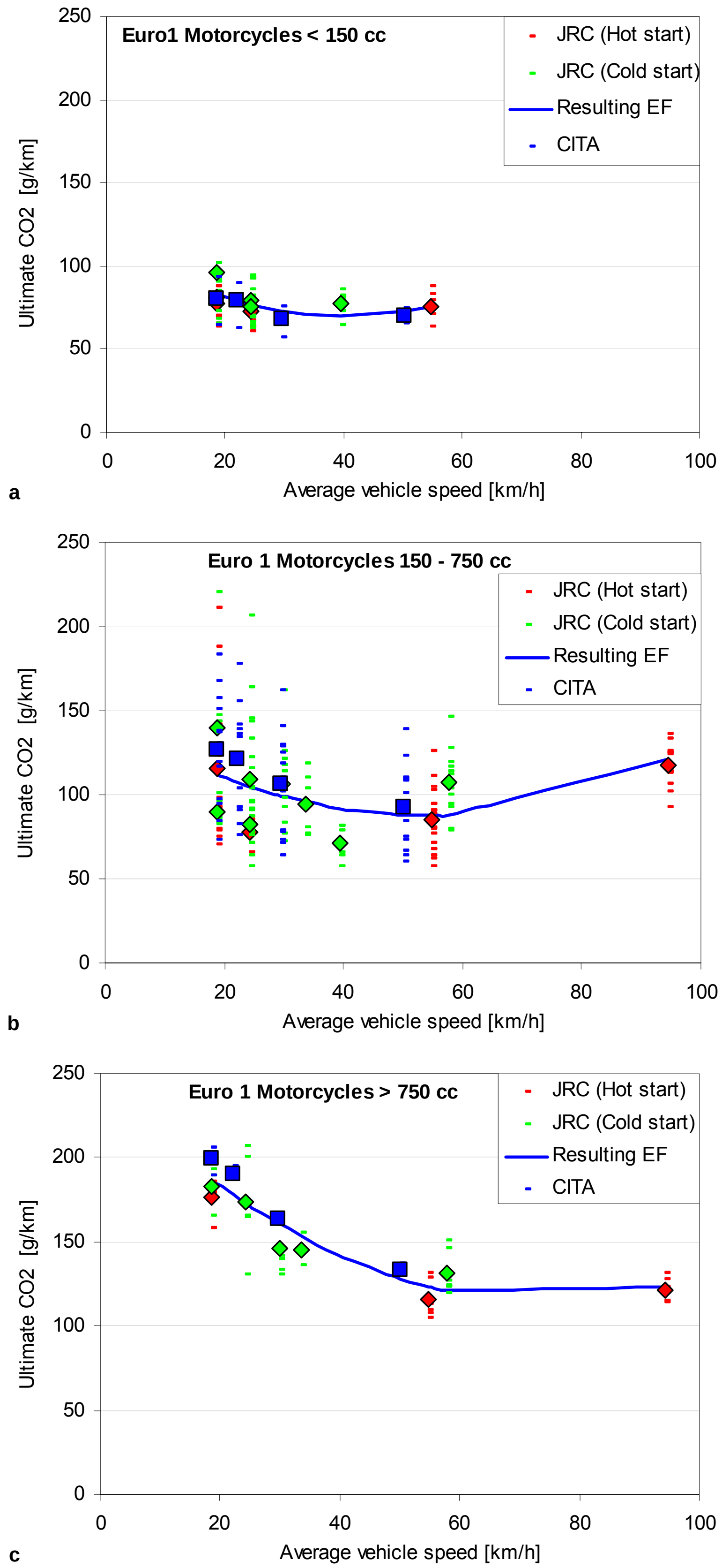


Figure 2-12: Derivation of the Euro 1 emission factors from the experimental data obtained from the JRC and CITA studies. Results for ultimate CO_2 emissions.

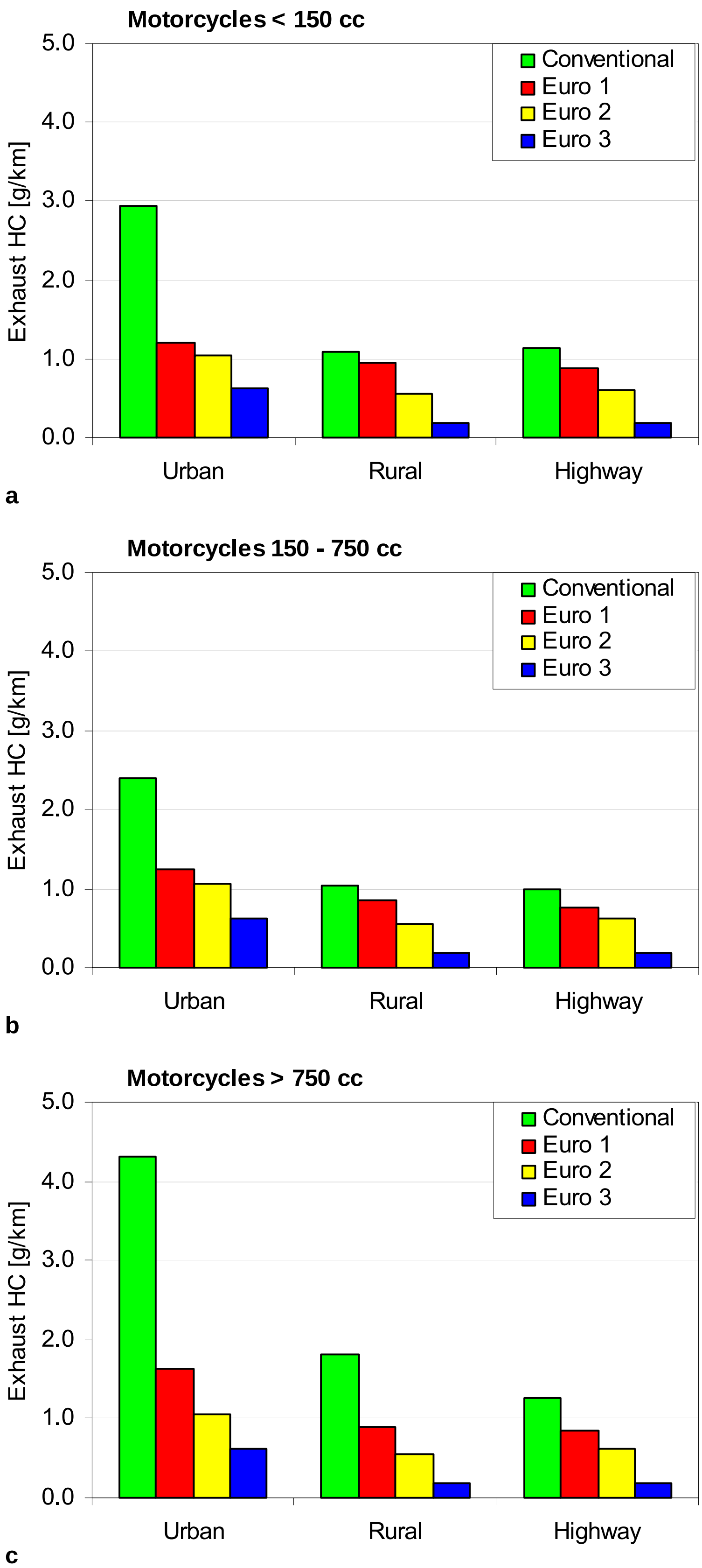


Figure 2-13: Proposed exhaust HC emission factors for 4-stroke motorcycles. The urban, rural and highway emission factors of the conventional and Euro 1 vehicles shown were calculated for average speeds of 25, 55 and 95 km/h respectively.

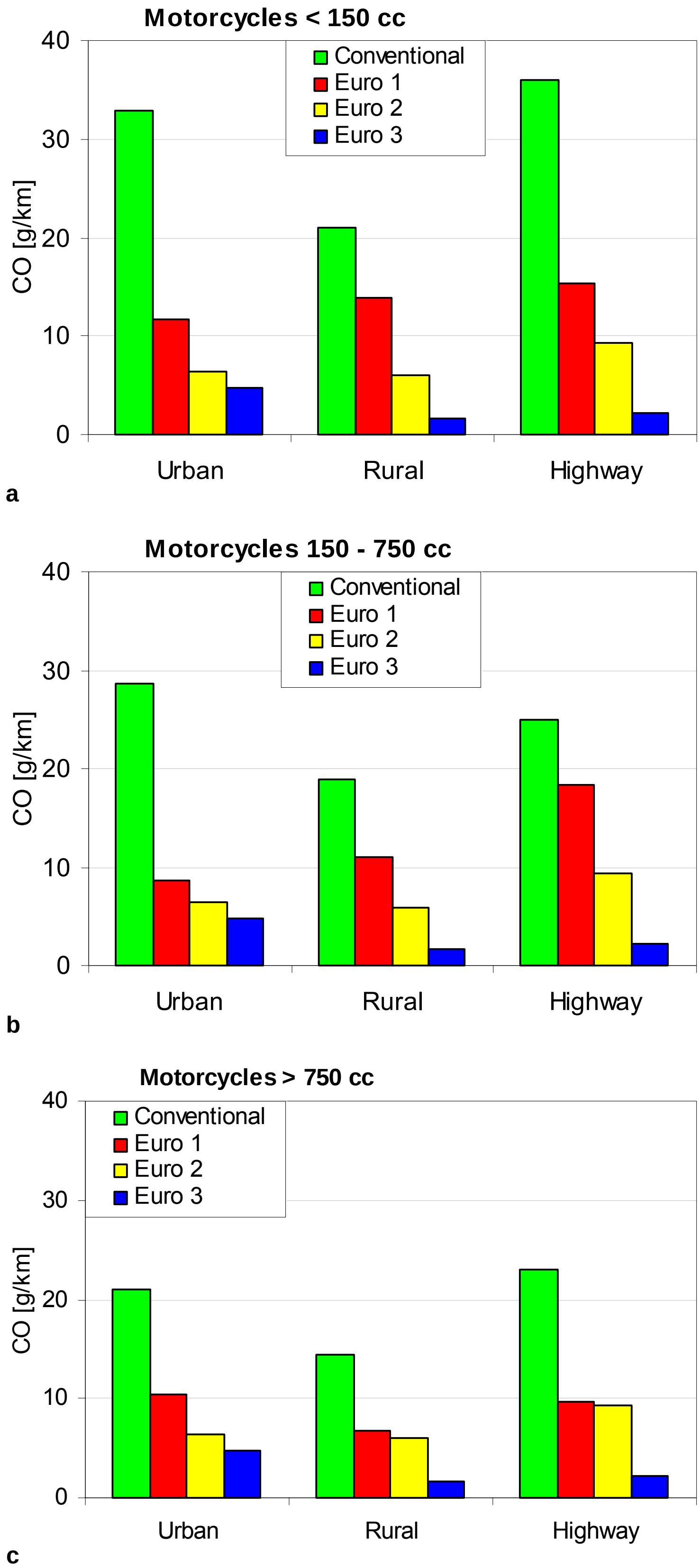


Figure 2-14: Proposed CO emission factors for 4-stroke motorcycles. Calculations described in caption of Figure 2-13.

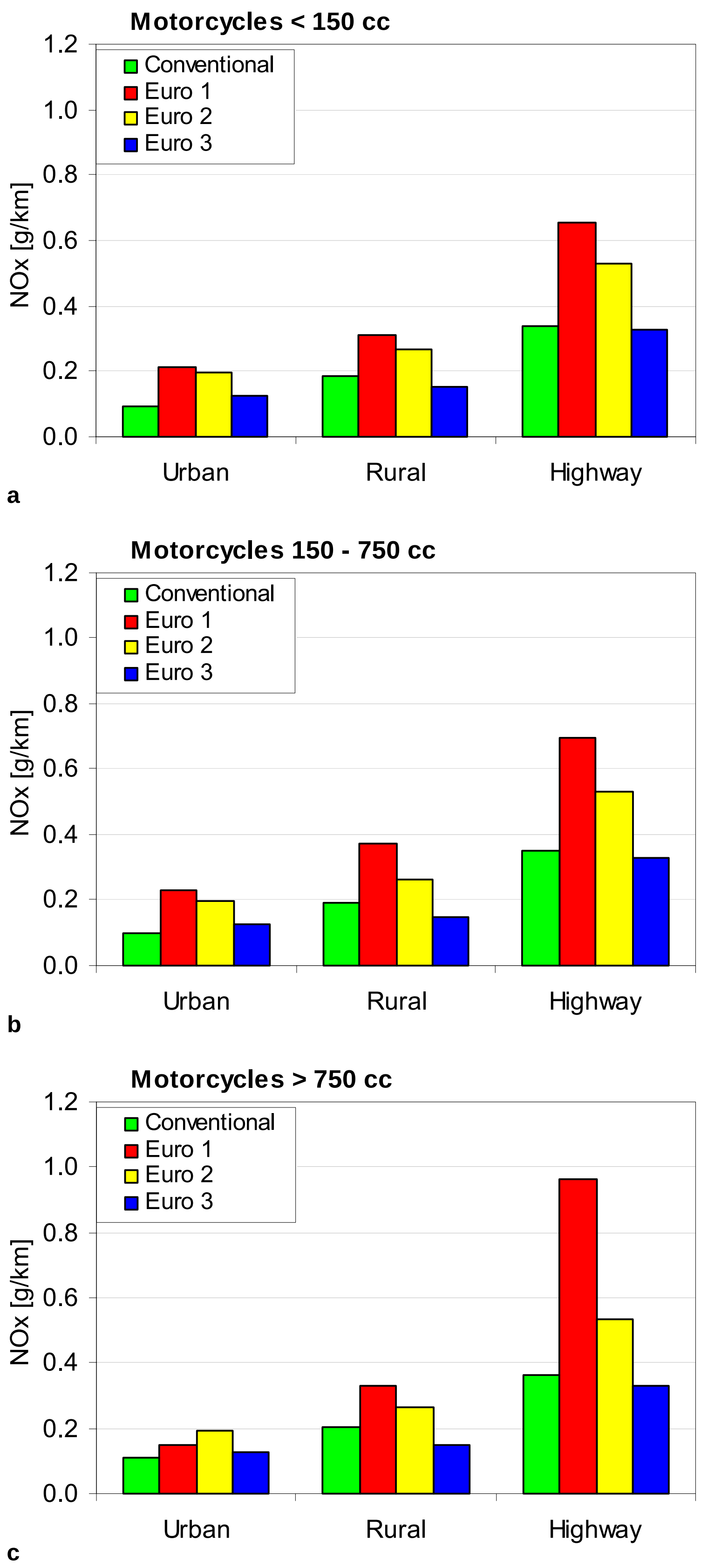


Figure 2-15: Proposed NO_x emission factors for 4-stroke motorcycles. Calculations described in caption of Figure 2-13.

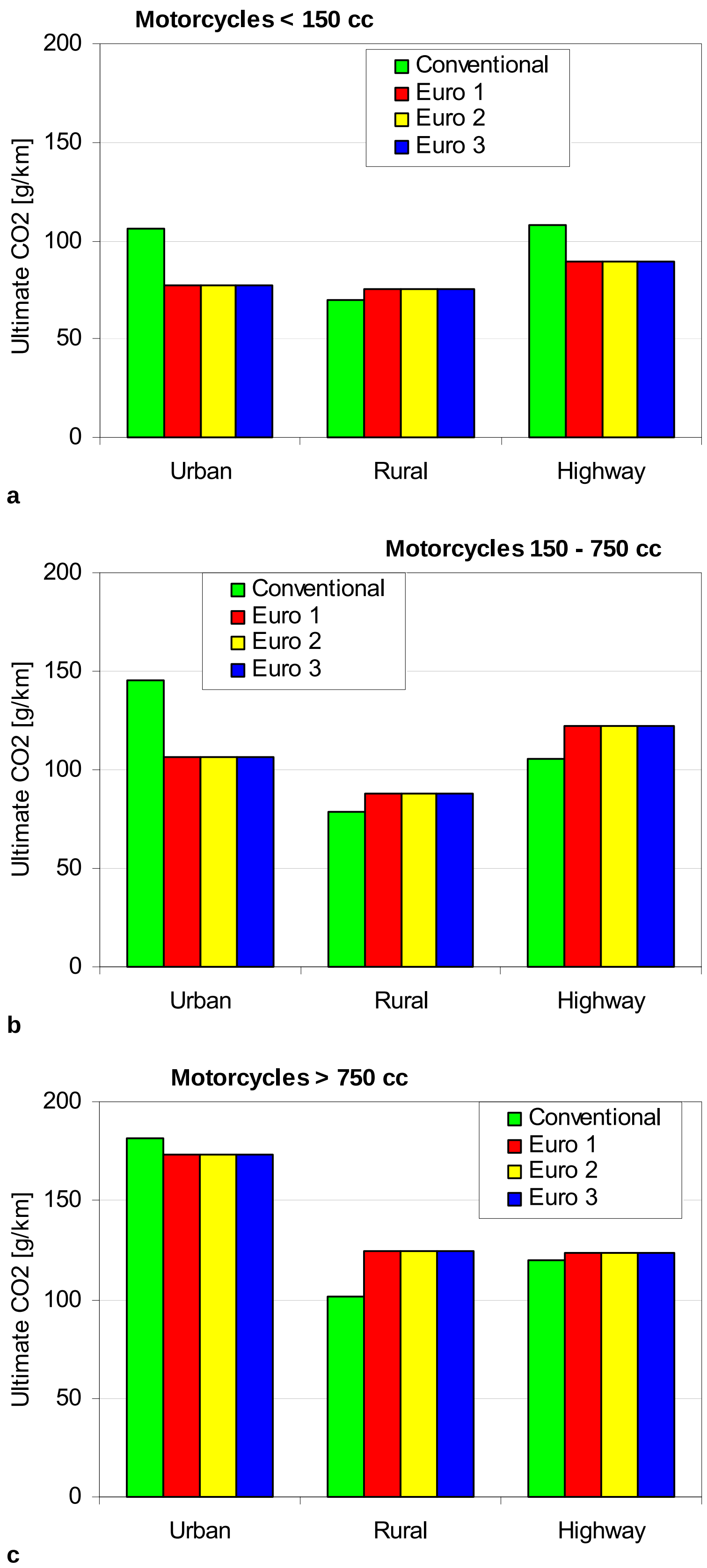


Figure 2-16: Proposed ultimate CO_2 emission factors for 4-stroke motorcycles. Calculations described in caption of Figure 2-13.

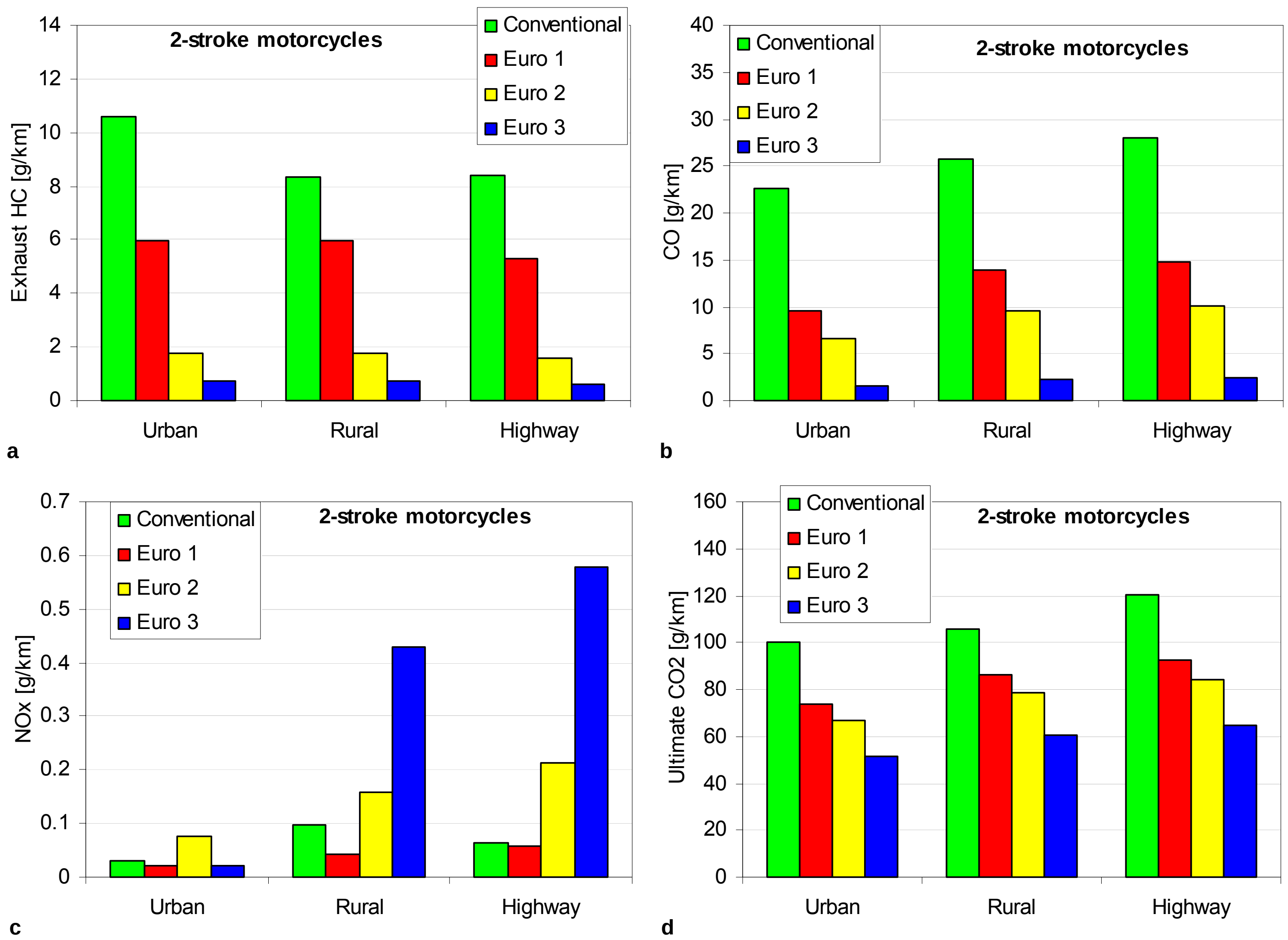


Figure 2-17: Proposed emission factors for 2-stroke motorcycles. Calculations described in caption of Figure 2-13.

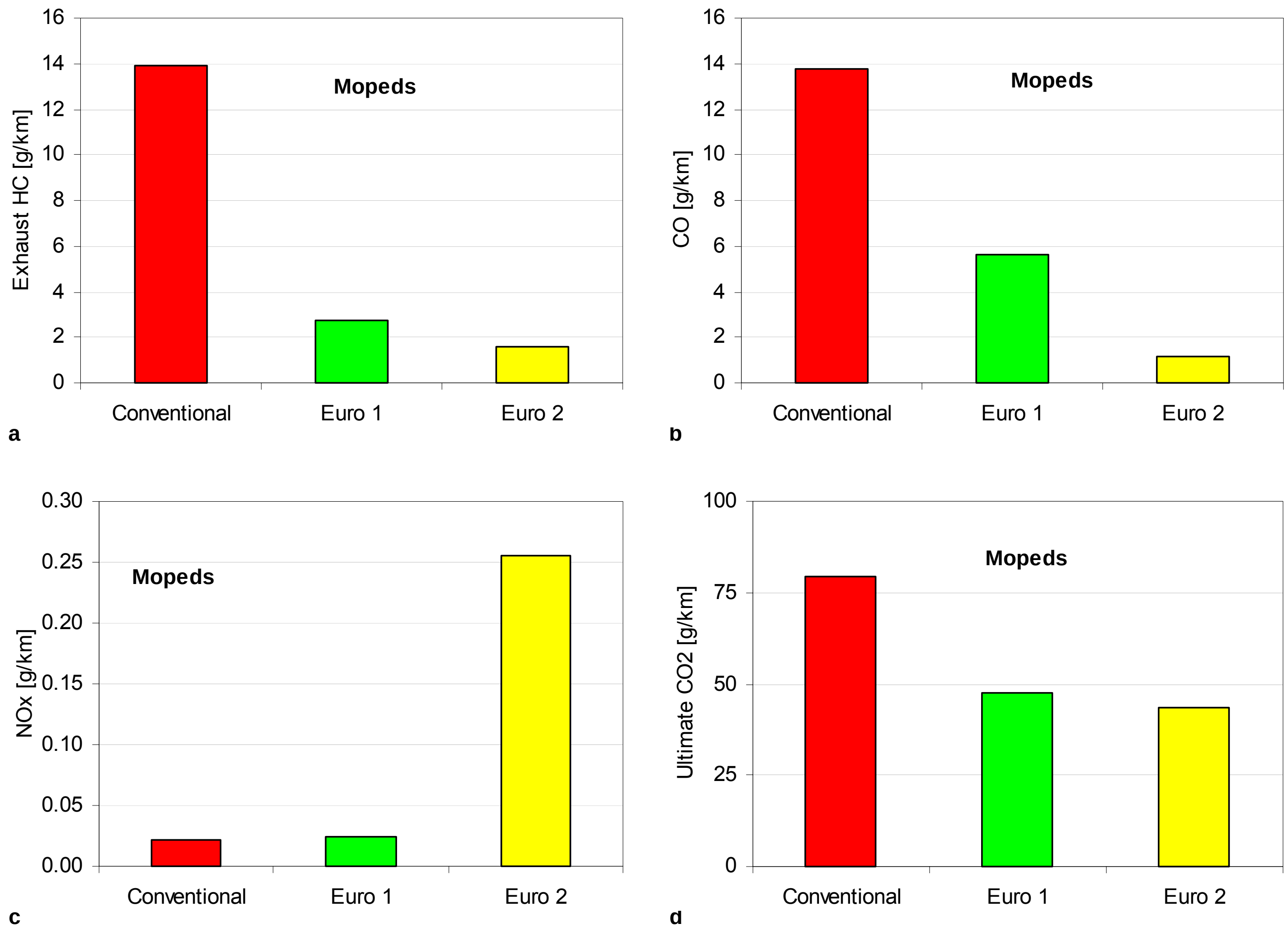


Figure 2-18: Proposed emission factors for mopeds.

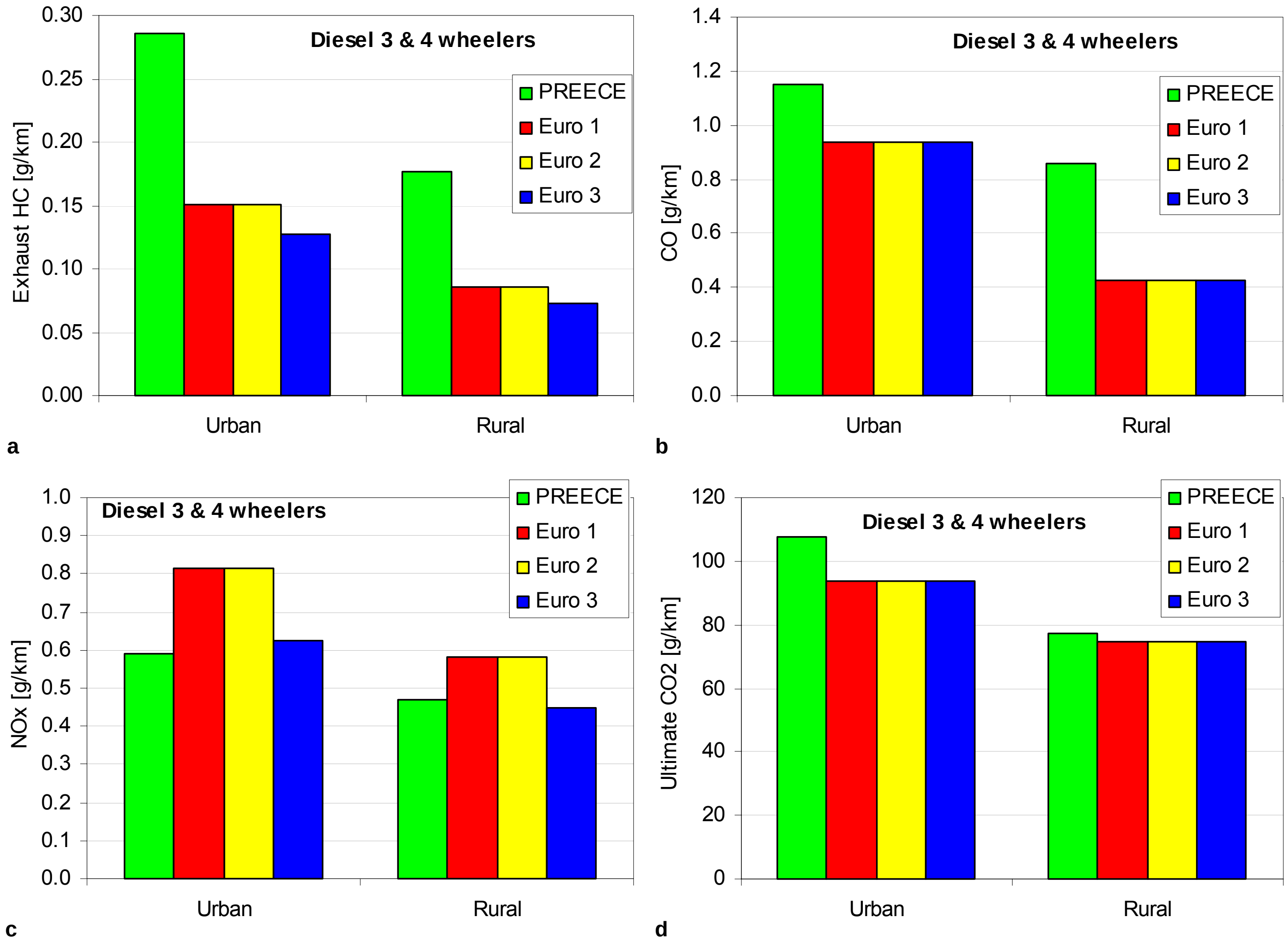


Figure 2-19: Proposed emission factors for diesel 3 & 4 wheelers.

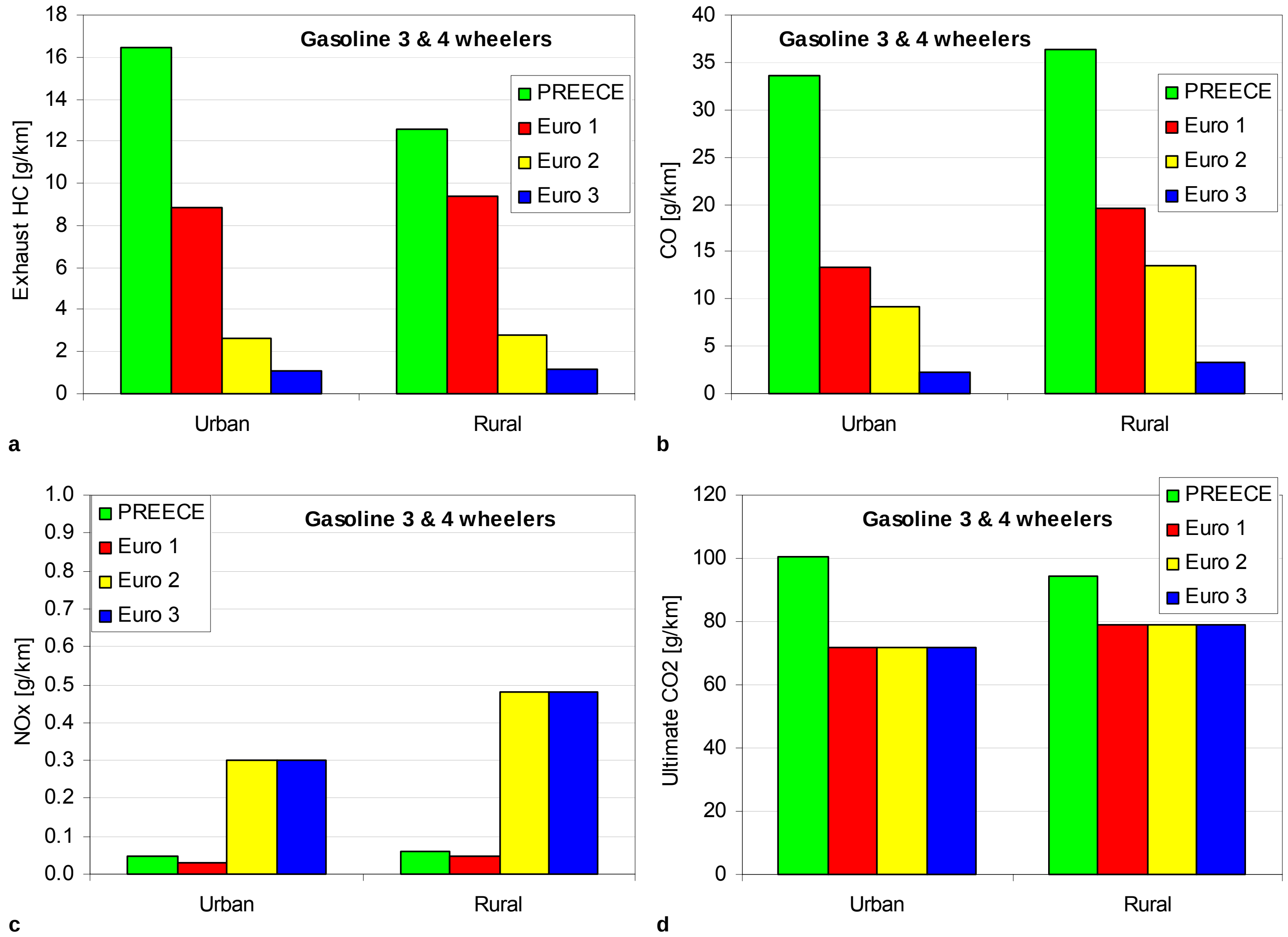


Figure 2-20: Proposed emission factors for spark ignition 3 & 4 wheelers.

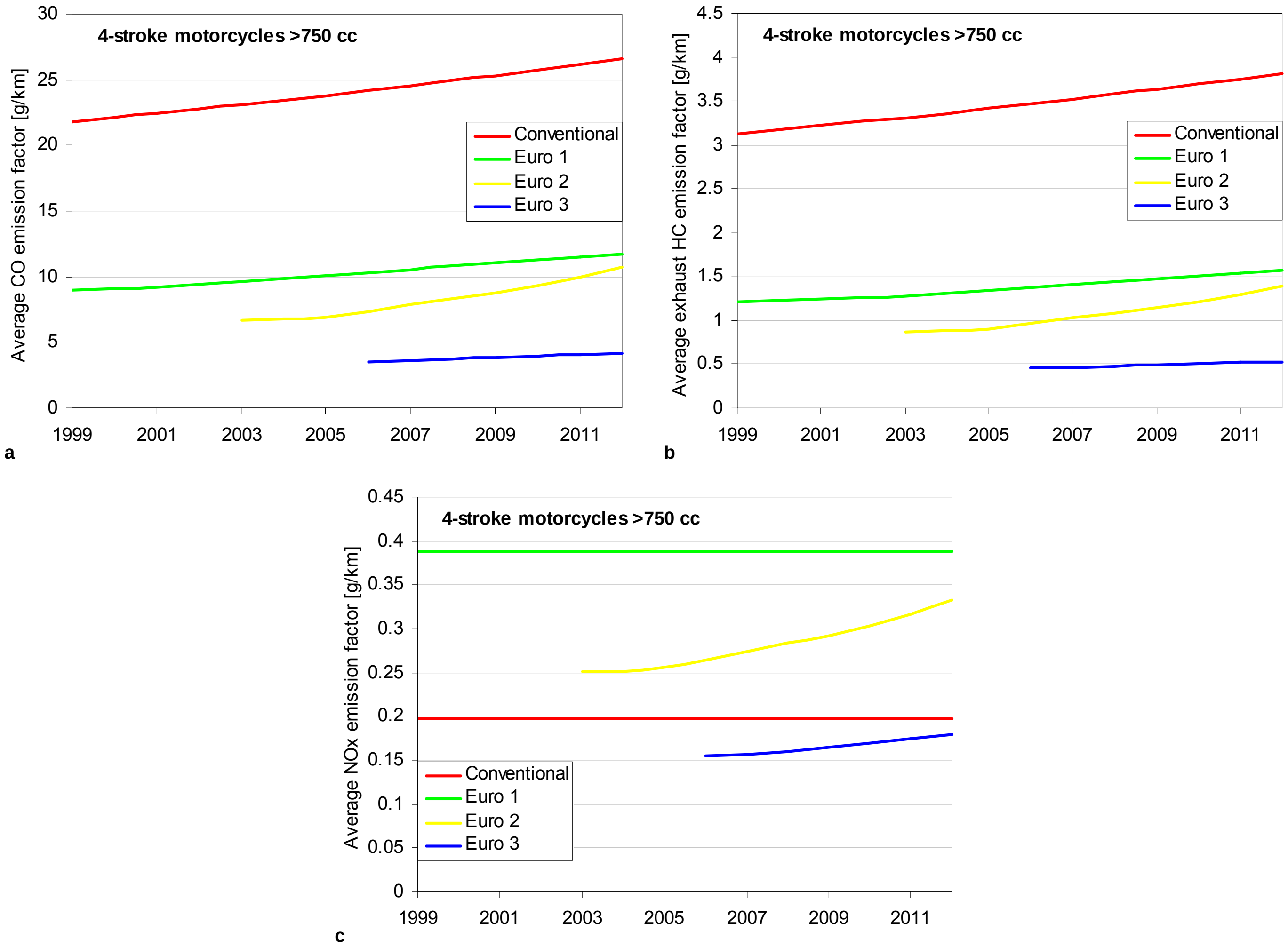


Figure 2-21: Evolution of the average fleet emission factors for each regulated pollutant in Italy (taking 4-stroke motorcycles as an example).

2.2.3 Evaporative Emissions

The COPERT III methodology of estimating evaporation emissions for passenger cars has been also transferred to PTW. COPERT III evaporation emission factors are based on tests conducted in the 90s on - mainly - uncontrolled passenger cars, and have been revised accordingly taking into account new experimental evidence which has been provided by UBA (Federal Environmental Agency Germany 2002, Kolke 2002, 2003a, 2003b). Evaporation losses calculation takes into account fuel evaporation which occurs due to diurnal, soak and running losses.

Compared to passenger cars, fuel evaporation from motorcycles should be expected to be lower due to their smaller fuel tanks. On the other hand, the fuel tank is located close to the engine and the mean fuel temperature might be higher than in the passenger cars case, thus promoting evaporation. Evaporation emissions in the future are expected to decrease primarily due to the gradual replacement of carburettors with sealed fuel injection systems, which practically halve soak and running losses. The legislation may additionally intervene to force the application of tank vent canisters and low permeability tank and transfer lines to eliminate diurnal losses.

Diurnal losses:

In the UBA study the evaporative emissions of 10 motorcycles were measured by applying a simplified SHED procedure. Figure 2-22 displays the resulted diurnal losses of the uncontrolled motorcycles (7 in total – one of the carburettor equipped motorcycles was regarded as an outlier and was excluded from any further analysis). The diurnal losses of each vehicle are plotted against the engine size. A weak dependence of diurnal losses on engine size can be seen, due to the larger fuel tank as motorcycle size increases. For comparison, the red line corresponds to the diurnal losses of a passenger car under the conditions of the SHED procedure (assuming a fuel RVP value of 70 kPa). A comparison of the two lines indicates that the actual evaporative emissions of the uncontrolled motorcycles are 25 – 60 % (depending on engine size) lower than those predicted from the COPERT III methodology for cars. This relationship was assumed to hold true under all ambient conditions, and has been used in order to estimate the evaporative emissions of PTWs in this study. Figure 2-8 displays the estimated diurnal losses of two motorcycles of different engine capacity under different ambient conditions. It can be seen that the larger the motorcycle (and therefore the fuel tank) the higher the diurnal losses as well as their dependence on ambient conditions. The average engine capacities of the different PTW classes used in the calculations are shown in Table 2-10.

Soak and running losses

In addition to diurnal losses, hot soak emissions levels were also monitored in the UBA study. Figure 2-22 displays the measured hot soak emissions of the different uncontrolled motorcycles tested. As expected, no dependence on engine size was found because soak losses occur in the carburettor or engine vents which are not necessarily related to engine size. The average hot soak emissions were found at ~1.7 g/hot soak procedure. The COPERT III estimation for hot soak emissions of an uncontrolled PC under the conditions of the SHED procedure is about 12 g/km, i.e. 7.2 times higher than the motorcycle levels. Again this ratio was assumed to hold true under all ambient conditions, and it has been used to relate the COPERT III estimations on warm soak and running losses with the actual motorcycle emissions.

Table 2-10: Average engine capacity of the different PTW categories used in the evaporative emission calculations.

PTW Category	Mopeds	2-stroke	4-stroke			Gasoline 3 & 4 Wheelers
			<150 cc	**150-750 cc**	**>750 cc**	
Engine capacity [cc]	50	125	125	500	850	125

The experimental data from two fuel injection vehicles in the UBA study provided the means for the estimation of the efficiency of the fuel injection system in reducing soak emissions and running losses. On average, the hot soak emissions of fuel injection vehicles were found at a 47 % of the carburettor vehicles level. Therefore, it has been assumed that the fuel injection system has a 53 % efficiency in reducing soak and running losses. Table 2-11 shows the share of fuel injected PTWs considered in the calculations, depending on vehicle category and emission standard level.

The evaporative emissions generally depend on the RVP of the gasoline fuel as well as the average ambient temperature and its daily variation. Since these values differ from country to country, but also vary during a calculation year, separate calculations were performed for each country and for each month of the year. The necessary information on climatic conditions and fuel properties for each country was collected for each member state in the framework of the COPERT III application and has been also used in the present study. The values used are summarized in Table 2-12 to Table 2-14. These values have been submitted by the national experts in each country and may differ in their assumptions. This is responsible for unreasonable deviations between different countries. In the absence of more reliable information, these values have been retained.

In addition to hot soak and diurnal losses, COPERT III methodology also includes running losses and warm soak evaporation. A similar scaling to hot soak emissions was also conducted in these cases.

In order to provide a frame of reference for PTW evaporation losses, Figure 2-25 provides a comparison of the annual evaporation emissions between the present estimate and the estimate of UBA in the MVEG in the case of a conventional motorcycle operating in Germany.

Table 2-11: Share of fuel injected PTWs for the different emission classes.

Share of FI PTWs	Mopeds	2-stroke	4-stroke		
			< 150 cc	150-750 cc	> 750 cc
Conventional	0 %	0 %	0 %	0 %	0 %
Euro I	0 %	0 %	0 %	0 %	0 %
Euro II	15 %	30 %	20 %	50 %	100 %
Euro III	100 %	100 %	100 %	100 %	100 %

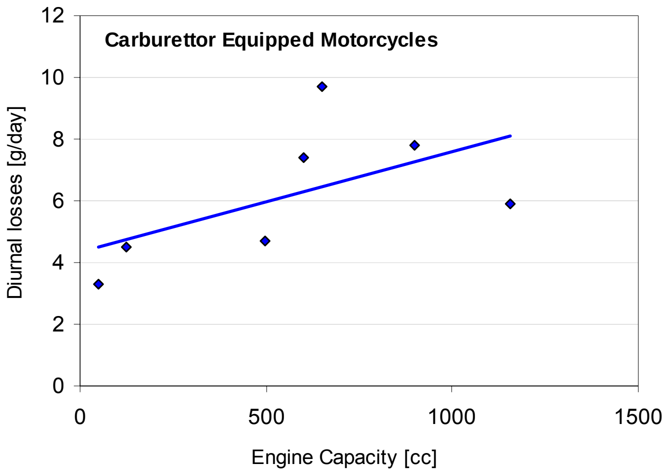


Figure 2-22: Measured diurnal losses of 7 uncontrolled (carburettor equipped) motorcycles and association with engine capacity.

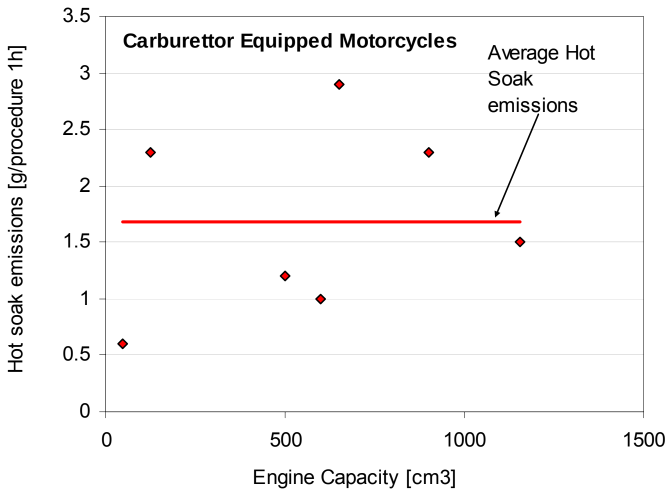
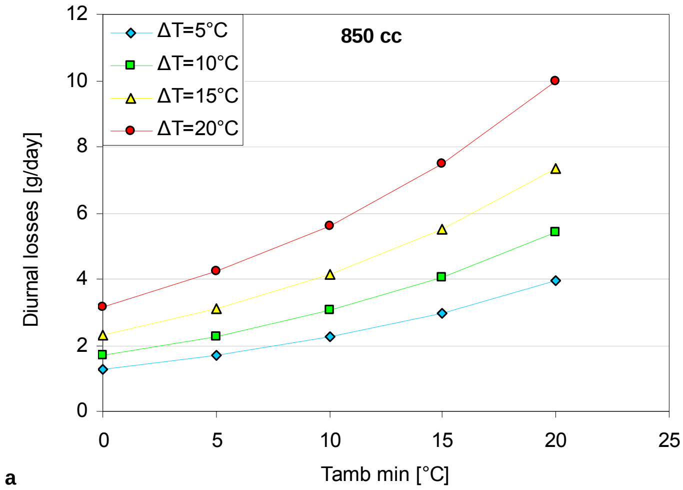


Figure 2-23: Measured hot soak emissions from 7 uncontrolled motorcycles. No association to engine capacity observed.



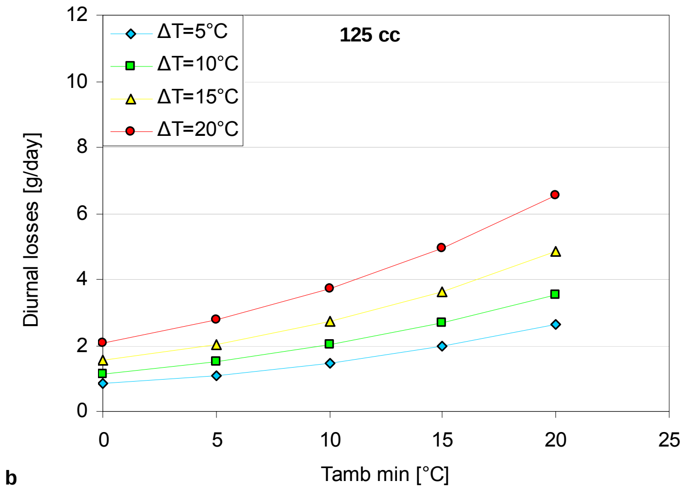


Figure 2-24: Examples of diurnal evaporation losses per day for uncontrolled motorcycles of 850 cm³ (up) and 125 cm³ (low) engine capacity.

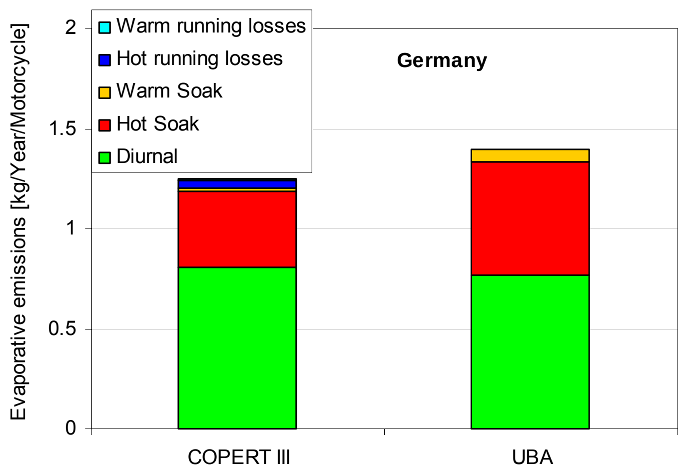


Figure 2-25: Comparison of the COPERT III and UBA estimations on annual evaporative emissions of uncontrolled motorcycles in Germany.

Table 2-12: Monthly RVP of gasoline fuels for each EU15 member state.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Austria	80	80	80	60	60	60	60	60	60	80	80	80
Denmark	95	95	90	90	85	85	85	85	90	90	95	95
Finland	96	96	86	86	77	77	77	77	77	96	96	96
Luxembourg	90	90	85	85	70	65	65	65	70	70	85	90
UK	80	80	80	65	65	65	65	65	65	80	80	80
France	80	80	80	65	65	65	65	65	65	80	80	80
Germany	80	80	80	60	60	60	60	60	60	80	80	80
Italy	85	85	75	75	75	75	75	75	75	75	85	85
Netherlands	95	95	95	45	45	45	45	45	45	95	95	95
Portugal	85	85	75	75	75	75	75	75	75	75	85	85
Sweden	96	96	86	86	77	77	77	77	77	96	96	96
Spain	85	85	75	75	75	75	75	75	75	75	85	85
Greece	80	80	80	64	64	64	64	64	80	80	80	80
Belgium	95	95	95	45	45	45	45	45	45	95	95	95
Ireland	125	125	110	110	110	95	95	95	110	110	120	125

Table 2-13: Maximum monthly ambient temperature for each EU15 member state (data submitted by national experts in each country).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Austria	2.6	8.9	11.8	13.0	19.3	20.3	23.0	24.2	16.4	14.6	6.3	0.4
Denmark	5.9	7.9	9.4	11.6	17.0	18.6	20.1	21.6	15.3	12.6	6.9	4.7
Finland	-5	-5	-0.5	6	14	18	22	19	14	7	2	-1.5
Luxembourg	12.2	17.1	21.2	23.7	28.4	34.5	34.2	35.9	23.6	24.1	12.2	13.4
UK	9.1	13.8	14.6	14.1	21.8	21.5	26.2	27.2	22	18.4	10.7	6.1
France	9.1	13.8	14.6	14.1	21.8	21.5	26.2	27.2	22	18.4	10.7	6.1
Germany	9.1	13.8	14.6	14.1	21.8	21.5	26.2	27.2	22	18.4	10.7	6.1
Italy	7.7	9	12.8	15.7	20.3	25.4	28	27.4	24.3	18.5	12.6	9.3
Netherlands	9.1	13.8	14.6	14.1	21.8	21.5	26.2	27.2	22	18.4	10.7	6.1
Portugal	14	15.7	18.2	20.9	22.5	26.1	28.9	29.3	27.2	23	17.8	14.4
Sweden	4.3	6.7	10.3	14.2	18.4	22	22.7	22.3	20.5	15.4	8.9	5.6
Spain	9.1	13.8	14.6	14.1	21.8	21.5	26.2	27.2	22	18.4	10.7	6.1
Greece	12.9	13.9	15.5	20.2	25	29.9	33.2	33.1	29	23.8	18.6	14.6
Belgium	7.9	11.6	12.5	13.8	20.2	19.5	23.4	25.8	18	16.7	9.5	6.4
Ireland	10.1	10	11.9	12.2	16.5	16.7	19.9	20.6	17	14	10.3	7.8

Table 2-14: Minimum monthly ambient temperature for each EU15 member state (data submitted by national experts in each country).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Austria	-5.9	-1.6	1	2	6.9	9.4	10.4	11.1	6.9	4.5	-0.5	-5.7
Denmark	2.4	3.1	2.8	3.2	7.2	10.9	11.6	12.4	8.6	6.9	1.6	0.5
Finland	-11	-11	-9	-2.5	3	9	12	10	6	1.5	-2.5	-7
Luxembourg	-2.8	-4	-3.1	-3.9	-0.1	2.1	3.9	5	0.5	-0.4	-3.9	-7.4
UK	1.6	5.4	4.1	5	10.2	11.9	14.1	14.7	10.7	9.8	4.8	0.2
France	1.6	5.4	4.1	5	10.2	11.9	14.1	14.7	10.7	9.8	4.8	0.2
Germany	1.6	5.4	4.1	5	10.2	11.9	14.1	14.7	10.7	9.8	4.8	0.2
Italy	0.6	1.4	4.5	6.5	10.4	14.8	17	16.8	14.6	10.2	5.2	2.7
Netherlands	1.6	5.4	4.1	5	10.2	11.9	14.1	14.7	10.7	9.8	4.8	0.2
Portugal	5.4	5.8	8.2	9.3	11	13.6	14.9	15	14.1	11.1	8.7	6.1
Sweden	-1.2	0.3	2.2	5.1	7.9	10.9	12.1	12.2	10.6	7.3	3.1	0.2
Spain	1.6	5.4	4.1	5	10.2	11.9	14.1	14.7	10.7	9.8	4.8	0.2
Greece	6.4	6.7	7.8	11.3	15.9	20	22.8	22.8	19.3	15.4	11.7	8.2
Belgium	3	4.3	4.3	3.7	8.4	10.6	11.6	13.6	8.8	8.6	3.6	1.8
Ireland	4.5	4.2	5.8	4.2	8.6	9.8	12.2	13	8.6	9.1	4.8	2.6

2.3 Activity data

Exhaust motorcycle emissions strongly depend on driving conditions. In order to account for the different driving behaviour and vehicle usage in each EU15 country, separate calculations were made for each member state. The activity data used in the calculations originate from the TRENDS model, and are summarized in Table 2-15. These include the average annual mileage driven, and its distribution to urban, rural and highway driving. Moreover, the mean travelling speeds for these three different modes were also provided.

2.4 Cost estimation

2.4.1 General assumptions

All the financial effects from the proposed legislative measures are examined by calculating the Net Present Values (NPV) of the technical and control measures associated with each policy option. All implementation costs are amortised to the fleet of new-registered vehicles each year and then this sum is added to the production/operating costs so that the final results are expressed in terms of cost per vehicle. Thus, the incremental costs for each policy option are made available. The total cost calculation involves the following assumptions:

Table 2-15: Activity data for the different EU15 countries, used in the calculations. The source for this data was COPERT 3.

Country	PTW category	Mileage [km]	Mileage Share			Mean travelling speed [km/h]		
			Urban	Rural	Highway	Urban	Rural	Highway
Austria	Mopeds	4500	60%	40%	0%	40	50	-
	2-stroke	7800	15%	65%	20%	32	75	106
	4-stroke	7800	15%	65%	20%	32	75	106
Denmark	Mopeds	3300	85%	15%	0%	40	50	-
	2-stroke	6700	40%	47%	13%	40	70	100
	4-stroke	6700	40%	47%	13%	40	70	100
Finland	Mopeds	2000	20%	80%	0%	40	50	-
	2-stroke	5000	30%	60%	10%	30	80	100
	4-stroke	5000	30%	60%	10%	30	80	100
Luxembourg	Mopeds	1500	58%	43%	0%	40	50	-
	2-stroke	4600	35%	45%	20%	40	60	95
	4-stroke	4600	35%	45%	20%	40	60	95
UK	Mopeds	5000	100%	0%	0%	30	50	-
	2-stroke	5000	54%	39%	7%	25	75	115
	4-stroke	5000	54%	39%	7%	25	75	115
France	Mopeds	3000	40%	60%	0%	40	50	-
	2-stroke	8000	30%	50%	20%	30	70	95
	4-stroke	11000	30%	50%	20%	30	70	95
Germany	Mopeds	2040	45%	55%	0%	40	50	-0
	2-stroke	2040	19%	60%	22%	37	75	106
	4-stroke	4050	19%	60%	22%	37	75	106
Italy	Mopeds	2040	70%	30%	0%	30	50	-
	2-stroke	2040	0%	0%	0%	30	70	110
	4-stroke	4050	60%	30%	10%	30	70	110
Netherlands	Mopeds	3220	90%	10%	0%	30	50	-
	2-stroke	7380	63%	25%	12%	25	60	100
	4-stroke	7380	63%	25%	12%	25	60	100
Portugal	Mopeds	5500	15%	85%	0%	40	50	-
	2-stroke	6500	22%	67%	12%	30	70	90
	4-stroke	6500	22%	67%	12%	30	70	90
Sweden	Mopeds	3260	80%	20%	0%	30	50	-
	2-stroke	4818	60%	30%	10%	25	50	103
	4-stroke	4818	60%	30%	10%	25	50	103
Spain	Mopeds	2070	100%	0%	0%	30	50	-
	2-stroke	3400	74%	13%	14%	30	60	83
	4-stroke	3400	74%	13%	14%	30	60	83
Greece	Mopeds	6000	100%	0%	0%	30	50	-
	2-stroke	9000	65%	20%	15%	30	60	90
	4-stroke	9000	65%	20%	15%	30	60	90
Belgium	Mopeds	1870	54%	46%	0%	40	50	-
	2-stroke	3380	48%	40%	11%	25	50	103
	4-stroke	3380	48%	40%	11%	25	50	103
Ireland	Mopeds	15000	38%	63%	0%	40	50	-
	2-stroke	15000	30%	55%	15%	30	50	85
	4-stroke	15000	30%	55%	15%	30	50	85

1. The different cost elements considered include the investment costs, the research & development costs, the fixed operating costs and other variable costs. The fixed operating costs equal to 6% of the Investment ones, according to EPA, (1999), and refer to the maintenance of the machines, the energy consumption, etc. Variable costs refer mainly to incremental hardware costs or to Inspection and Maintenance (I&M) implementation costs.

2. All costs are marked up at a rate of 300 % according to Rijkeboer et al. (2002) to account for the total cost of the supply chain from the manufacturer to the consumer, including the manufacturers' overhead and profit. This means that the pure cost burden for the manufacturer has been multiplied by 4 to take into account the price increase that the customer will face. This does not apply to measures such as inspection and maintenance, synthetic oil use, in-use compliance related costs and in general costs that are not a pure burden to the manufacturer.

3. Whenever costs are expressed per vehicle, this figure corresponds to the pure production cost and are not marked up by 300%.

4. All costs are in EUROs (2004 monetary terms).

5. The warranty period for any kind of vehicle and emission control equipment is considered to be 2 years. This means that any maintenance or component replacement that takes place in the first two years of vehicle lifetime is excluded from the total cost estimate.

6. The amortization period of fixed costs is 5 years (Rijkeboer et al. 2002).

7. The population of compression-ignition 3 and 4 wheelers is considered to be too small to be examined for a cost-effectiveness analysis.

8. We use a discount (interest) rate of 4%.This discount rate is expressed in real terms, taking inflation into account. It is applied to costs expressed in constant prices. This discount rate broadly corresponds to the average real yield on longer–term government debt in the EU in the period since the early 1980s (EC, 2002).

9. In order to calculate and allocate total development costs to new vehicles, we need information on the type approvals that are issued each year. Type Approvals may be issued either for new types or for modified existing types. We define as 'New Types' those vehicle families which are for the first time introduced into the market and require long developing phases. Existing types that might require new type approvals are new versions (e.g. new model year) of existing bikes. Development costs to introduce a new emission control consist of different elements in each case. Therefore, we need to separate between the

two. Table 2-16 illustrates the number of small, medium and big manufacturers producing two-wheelers for the European region, and the number of annual New Types and Type Approvals per manufacturer size. In addition, and the total types in production by each manufacturer size are shown. This information is then classified further per vehicle category as shown in Table 2-17.

10. Finally, we also consider that sales end up being equal to the vehicles' production, in the long run.

Table 2-16: Number of PTW manufactures in Europe and number of New Types, Type Approvals & Types in Production per size of manufacturer and per year.

	Number of Manufacturers	New Types per Manufacturer	New Type Approvals per Manufacturer	Total Types in Production per Manufacturer
Large Manufacturers	4	5-7	12	25 – 40
Medium Manufacturers	7	2-3	8	15-18
Small Manufacturers	5	1	4	6 – 8

Table 2-17: New Types and Type Approvals for all PTW manufacturers in Europe per year and vehicle type.

	New Types per year and per vehicle class	Type Approvals per year and per vehicle class
2-Stroke Motorcycles	4	10
4-Stroke Motorcycles	34	84
Mopeds	12	30
Total	50	124

2.4.2 Cost Elements – First Approach

In order to compare the cost for implementation of the Euro 3 emission standards, we first conducted a cost-effectiveness analysis for the implementation of Euro 1 and Euro 2 regulations.

Euro 1

No emission control cost was considered for pre-Euro 1 vehicles. Then, the implementation of Euro 1 was associated with different cost elements for mopeds and motorcycles:

For mopeds, Euro 1 is assumed for all models launched in the period 1997 - 2001. In order to define and calculate the total cost associated with Euro 1, we considered a negligible population of 4–stroke mopeds during these years and the entire fleet is assumed to consist exclusively of 2–stroke vehicles. It is considered that Euro 1 levels where reached only with the introduction of an oxidation catalyst (OxCat) at a cost of €16 – €30 per vehicle (EPA, 2003).

Due to the relatively relaxed emission levels set for Euro 1 motorcycles, it was considered that no additional costs were involved to shift to this new technology.

Euro 2

Euro 2 for mopeds is considered for all models to be introduced in the period 2002-2005. During this stage, a gradual transition from 2–stroke to 4–stroke vehicles is considered. 50% of the Euro 2 mopeds have been taken as 4-stroke ones and the transition from 2-stroke costs €130 - €160 per vehicle, according to Rijkeboer et al. (2002). The remaining 50% of the fleet (2-strokes) requires new emission control systems to comply with the new limits. It is considered that 70% of the remaining population – i.e. 35% of the total population - requires Secondary Air Injection (SAI), which costs €24 - €28 (EPA, 2000). The remaining 30% of 2-strokes (15% of the total Euro 2 population) is fitted with Direct Injection (DI), which costs approximately €50 - €100 (Rijkeboer et al., 2002).

Euro 2 for motorcycles is considered for all models to be introduced from 2003 to 2005. In this period, there are different costs involved in the cases of 2-stroke and 4-stroke Motorcycles. For two-stroke motorcycles, 30% of the total new registrations in the period considered are assumed to be fitted with DI + OxCat and the cost of both systems is estimated to be 20% higher than in the Mopeds case (€60 – €120 per vehicle for DI and €19 - €36 per vehicle for OxCat). 70% of the new registrations are assumed to be fitted with SAI + OxCat. Similarly, the cost for SAI is 20% higher than in the mopeds' case, at €29 – €34 per vehicle. The costs for the 4-stroke motorcycle category are further distinguished for the three capacity classes (§2.1.1), with each class corresponding to 1/3 of the entire 4–stroke motorcycle population. It is further estimated that 20% of Class 1 Motorcycles, 50% of Class 2 and 100% of Class 3 are equipped with Three Way Catalyst (TWC) and Fuel Injection (FI). In total, it is considered that FI+TWC are installed to 57%

of the total 4-stroke Euro 2 motorcycle fleet. TWC cost is estimated at €100 - €150 (CITA, 2002) and FI cost is considered equal to the DI cost for 2-strokes (€50 - €100). The remaining 43% of the Euro 2 vehicles are assumed to be equipped with SAI+OxCat, at an equal cost to 2-strokes.

Euro 3

Euro 3 cost is here considered only for motorcycles launched later than 2005, because Euro 3 emission standards for mopeds have not been agreed yet. The Euro 3 cost for mopeds is given at §4.5.4. We consider the costs for two periods. One for the period 2006-2008 (Medium-term) which corresponds to a similar duration with the duration of Euro 1 and Euro 2 and one for the period 2006-2012 (Long-term) to estimate the benefits for a longer period. The costs to meet the reduced Euro 3 emission standards should be combined with additional costs invested by the manufacturers to meet durability distances already foreseen by legislation 2002/51/EC. We describe the cost estimation for both these requirements.

In order to comply with the emission standards, it is assumed that all 2-stroke engines need to be fitted with DI+OxCat and all 4-stroke engines should be equipped with FI+TWC. The costs for these devices are similar to the Euro 2 case.

In order to meet durability requirements, additional costs are associated with new engine calibration. For each manufacturer, it is assumed the engine calibration requires an investment cost of €300,000 (ACEM) per engine family that is calibrated. The cost involved during the first year of the durability distances requirements is defined by taking into account the engine families' calibration cost and the number of type approvals for all manufacturers per year. For each year thereafter, the annual cost is defined by taking into account the engine calibration cost and the number of the New Types per year.

2.4.3 Cost elements - Second Approach

An additional approach to estimate the total cost for transition of the different emission technologies is obtained using data from PTW manufacturers. In this case, the costs are given as a fraction of total production costs and they correspond to one manufacturer of motorcycles only (not mopeds). Hence, uncertainties may occur due to variations in these figures for different manufacturers.

Based on this second approach, the transition from Euro 1 to Euro 2 for motorcycles is associated with a production cost increase from 4% to 6%, whereas the transition from Euro 2 to Euro 3 is expected to correspond to 5% to 9% of the total production costs (ACEM 2002, Mills 2004). We assume that the production cost per average Euro 2 motorcycle is €1000 – €1800 (3 times the production cost assumed for mopeds according to Rijkeboer et al. 2002). Therefore, the transition from Euro 1 to Euro 2 costs €40 – €110 per vehicle, while the transition from Euro 2 to Euro 3 costs €50 – €160 per vehicle, approximately. The production cost may be much higher for advanced motorcycles, but in that case, the share of emission control cost will be also less. Hence, we consider the total costs per vehicle considered to be realistic.

2.5 Cost-Effectiveness calculation

The cost-effectiveness calculation (cost per ton of pollutant saved) was calculated by dividing the total cost associated with each pollutant with the emission benefit of a particular measure. The costs were allocated to different pollutants, using information on the estimates of marginal external costs of air pollution in Europe (DG Environment, 2004). DG Environment has had prepared the Benefits Table (BeTa) database of externalities for air pollution in Europe. BeTa gives the marginal external costs of air pollution (SO_2, NO_x, VOCs and PM_{10}) in terms of euros per ton of pollutant for each EU Member State. For European rural areas, the ratio of benefit for each pollutants is PM: 6.6%, NO_x: 3.8%, HC: 89.6%. We have used this information to allocate the total cost to different pollutants. CO_2 cost effectiveness is solely examined by allocating the whole of the calculated cost to this specific pollutant. No cost-effectiveness analysis for CO is conducted (since it is not considered as an urgent issue anymore).

2.6 Social impacts

The implementation of each of the additional measures considered by the Commission for inclusion in Euro 3 inevitably triggers a sequence of changes that affect the market chain as a whole, due to the interactive relation between manufacturers and consumers.

The methodology that was followed for the identification and characterization of the social impacts of each investigated policy option (per task) can be summarized as follows:

Step 1: External impacts are defined as identical to the social impacts. Improved air quality, willingness of customers to purchase a more expensive and more environmentally friendly motorcycle, viability of SMEs, motorcycles of certain types that may come near to their extinction, etc. are all regarded as social impacts.

Step 2: Search for appropriate data from similar studies and classify them according to the form proposed for an impact assessment study by the European Commission (2002a).

Step 3: Build impact matrices (European Commission, 2002b) to capture the most significant impacts per policy option.

Step 4: Build matrices to capture the main actual results per policy option (European Commission, 2002b).

Step 5: Discussion and conclusions.

Each policy option that will be finally adopted by the Commission to formulate a new legislation, contributes uniquely to a "common purpose", which apparently 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. In the different tasks examined (Section 4), any decision is first discussed according to its "general social impacts" and then any additional impacts are separately examined.

3 Emission Standards Effectiveness

3.1 "Baseline" scenario Definition

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 (end 2003) will be taken. This corresponds to moped emission standards up to Euro 2 and motorcycle emission standards including only the reduced emission limits of Euro 3, i.e. the situation reached up to regulation 2002/51/EC. The effectiveness of additional legislative measures (such as OBD introduction, In-Use Compliance, Roadworthiness, etc.) could then 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 in section 2.2.1, reaching up to Euro 2 for mopeds and up to Euro 3 for motorcycles.
- No particular durability requirements. Hence, the deterioration in exhaust HC and CO emissions of all pre-Euro 3 PTWs is set equal to 20 % per useful life (Table 2-9). Deterioration in exhaust HC, CO and NO_x (only for 4-stroke) emissions of Euro 3 PTWs is set equal to 10 % per useful life (Table 2-9). We have reduced the deterioration of Euro 3 emission levels even in the baseline scenario because we have assumed that the new emission control systems would be in any case effective for this period (i.e. to comply with US standards).
- No specific evaporation control legislation.
- No introduction of a Euro 3 stage for mopeds.
- Use of mineral oil in all 2-stroke motorcycles and mopeds.
- No OBD requirement. Emission deterioration due to OBD absence is discussed in Section 4.6.
- No In-Use Compliance (IUC) requirement. Fleet emissions increase due to the absence of IUC is described in Section 4.2.
- No Roadworthiness test (RW) requirement.

We examine the evolution of emissions with the baseline scenario up to year 2012, i.e. 7 full years after the implementation of Euro 3 regulations.

3.2 PTW Share of total road-transport emissions

In order to demonstrate the efficiency of the *Baseline* scenario we decided to compare the emission evolution from two and small three and four wheelers with the emission evolution from all road transport sources. Therefore, we ran a typical scenario with the TRENDS model to include passenger cars, light duty vehicles, heavy duty trucks, busses and coaches. This scenario takes into account the introduction of Euro 4 standard for passenger cars (2006) and light duty vehicles (2007) and the introduction of Euro 5 (2010) for heavy duty vehicles. Implementation years may come later than the actual year of introduction of each regulatory step, because an initial transition period is considered (e.g. sales of fuel efficiency optimised HDVs in US increased before the mandatory introduction of the new NO_x-reflashed engines). In year 2010, a new Euro step for passenger cars may be decided which will further reduce total emissions. Unfortunately, it was not possible to predict the effect of Euro 5 PCs. This scenario considers all regulated pollutants, CO_2 and PM.

Figure 3-1 shows the evolution of emissions from mopeds and motorcycles, according to the baseline scenario, and the emission evolution from all other road transport sources. Motorcycle emissions also include three and four wheelers' emissions. 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 proposed for motorcycles (Euro 2 for mopeds) the contribution of PTWs in THC rises steadily, reaching ~20 % in 2012, with mopeds being the most significant contributors (12.5 % in 2012). This is mainly due to the significant reduction of the THC emissions from the other road transport sources (which may be even more reduced with the introduction of Euro 5 for passenger cars in 2010). This figure could be somehow improved however, with the introduction of the foreseen - but not yet decided - Euro 3 standard for mopeds. This is further discussed in section 4.5.

PTW contribution to CO is significant (7-8% of total) and does not seem to differentiate much in the years to come. Similar to THC, additional reductions may be expected when Euro 3 for mopeds has been decided, which can again be counterbalanced with a Euro 5 passenger car regulation.

It is also noteworthy that the contribution of PTWs to total PM emissions is steadily decreasing even though no particular legislation addressing PM has been assumed in the baseline scenario. This reduction is expected to be higher due to the introduction of the Euro 3 standard for mopeds (section 4.5), but the introduction of diesel particle filters on passenger cars may again increase the relevant significance of two-wheelers.

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, this is not assumed to be a significant problem (max contribution 0.66% in 2012). This is also the case in urban areas were the estimated contribution of PTWs is increasing from 0.13% in 1999 to 0.57% in 2012.

Finally, PTWs are a negligible contributor to total CO_2 from road transport. (1 % in 1999 to 0.6 % in 2012). The decrease of relative contribution is associated with the decreasing fleet density for mopeds and motorcycles while, on the other hand, the passenger car fleet continues to grow. Additionally, the specific CO_2 emissions from two wheelers are calculated at 83.5 g/passenger-km compared to 126 g/passenger-km for passenger cars (TERM, 2004). This is an additional reason for the low contribution of two wheelers to total CO_2 emissions.

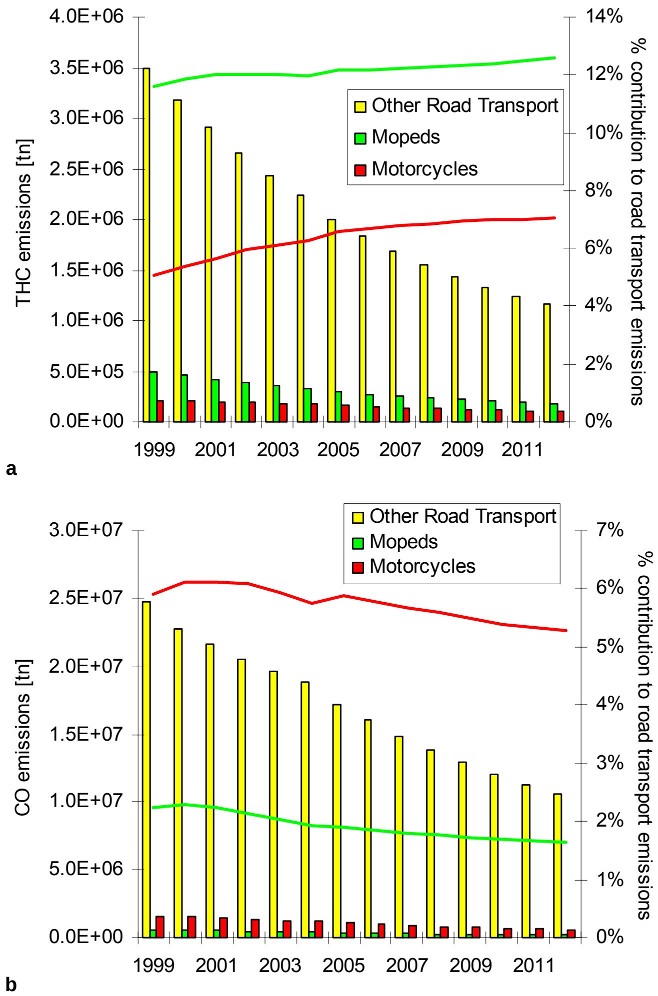


Figure 3-1: Evolution of PTW (incl. three and four wheelers) according to the Baseline scenario. Comparison with emissions with all other road transport sources.
(a) total HC (exhaust & evaporation), (b) CO

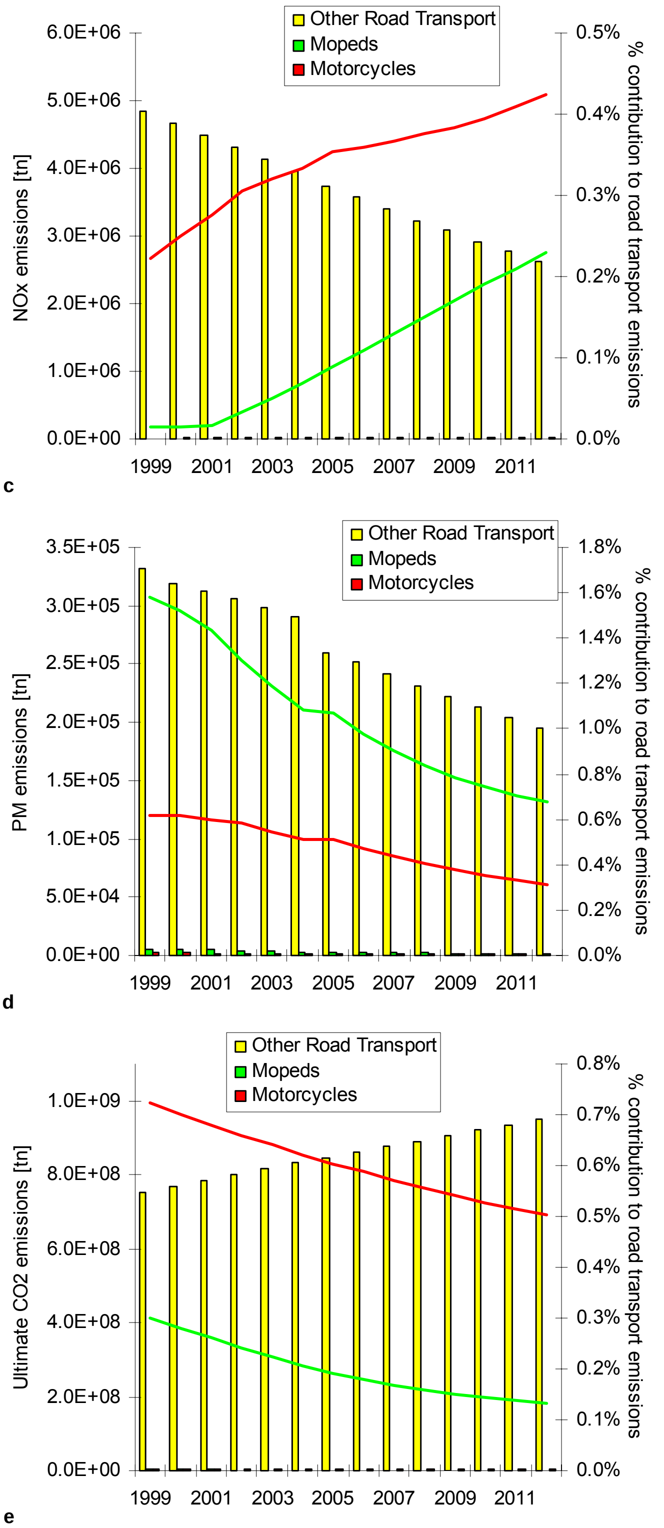


Figure 3-1: Evolution of PTW (incl. three and four wheelers) according to the Baseline scenario. Comparison with emissions with all other road transport sources.
(c) NO_x, (d) PM, (e) Ultimate CO_2.

3.3 Contribution from 3 & 4 wheelers

3 & 4 wheeler vehicles are a special category corresponding to a very small portion of the total vehicle fleet (estimated to be 0.3%). 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. Emissions from three and four wheelers 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, the following assumptions were made:

- Constant population of 67700 vehicles and a uniform age distribution over 10 years (based on information submitted by the manufacturers).
- 30 % of total fleet consists of compression-ignition vehicles and 70% of gasoline 2-stroke ones.
- The annual mileage is 3000 km under urban conditions (with an average speed of 30 km/h) and 3000 km under rural conditions (with an average speed of 50 km/h).
- 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.
- Introduction of a Euro 3 standard in 2006 that would include reduced emissions for this PTW category. According to section 2.2.1.4, emission factors are higher than for motorcycles.
- No additional deterioration of emissions due to failures, etc.
- Ambient conditions and fuel specifications for evaporation calculations selected according to Italian data, were most of these vehicles are sold.

Figure 3-2 displays the contribution of the 3 & 4 wheelers to the total motorcycle emissions. This is estimated to be smaller than 1 % for all emissions. Therefore, any introduction of stricter legislative measures for these vehicles is not expected to bring any significant reduction in motorcycle emissions. In that respect, we do not consider any further policy measures to be mandated for such vehicles, with the exception of synthetic oil use and probably reduced emission limits – Sections 4.4 & 4.5.

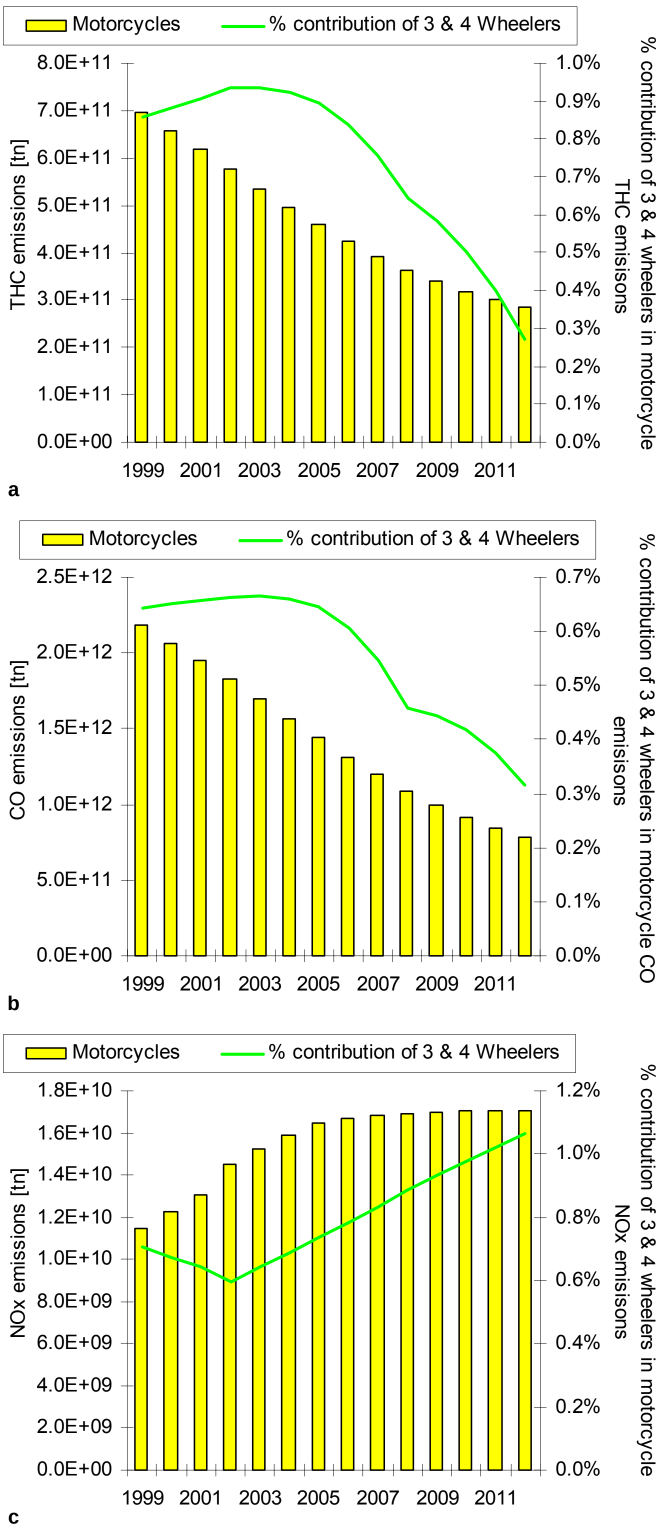


Figure 3-2: Evolution of emissions of 3 & 4 wheelers and comparison with total motorcycle emissions. (a) total HC (exhaust & evaporation, (b) CO, (c) NO_x.

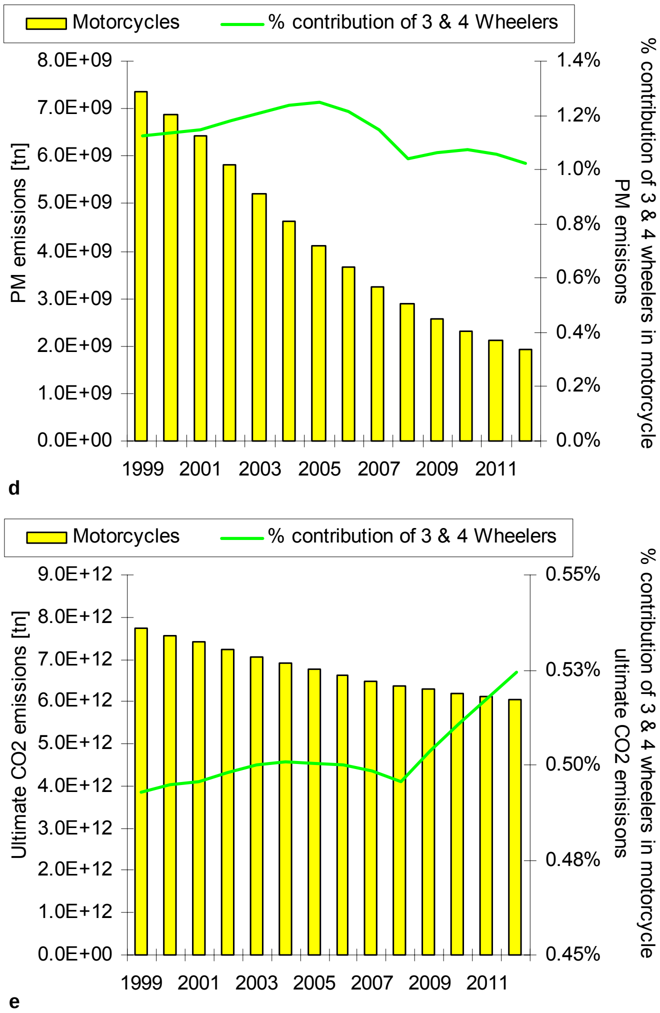


Figure 3-2: Evolution of emissions of 3 & 4 wheelers and comparison with total motorcycle emissions. (d) PM, (e) CO_2.

3.4 "Pre-Euro 3" scenarios

In order to compare the efficiency of the Euro 3 regulation with the emission reductions achieved so far with previous regulatory steps, we ran three additional scenarios to the baseline one. For obvious reasons, we named these scenarios as "pre-Euro 3" ones:

- Scenario "Conventional": This scenario assumes that no emission legislation for two wheelers has been introduced and the emission performance remains at pre-Euro 1 (conventional) levels.

- Scenario "Euro 1": Introduction of the Euro 1 emission standard for mopeds and motorcycles (Year of implementation as in Table 2-2).

- Scenario "Euro 2": In addition to Euro 1, Euro 2 emission standards for all PTWs are progressively introduced, according to the implementation dates of Table 2-2.

All above scenarios were formulated using exactly the same assumptions 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 3-3. The situation is also shown separately for motorcycles and mopeds in Figure 3-4 and Figure 3-5 respectively. Figure 3-6 displays the evolution of ultimate CO_2 emissions.

These figures show that even if no emission standard had been introduced, total emissions would have been decreasing following the shrinkage of the fleet size. The introduction of the Euro 1 emission standard though, led to a significant environmental benefit for total HC and CO emissions. PM and ultimate CO_2 emissions were also reduced, especially from mopeds, reflecting the reduced scavenging losses of the Euro 1 technology 2-stroke vehicles. There was a trade off for this environmental benefit: Particularly, all Euro 1 PTWs, but especially motorcycles, were higher NO_x emitters from their predecessors. As a result the total NO_x emissions from motorcycles progressively increased though the years. However, as was shown in §3.2, the contribution of mopeds and motorcycles to NO_x emissions from road transport is insignificant.

The introduction of the Euro 2 emission standard caused a further decrease in total HC and CO emissions from all PTWs. There was also an additional reduction in PM and ultimate CO_2 emissions as a result of the even lower scavenging losses of the 2-srtoke Euro 2 PTWs. The trends for NO_x emissions were different for mopeds and motorcycles though. In particular, the Euro 2 standard led to a further reduction in NO_x emissions from motorcycles, but as a result of the expected extensive introduction of DI 2-stroke and 4-stroke mopeds, NO_x emissions from these PTWs have been increasing.

Finally, the introduction of the Euro 3 standard for motorcycles is expected to further reduce all regulated emissions and PM, but this reduction is much smaller than the one brought by Euro 1 and 2. Introduction of a Euro 3 also reduces CO_2 emissions, since all Euro 3 2-stroke motorcycles are expected to be DI vehicles. The potential of the Euro 3 standard in decreasing emissions from mopeds is discussed separately in the relevant section (Section 4.5).

Table 3-1 summarizes the estimated reduction of each pollutant (in tons) brought by the introduction of a new emission standards over the previous ones. These reductions are shown for the effective period of each standard. The corresponding percentage reductions (defined as the ratio of the reduced emissions over the absolute emission level before the reduction) are summarized in Table 3-2.

The reduction in emissions (both in absolute levels and as percentage) is strongly affected from the effective period. Since it is not already known what will be the effective period of the Euro 3 emission standard, the results for this standard are shown for two different effective periods:

Table 3-1: Absolute emission reduction due to the introduction of different emission standards. Results expressed in total for the effectiveness period of each regulation.

Category & Emission Standard		Exh. HC [t]	Evap. HC [t]	CO [t]	NO_x ** [t]	PM [t]	CO_2 [t]
Mopeds	Euro 1 (1999-2001)	3.7E+05	0	4.5E+05	-1.1E+02	4.5E+03	1.2E+06
	Euro 2 (2002-2005)	6.1E+04	2.9E+02	1.2E+05	-6.7E+03	1.7E+03	2.7E+05
	Euro 3 (2006-2008)	*	*	*	*	*	*
	Euro 3 (2006-2012)	*	*	*	*	*	*
2-stroke	Euro 1 (1999-2002)	2.3E+04	0	7.4E+04	1.7E+02	6.3E+02	1.3E+05
	Euro 2 (2003-2005)	1.2E+04	5.7E+01	1.0E+04	-2.3E+02	1.1E+02	2.0E+04
	Euro 3 (2006-2008)	2.8E+03	1.2E+02	1.7E+04	-4.8E+02	7.2E+01	4.3E+04
	Euro 3 (2006-2012)	1.4E+04	5.3E+02	8.1E+04	-2.1E+03	3.1E+02	1.8E+05
4-stroke	Euro 1 (1999-2002)	3.7E+04	0	5.8E+05	-9.3E+03	0	1.5E+04
	Euro 2 (2003-2005)	5.6E+03	8.9E+02	1.3E+05	3.7E+03	3.7E+02	0
	Euro 3 (2006-2008)	1.0E+04	6.5E+02	9.1E+04	2.5E+03	0	0
	Euro 3 (2006-2012)	5.1E+04	2.9E+03	4.5E+05	1.0E+04	0	0
4/3 Wheelers	Euro 1 (1999-2002)	1.7E+03	0	5.8E+03	-1.7E+01	4.6E+01	7.3E+03
	Euro 2 (2003-2005)	1.2E+03	0	9.4E+02	-6.0E+01	6.8E+00	0
	Euro 3 (2006-2008)	3.1E+02	0	1.6E+03	1.2E+01	8.4E+00	0
	Euro 3 (2006-2012)	1.7E+03	0	8.4E+03	5.5E+01	3.9E+01	0
Motorcycles	Euro 1 (1999-2002)	6.1E+04	0	6.6E+05	-9.2E+03	6.7E+02	1.5E+05
	Euro 2 (2003-2005)	1.9E+04	9.5E+02	1.4E+05	3.4E+03	4.9E+02	2.0E+04
	Euro 3 (2006-2008)	1.3E+04	7.7E+02	1.1E+05	2.0E+03	8.1E+01	4.3E+04
	Euro 3 (2006-2012)	6.6E+04	3.4E+03	5.4E+05	8.3E+04	3.5E+02	1.8E+05

* The introduction of a Euro 3 standard for mopeds is evaluated separately in section 4.5.
** Negative figures designate emission increase

Table 3-2: Percentage reduction in emissions due to the introduction of the different emission standards. Percentages were calculated separately for the moped and the motorcycle categories.

Category & Emission Standard		Exha. HC [%]	Evap. HC [%]	CO [%]	NO_x [%]	PM [%]	CO_2 [%]
Mopeds	Euro 1 (1999-2001)	21.6	0	21.1	-5.3	23.1	15.4
	Euro 2 (2002-2005)	4.4	0.6	6.7	-230.6	10.9	3.7
	Euro 3 (2006-2008)	*	*	*	*	*	*
	Euro 3 (2006-2012)	*	*	*	*	*	*
2-stroke	Euro 1 (1999-2002)	2.8	0	1.1	0.4	7.4	0.6
	Euro 2 (2003-2005)	2.5	0.1	0.3	-0.5	2.3	0.1
	Euro 3 (2006-2008)	0.7	0.3	0.6	-1.2	2.2	0.3
	Euro 3 (2006-2012)	1.6	0.5	1.3	-2.3	4.8	0.5
4-stroke	Euro 1 (1999-2002)	4.5	0	8.8	-24.0	0	0.1
	Euro 2 (2003-2005)	1.1	2.0	3.4	8.6	7.4	0
	Euro 3 (2006-2008)	2.6	1.5	3.2	6.1	0	0
	Euro 3 (2006-2012)	6.0	3.0	7.5	10.8	0	0
4/3 Wheelers	Euro 1 (1999-2002)	0.2	0	0.1	-0.04	0.5	0.03
	Euro 2 (2003-2005)	0.2	0	0.03	-0.1	0.1	0
	Euro 3 (2006-2008)	0.1	0	0.1	0.03	0.3	0
	Euro 3 (2006-2012)	0.2	0	0.1	0.1	0.6	0
Motorcycles	Euro 1 (1999-2002)	7.5	0	10	-23.7	7.9	0.7
	Euro 2 (2003-2005)	3.9	2.1	3.7	7.9	9.8	0.1
	Euro 3 (2006-2008)	3.3	1.8	3.8	5.0	2.4	0.3
	Euro 3 (2006-2012)	7.8	3.5	9.0	9.0	5.4	0.5

* The introduction of a Euro 3 standard for mopeds is evaluated separately in section 4.5.
** Negative figures designate emission increase

- Medium Term: 2006-2008 (that is for an effective period of 3 years).
- Long Term: 2006-2012 (which corresponds to an effective period of 7 years).

As shown in Table 3-2, the introduction of the Euro 3 baseline emission standard is expected to bring about the same levels of reduction in regulated emissions of motorcycles with those brought by the Euro 2 emission standard, when evaluated over the same period of time. It is also noteworthy that the introduction of the Euro 2 and Euro 3 standards already led to a moderate reduction of the evaporative HC emissions (about 2 %), although no relevant legislation was defined. This is due to the introduction of fuel injected motorcycles, whose soak and running losses are estimated to be lower than their carburettor equipped counterparts.

3.5 Total cost for the Baseline, Euro 1 and Euro 2 Scenarios

The total costs (Net Present Value – NPV) for the different scenarios are calculated according to the cost elements presented in section 2.4.2 and they are compared with the estimates of section 2.4.3. The total costs for Euro 1, 2 and the Baseline Scenario (Euro 3) for motorcycles are illustrated in Table 3-3, and the total costs of Euro 1 and 2 (Baseline Scenario) for mopeds are illustrated in Table 3-4

Table 3-3: Total cost (NPV) for Motorcycle Euro 1, 2 and 3

Motorcycles	**2–Stroke**		**4-Stroke**		**Total**	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
Euro 1	0	0	0	0	0	0
Euro 2	66	109	1054	1712	1120	1821
Baseline Euro 3 – Medium Term (2006-2008)	55	100	1365	2224	1419	2325
Baseline Euro 3 – Long Term (2006-2012)	118	210	2959	4789	3077	4999

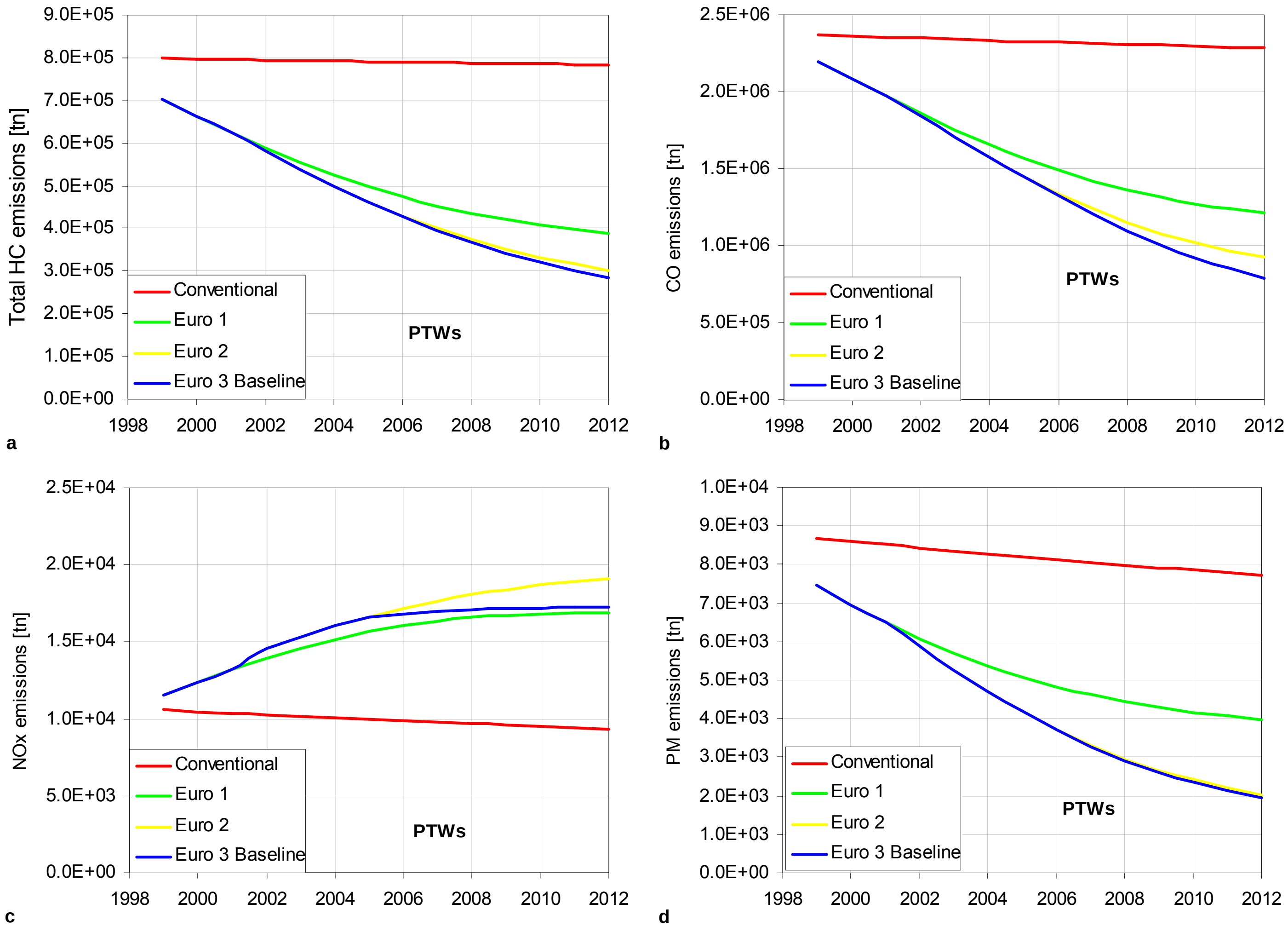


Figure 3-3: Estimated evolution of regulated pollutants and PM from total **PTWs** in EU15 due to the introduction of different emission standards

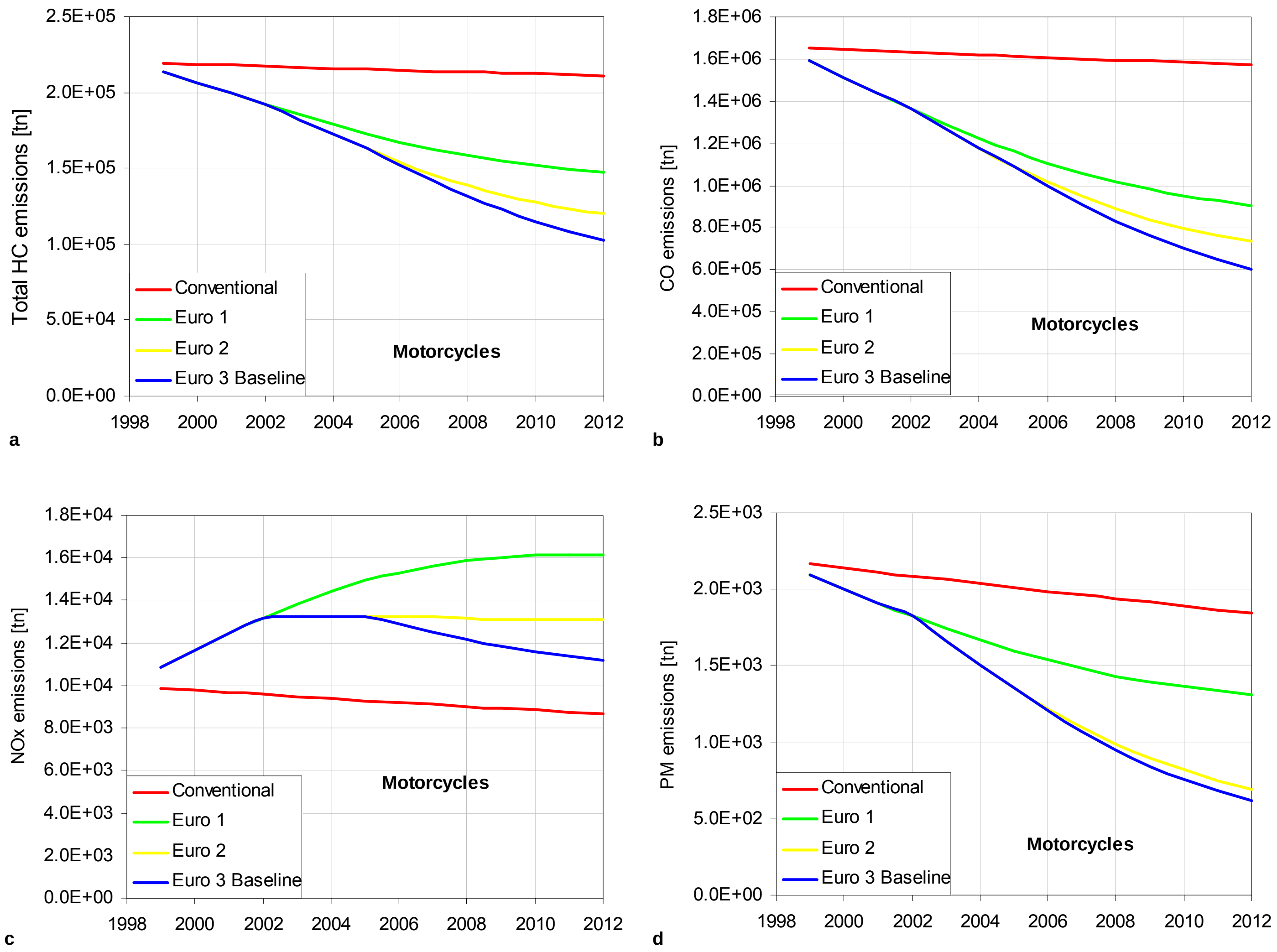


Figure 3-4: Estimated evolution of regulated pollutants and PM from **motorcycles** in EU15 due to the introduction of different emission standards.

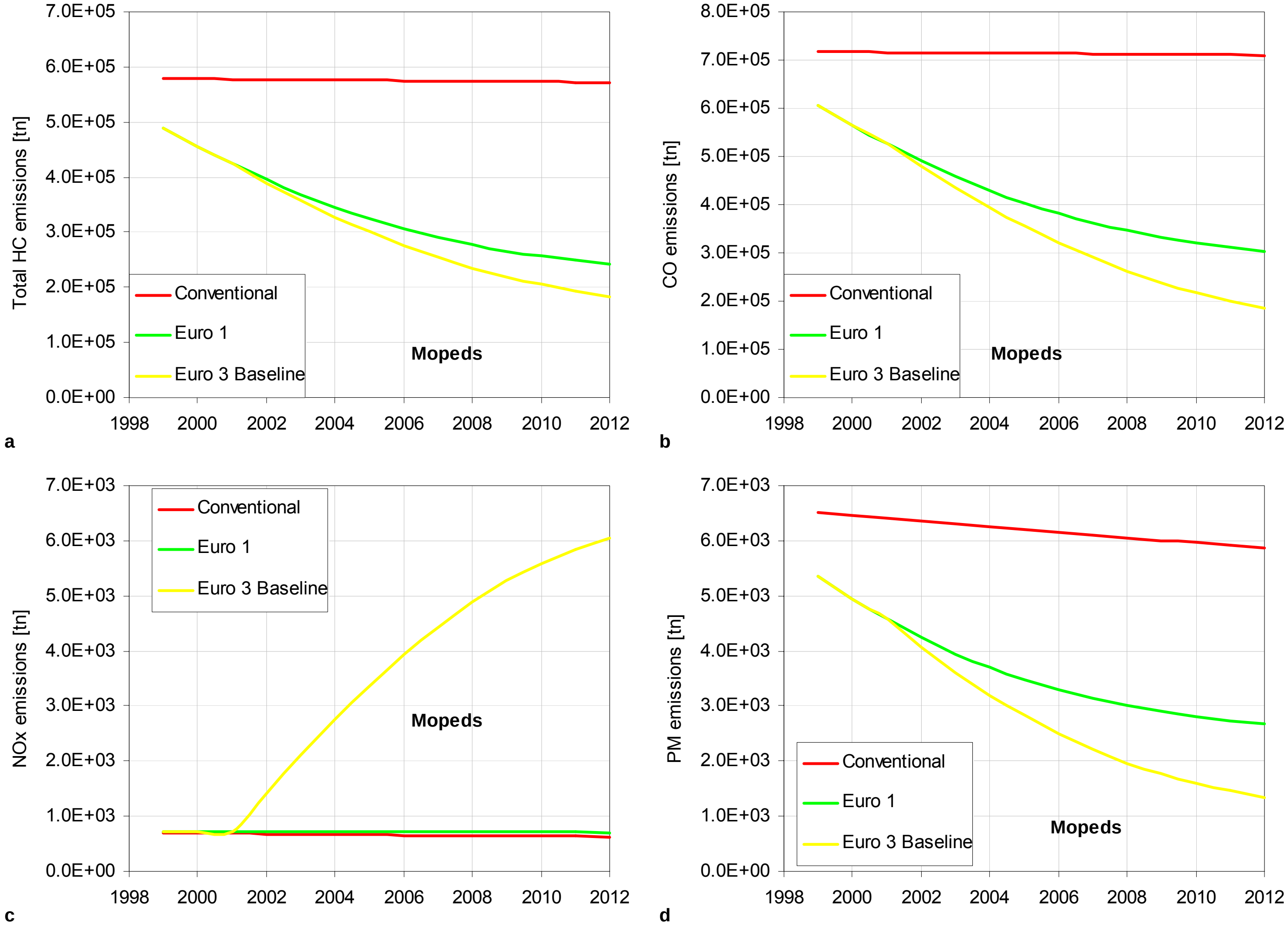


Figure 3-5: Estimated evolution of regulated pollutants and PM from **mopeds** in EU due to the introduction of different emission standards.

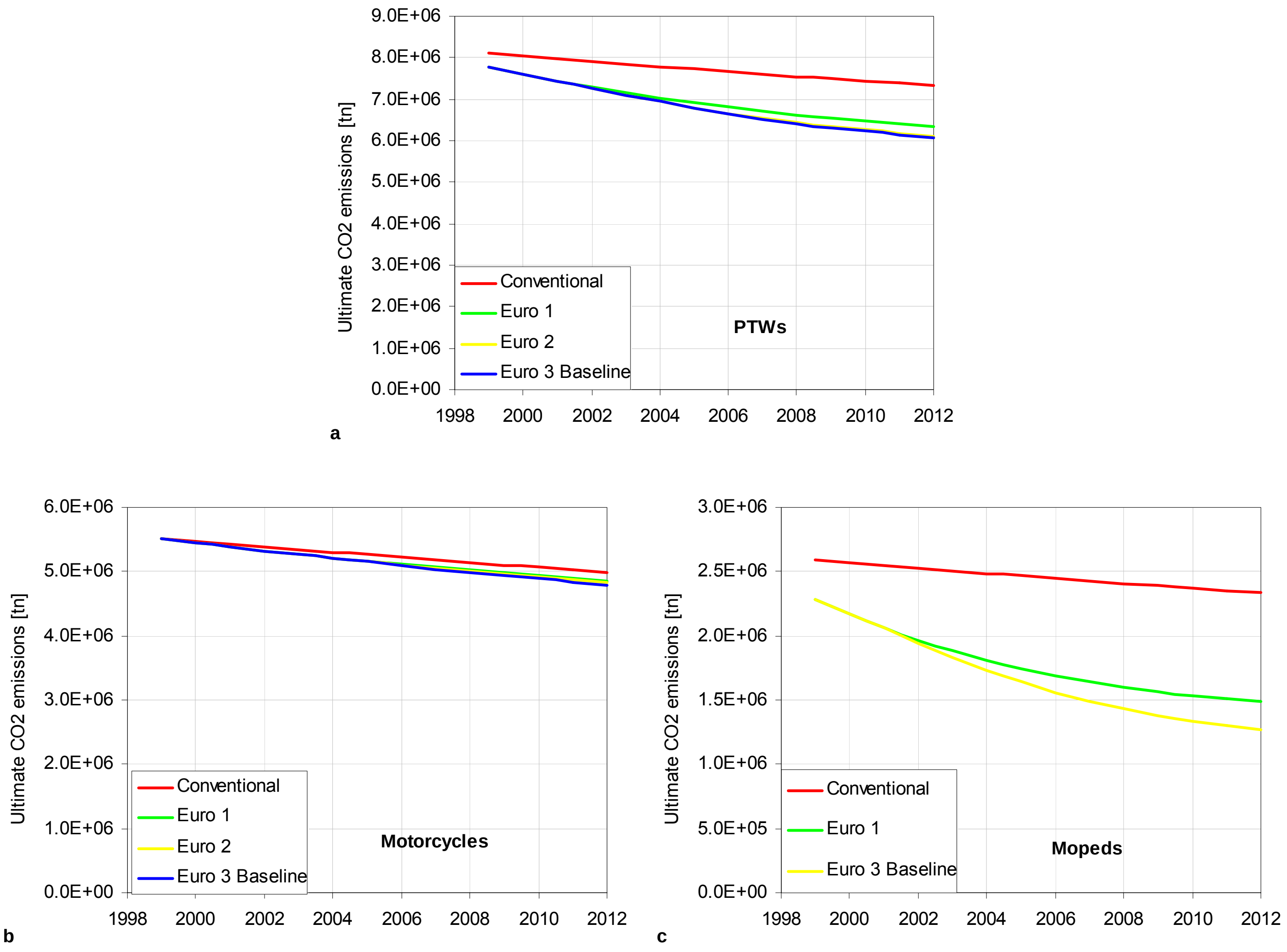


Figure 3-6: Estimated evolution of ultimate CO_2 emissions from total PTWs (a), motorcycles (b) and mopeds (c) in EU due to the introduction of different emission standards**.**

Table 3-4: Total cost (NPV) for Moped Euro 1 and 2

Mopeds	Low Estimate (M€)	High Estimate (M€)
Euro 1	263	494
Euro 2 Baseline Scenario	1454	1883

Table 3-5 presents the additional cost expressed per vehicle.

Table 3-5: Mean additional cost per new vehicle (€/vehicle)

	2–Stroke MCs		4-Stroke MCs		Mopeds	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Euro 1	0	0	0	0	16	30
Euro 2	57	96	106	172	81	105
Baseline Euro 3 – Medium Term (2006-2008)	90	140	186	286	Section 4.5	
Baseline Euro 3 – Long Term (2006-2012)	69	119	166	266	Section 4.5	

3.5.1 Cost–Effectiveness Analysis

The cost-effectiveness (cost per mass pollutant saved) for the Euro 1 & 2 and the Euro 3-baseline Scenario for motorcycles is illustrated in Table 3-6, and the outcome of the cost-effectiveness analysis for each of the Euro 1 and Euro 2-baseline for mopeds is illustrated in Table 3-7 and in Figure 3-7 to Figure 3-13. For these assumptions, the share of total cost to different pollutants was estimated according to §2.5.

Table 3-6: Cost–effectiveness of different motorcycle emission standards (€/kg ≡ M€/kton). HC and NO_x.

Motorcycles	2–Stroke		4-Stroke		Total	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
HC						
Euro 1	0	0	0	0	0	0
Euro 2	4.9	8.2	146.1	237.3	53.3	86.7
Euro 3 – Baseline Scenario (2008)	17.6	32.3	121.4	197.9	99.4	162.8
Euro 3 – Baseline Scenario (2012)	7.6	13.6	53.1	85.9	43.4	70.5
NO_x						
Euro 1	0	0	0	0	0	0
Euro 2	*	*	10.8	17.5	**11.5	**18.7
Euro 3 – Baseline Scenario (2008)	*	*	22.5	36.6	**28.0	**45.6
Euro 3 – Baseline Scenario (2012)	*	*	11.7	18.9	**14.6	**23.6

Table 3-6: Cost–effectiveness of different motorcycle emission standards (€/kg ≡ M€/kton). PM and CO_2.

Motorcycles	2–Stroke		4-Stroke		Total	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
PM						
Euro 1	0	0	0	0	0	0
Euro 2	39.9	66.4	187.7	304.8	153.2	249.1
Euro 3 – Baseline Scenario (2008)	51.9	95.4	***	***	51.9	95.4
Euro 3 – Baseline Scenario (2012)	25.9	46.2	***	***	25.9	46.2
CO_2						
Euro 1	0	0	0	0	0	0
Euro 2	3.3	5.5	***	***	3.3	5.5
Euro 3 – Baseline Scenario (2008)	1.3	2.4	***	***	1.3	2.4
Euro 3 – Baseline Scenario (2012)	0.6	1.1	***	***	0.6	1.1

* Emissions increase

** Cost-effectiveness for NO_x of Euro 2, 4-stroke motorcycles is different from the cost-effectiveness of "Total", because we take into account the increase in NO_x from 2-stroke motorcycles in the latter.

*** No emissions reduction calculated

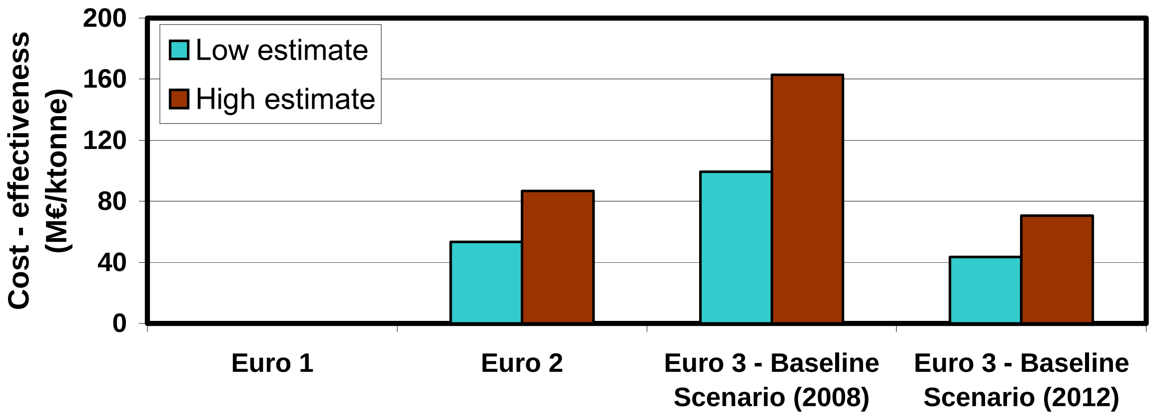


Figure 3-7: HC cost effectiveness for different motorcycle emission standards

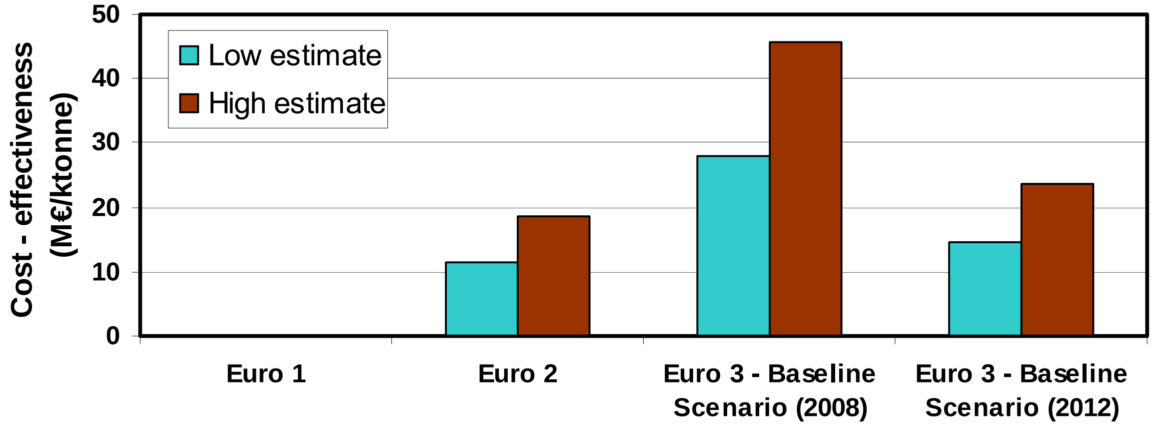


Figure 3-8: NO_x cost effectiveness for different motorcycle emission standards

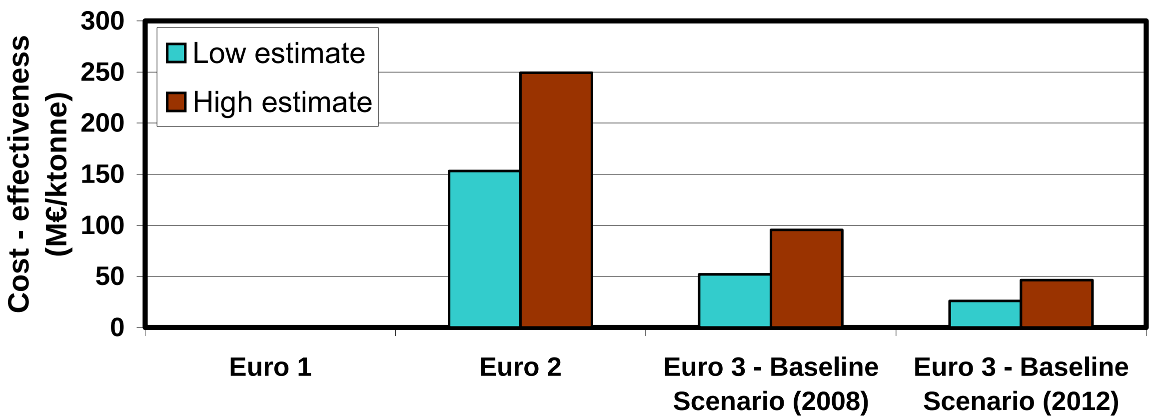


Figure 3-9: PM cost effectiveness for different motorcycle emission standards

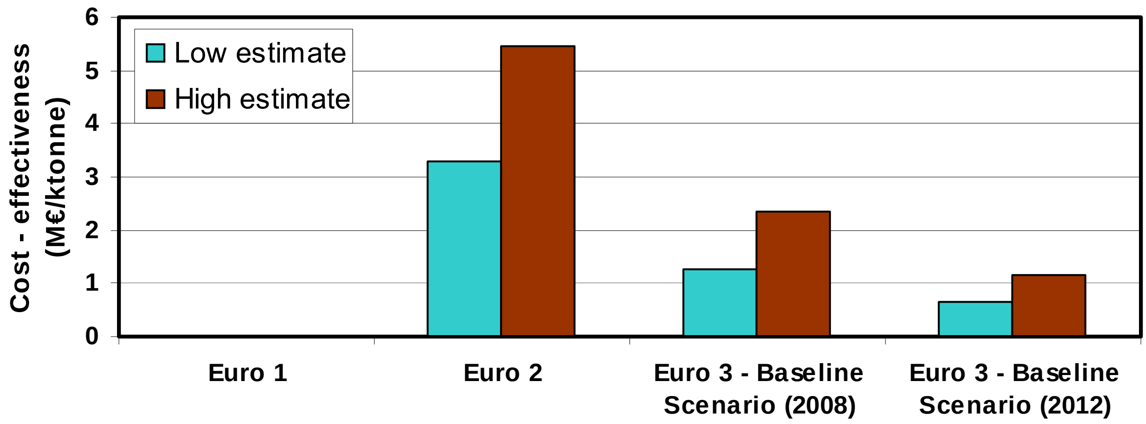


Figure 3-10: CO_2 cost effectiveness for different motorcycle emission standards

Table 3-7: Cost–effectiveness of different moped emission standards (€/kg ≡ M€/kton)

Mopeds	Low Estimate	High Estimate
HC		
Euro 1	0.7	1.3
Euro 2 – Baseline Scenario	21.8	28.3
NO_x		
Euro 1	*	*
Euro 2 – Baseline Scenario	*	*
PM		
Euro 1	4	7.6
Euro 2 – Baseline Scenario	85.9	111.3
CO_2		
Euro 1	0.2	0.4
Euro 2 – Baseline Scenario	5.4	7.0

* Emissions Increase

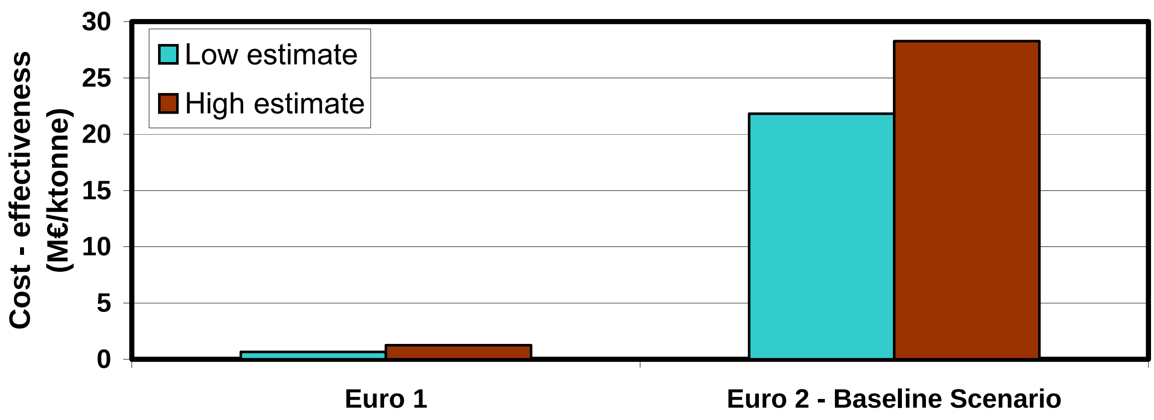


Figure 3-11: HC cost effectiveness for different moped emission standards

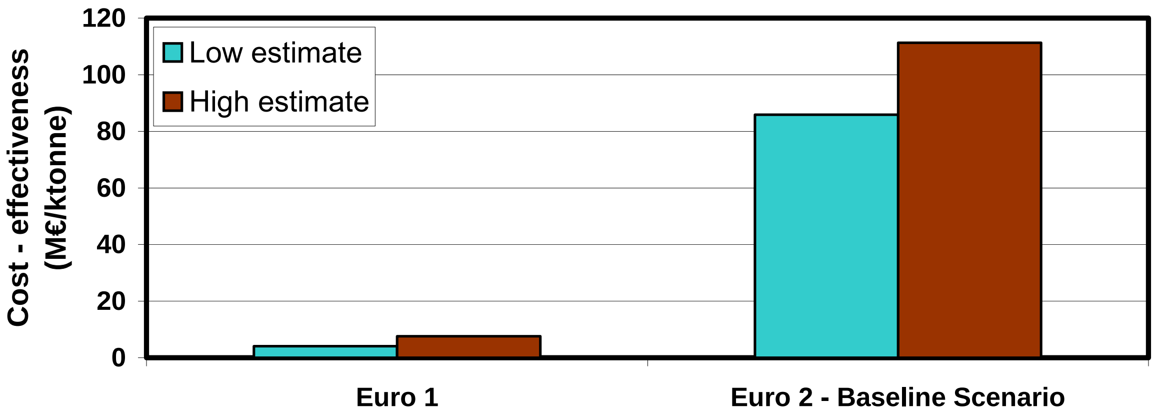


Figure 3-12: PM cost effectiveness for different moped emission standards

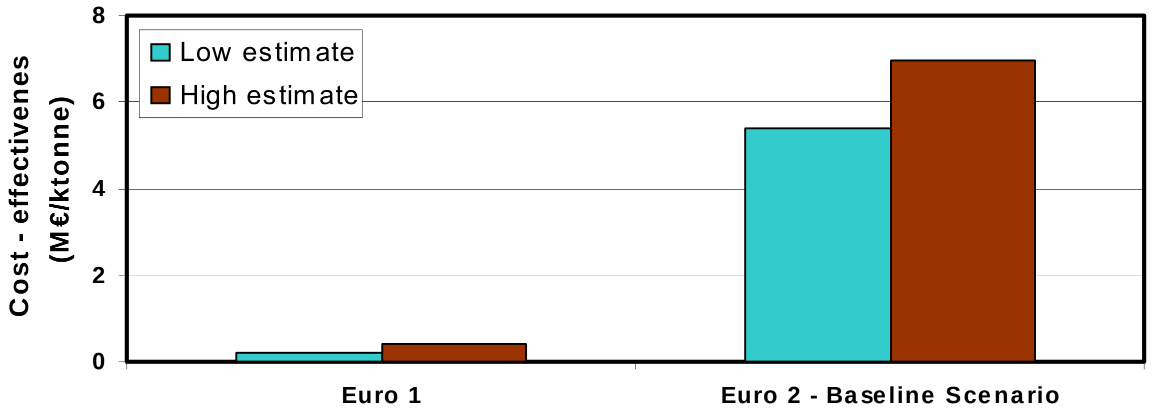


Figure 3-13: CO_2 cost effectiveness for different moped emission standards

4 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 in the future. These measures will be considered as part of the Euro 3 regulations. 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.

4.1 Durability of emission control systems

4.1.1 Objective, Background and Policies Definition

The European Commission wishes to introduce 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 objective in this task is to examine how much different useful lives (total distances) affect the emission evolution from such vehicles.

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 policy options may be discriminated:

- **Policy 1:** Directive 2002/51/EC already prescribed a ceiling for emission control devices durability of 30 000 km. The same Directive requested from the Commission to come up with supplementary provisions, also defining the "normal life" of vehicles. The durability requirement is one of the issues extensively discussed during the ad-hoc MVEG meetings. ACEM has therefore come up with a proposal 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. However, one might still need to consider whether the classification of different motorcycles should be done following the recommendations of EPA or whether the new WMTC classes should be considered. From a practical – but also harmonization – point of view, it is expected that the WMTC classes better correspond to different durability requirements. In any case, due to the maturity of the proposal and since no obvious contradictions are apparent to the study team, it is assumed that this proposal also corresponds to the Commission's view.

- **Policy 2:** "Best available technology" should correspond to catalytic converters of new formulations which - in any case - start to appear in order to reach the type-approval emission levels. Hence, it may come out that the new emission standards as such also guarantee a higher durability of the emission control devices. However, there is always a trade-off between lowering the emission standards and requesting higher durability. There is no experimental basis though to quantify the potential of any new technology for efficient operation over longer periods. Hence, any decisions on the maximum durability distance possible should be based on engineering judgement. Issues that need to be considered include the use of both four-stroke and two-stroke engines in motorcycles. In particular, two-stage oxidation catalysts with SAI (secondary air injection) or a pre-cat and Direct Injection combustion are expected to become a widespread technical solution for smaller capacity two-stroke engines. For larger four-stroke motorcycles, three-way catalytic converters with closed loop lambda control are already a reality and a necessity to fulfil 2006 emission standards. Durability is critical in both cases but due to different reasons: In the 2-stroke case the high temperatures developed in the catalyst due to scavenging losses give rise to thermal deactivation. In the three-way catalyst, temperatures are lower but the catalytic converter may be more sensitive to poisoning from trace metals in the lubricant and the fuel. Assuming that smaller vehicle would make use of both engine types (2S and 4S) and that this is the class that puts the maximum stress on emission control devices, due to the nature of operation of these engines, it is obvious that even when BAT is considered, the useful life should be less than for larger classes to accommodate technical feasibility. For example, a discussion was initiated in the US (Policy 4) to extend the useful life period to 40 000 km. This decision was eventually not taken, not because it contradicted technical limitations (which were actually an unknown) but not to hamper interstate harmonisation, especially with California regulations. Summarising these concerns, it is evident that the impact on total emissions of increasing the useful life of emission control devices needs to be examined, even as a sensitivity analysis on the proposed distances from ACEM.

- **Policy 3:** This policy option may be met by either deciding not to include any durability requirements in the new regulation provisions, or decreasing the useful life (resp. relaxing the deterioration factors) for the durability requirements. In the former case, policy 3 would correspond to the "no policy change" baseline scenario. In the latter, it would correspond to Policy 1/2 with different durability distance requirements. In order not to bring an additional policy option which will complicate decisions, we have decided to treat policy 3 as either being already included in the "no policy change" scenario or included in the sensitivity analysis of useful lives proposed in Policy 2. Hence, no separate scenario has been run for policy 3.

- **Policy 4:** Already established durability requirements are today in force in the US (+ California) and in Taiwan and in Thailand which have a PTW population of 11 MVeh. and 13 Mveh. respectively (each equal to the whole of Europe), compared to (only) 2.1 Mveh. of passenger cars (Noda, 2001; Suksod, 2001). These tests basically adopt similar approaches to the one that ACEM proposes in Policy 1, with variations arising mainly from the need to accommodate regional particularities. In the US, the useful life is identical to the proposal from ACEM but a slightly different mileage accumulation cycle is used. In Taiwan and Thailand the useful life for both 2S and 4S engines has been increased to 15 000 km since 31.12.2003, using ECE40 as a mileage accumulation cycle (Shu, 2001). This description shows that the spirit of relevant legislation is similar around the globe and technical particularities only differentiate the application of the regulations.

4.1.2 Technical Description

The useful lives considered in the Baseline scenario were presented in Table 2-9. During these periods, a 20 % 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 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 to be 10 % as a result of the durability requirement in the commission's proposal (Policy 1). The same deterioration rate was also considered for NO_x emissions from Euro 3 vehicles, due to the expected extensive use of TWC.

In order to demonstrate the effect of different durability requirements to fleet emissions, two additional scenarios were examined, considering a different useful life for Euro 3 vehicles in each case. In that respect, a lower useful life would correspond to a relaxed durability requirement, while a stringent regulation would define a higher useful life. The alternative scenarios examined, included the following modifications over the baseline scenario:

- 50 % higher useful life for all Euro 3 motorcycles. This would correspond to a Policy 2 approach.

- 30 % lower useful life for all Euro 3 motorcycles. This would correspond to a Policy 3 approach.

4.1.3 Environmental Benefit

The difference in the total regulated emissions over the baseline scenario for the two alternative scenarios considered is summarized in Table 4-1. This difference is shown both in absolute terms (mass of pollutants saved) and as percentage difference from total emissions. These results refer to the total mass of emissions saved for a long-term application of this measure (period 2006-2012). Furthermore, Figure 4-1 shows how much emission with different useful lives differ each year.

The calculations show that the maximum benefit can be achieved in 2012 for NO_x (0.7% over the baseline) when the useful life is increased by 50%. The difference for CO and HC is expected to be lower than 0.3 % .This higher relative reduction for NO_x is because no deterioration has been assumed for NO_x emissions of pre-Euro 3 motorcycles. Hence, any improvement in the emission performance of Euro 3 vehicles is directly translated to an environmental benefit. The expected difference is increasing exponentially (Figure 4-1) due to the increased penetration of Euro 3 motorcycles.

4.1.4 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 50% increase in useful life would bring, we considered that it would not be necessary to further investigate this.

4.1.5 Social Impacts

Durability requirements are not assumed to lead to any additional effects to what included in the "General Social Impacts" (§2.6).

4.1.6 Conclusion

The change of Euro 3 emissions when changing the useful life from -30% up to +50% of the baseline condition was less than 0.3% for CO (16 kt) and exhaust HC (2 kt) at an average, for a total period of 7 years after the implementation of this measure.

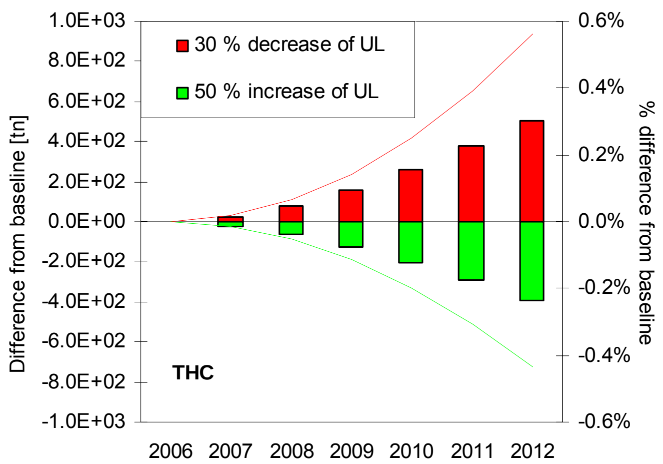
We therefore consider that the exact definition of useful life is not a critical issue for the implementation of a durability requirement. It is obviously important to introduce a durability requirement, to makes sure than no "unexpected" increase of fleet emissions takes place, i.e. a rapid deterioration of emission control devices. But once such a decision has been taken within reasonable approximations, the sensitivity of the total fleet emissions to its detailed parameters is not very high. It is therefore expected, that the manufacturer's proposal (Table 2-9), also rather accepted by the MVEG, is a reasonable approach which addresses the requirements and fulfils the target of a durability regulation.

Table 4-1: Estimated difference in motorcycle emissions over the baseline scenario for the different durability requirements in absolute levels (upper table) and as percentage over the total motorcycle emissions (lower table).

Difference in emissions over baseline 2006-2012		**Exhaust HC [t]**	**CO [t]**	**NO_x [t]**
2-Stroke	30 % decrease of UL	-3.6E+02	-7.6E+02	*
	50 % increase of UL	2.8E+02	5.9E+02	*
4-Stroke	30 % decrease of UL	-1.0E+03	-8.3E+03	-4.5E+02
	50 % increase of UL	8.1E+02	6.5E+03	3.5E+02

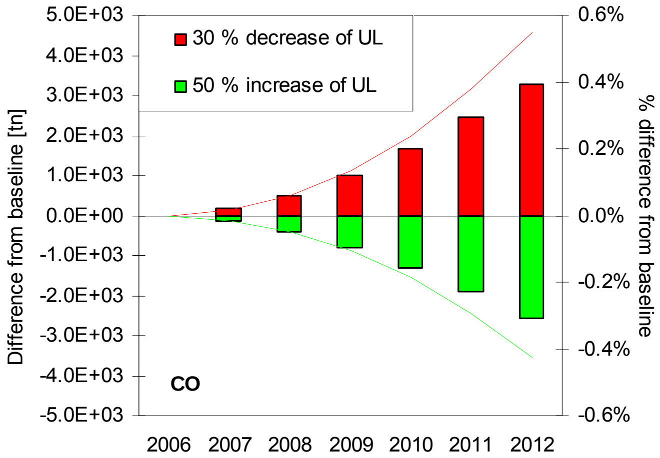
% difference in emissions over baseline 2006-2012		**Exhaust HC (%)**	**CO (%)**	**NO_x (%)**
2-Stroke	30 % decrease of UL	-0.05	-0.01	*
	50 % increase of UL	0.04	0.01	*
4-Stroke	30 % decrease of UL	-0.13	-0.15	-0.54
	50 % increase of UL	0.10	0.12	0.42

*No deterioration has been assumed for NO_x emissions of 2-stroke motorcycles, because they are not considered to be equipped with TWC

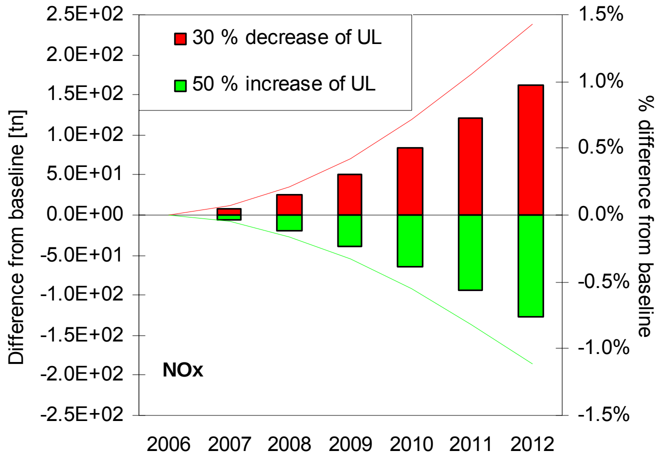


a

Figure 4-1: Annual estimated difference in motorcycle emissions over the baseline scenarios for the different durability requirements in absolute levels (bars) and as percentages (lines). (a) THC.



b



c

Figure 4-1: Annual estimated difference in motorcycle emissions over the baseline scenarios for the different durability requirements in absolute levels (bars) and as percentages (lines). CO (b) and NO_x (c).

4.2 In-Use Compliance procedure for PTWs

4.2.1 Objective, Background and Policies Definition

In-Use compliance (IUC) regulations are established to make sure that the emission levels of a vehicle family 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 only been recently 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. However, since these reports have not been made available, possible policy options are described in the following list:

- **Policy 1:** There is no formal proposal from the Commission yet. The in-use conformity issue seems to be one of the main fields of contradicting argumentation between the manufacturers and authorities.

- **Policy 2:** This option would mainly correspond to the introduction of an in-use compliance checking procedure, mainly along the lines of policy 4. However, several particularities for motorcycles may arise, which need additional elaboration. These individual points are described later in this section.

- **Policy 3:** Contradicting policy 2, a policy option aiming at minimizing costs of IUC would probably be an option either not including any IUC testing, or focusing it only on models which exceed a specific production volume limit to allow for a representative sample to be easily collected. A proposal from the manufacturers seems to be introduction of IUC only for those vehicles for which a durability certification has been granted only by application of the degradation factors and not with an actual execution of a durability test. This also seems a proposal which tries to eliminate unnecessary duplication of a mileage accumulation emission test.

- **Policy 4:** There is no IUC checking of two-wheelers in other parts of the world. Therefore, policy 4 in this case would better reflect the approach established by 2002/80/EC for passenger cars testing. Hence, depending on how limiting and strict an IUC regulation wishes to be, different parts of this Directive may be transplanted to any of the previous policy options.

In fact, the approach decided for larger vehicles seems to be, in principle, transferable to two and three wheel vehicles. As has been very well addressed by Mr Ericsson (2003) from the Swedish EPA, 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 road-worthiness (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. However, 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.

4.2.2 Technical Description

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 relative 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, two scenarios were examined:

- Scenario 1 (Policy 2): Requirement for an annual IUC procedure for all Euro 3 motorcycles from 2006. This would correspond to a Policy 2 approach.

- Scenario 2 (Policy 3): Requirement for an annual IUC procedure for those Euro 3 motorcycles produced in relatively large production volumes. It has been assumed that this corresponds to 20 % of the new registered vehicles. This would correspond to a Policy 3 approach.

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.

4.2.3 Environmental Benefit

The estimated reduction in motorcycle emissions for each of these two alternative scenarios over the baseline one is shown in Figure 4-2. As expected, the reduction in regulated emissions from a policy 3 approach is 20 % lower than that from a policy 2 one. However, even if we assume an IUC procedure becomes mandatory for all Euro 3 motorcycles, the corresponding direct environmental benefit is found only 0.1 % of total HC and CO emissions in 2012. The reduction in NO_x emissions is somehow greater (due to the assumption that only the NO_x emissions of the Euro 3 4-stroke motorcycles are deteriorating) but again rather marginal (only 0.25 % in 2012).

Table 4-2 summarizes the anticipated additional emission reduction from 2-stroke and 4-stroke motorcycles due to the introduction of the two alternative IUC requirements examined. Results are shown in absolute levels but also as percentages over the total motorcycle emissions and refer to the period 2006 to 2012.

Table 4-2: Estimated reduction in motorcycle emissions due to IUC; absolute emission reduction (upper panel) and percentage of total motorcycle emissions from 2006 to 2012 (lower panel).

Reduced emissions (t) 2006-2012		**Exhaust HC**	**CO**	**NO_x**
2-Stroke	IUC (all Euro 3 MCs)	5.2E+01	1.1E+02	2.0E+01
	IUC (Euro 3 MCs produced in large volumes)	1.0E+01	2.2E+01	4.0E+00
4-Stroke	IUC (all Euro 3 MCs)	2.4E+02	1.9E+03	1.0E+02
	IUC (Euro 3 MCs produced in large volumes)	4.8E+01	3.8E+02	2.0E+01

% reduction in total motorcycle emissions 2006-2012		**Exhaust HC**	**CO**	**NO_x**
2-Stroke	IUC (all Euro 3 MCs)	0.006%	0.002%	0.023%
	IUC (Euro 3 MCs produced in large volumes)	0.001%	0.0004%	0.005%
4-Stroke	IUC (all Euro 3 MCs)	0.026%	0.035%	0.120%
	IUC (Euro 3 MCs produced in large volumes)	0.005%	0.007%	0.024%

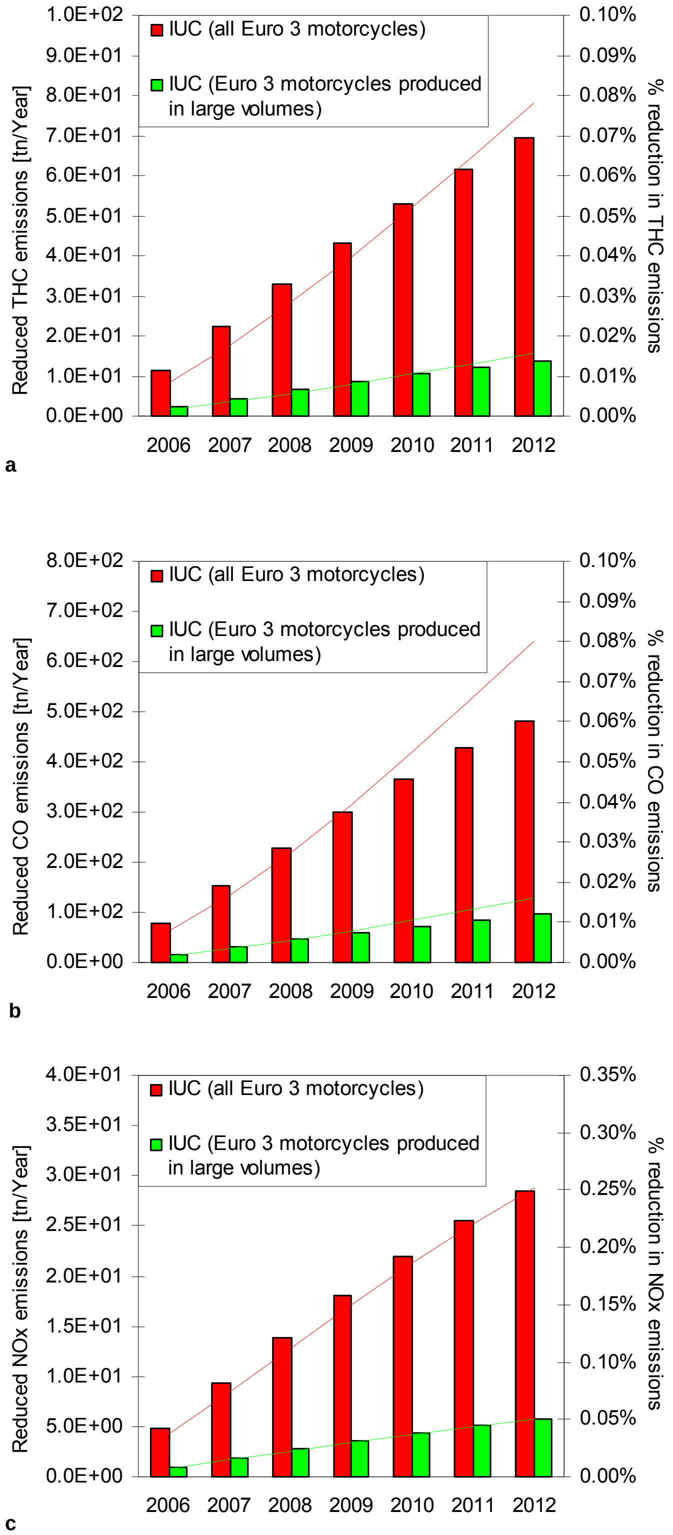


Figure 4-2: Annual estimated reduction in motorcycle emissions due to the different IUC procedure requirements considered in absolute levels (bars) and percentages (lines).

4.2.4 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 (Table 2-17).

In scenario 2, where IUC is focused only on large production volumes, our reasoning remains the same as in scenario 1, except for the number of the engine families that are going to be tested; only 5% of the engine families of the total type approvals will be tested; a percentage which is considered to correspond to the high volume production series. The total cost per policy is illustrated in Table 4-3.

It needs to be noted that it is not clear who is responsible of taking over the IUC cost. In case that the manufacturer will be the only responsible for this, it might be necessary to mark up the total cost of Table 4-3 by 300% in order to take into account the general assumption of section 2.4.1.

Table 4-3: Total marked-up cost (NPV) for each scenario and motorcycle type.

Motorcycles	2-Stroke		4-Stroke		Total	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
Scenario 1	0.43	0.49	3.60	4.15	4.03	4.64
Scenario 2	0.05	0.05	0.23	0.26	0.27	0.31

The implementation cost of an IUC test results to a mean additional cost per new vehicle for every manufacturer, which is illustrated in Table 4-4.

Table 4-4: Mean additional cost per motorcycle (€/vehicle).

Motorcycles	2-Stroke		4–Stroke	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Policy 2	0.95	1.09	0.80	0.92
Policy 3	0.50	0.57	0.25	0.29

4.2.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each policy is illustrated in Table 4-5 and in Figure 4-3 to Figure 4-4.

Table 4-5: IUC cost-effectiveness per motorcycle type (€/kg ≡ M€/kton).

Motorcycles	2–Stroke		4–Stroke		Total	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
HC						
Policy 2	7.8	9.0	14.3	16.5	13.1	15.1
Policy 3	4.1	4.7	4.5	5.1	4.4	5.1
NO_x						
Policy 2	0.9	1.0	1.4	1.6	1.3	1.5
Policy 3	0.5	0.5	0.4	0.5	0.5	0.5

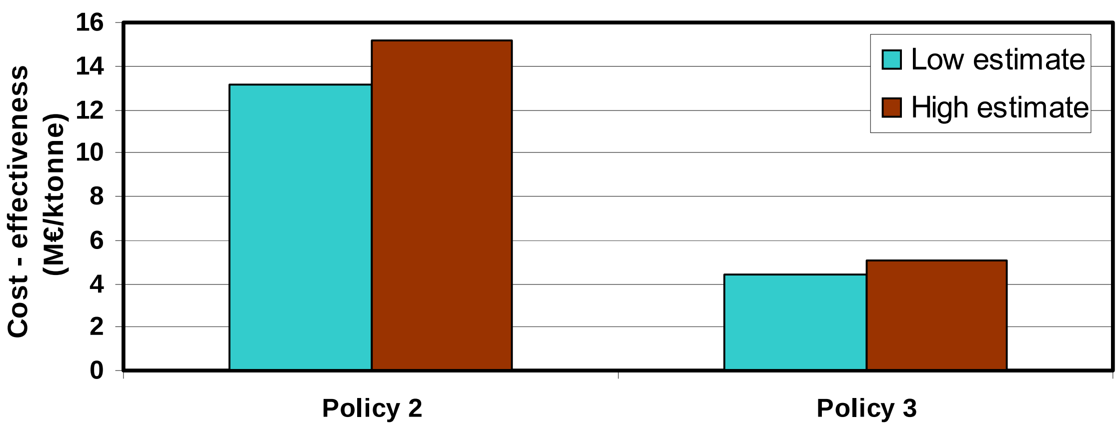


Figure 4-3: HC cost effectiveness for IUC of motorcycles.

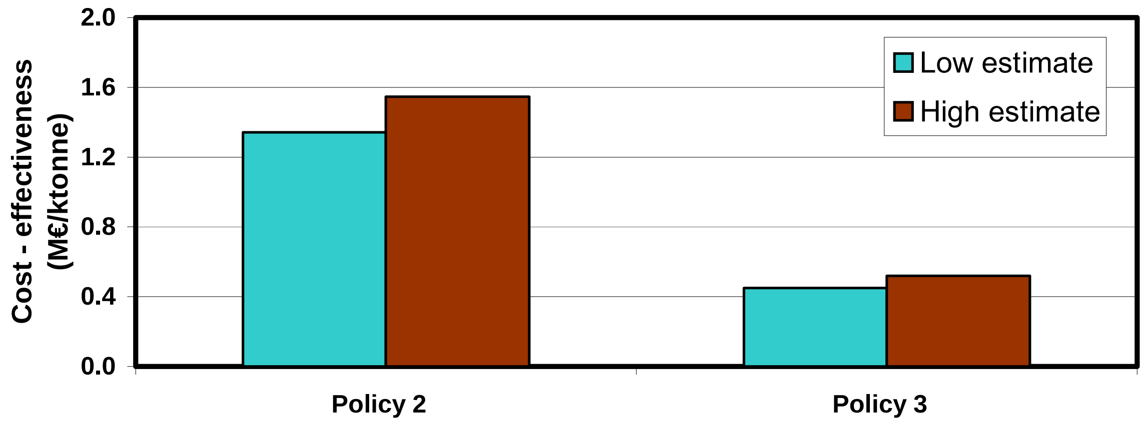


Figure 4-4: NO_x cost effectiveness for IUC of motorcycles.

4.2.6 Social 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.

4.2.7 Conclusions

IUC could be 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 indirect effect of IUC discussed before cannot be evaluated although it could be considered as the most important element of the procedure. However, we have tried to simulate it, assuming that if no IUC were in place, then some of the vehicle families might emit more than their type-approval limits. In order to obtain an order of magnitude of the effect, we have assumed that 3% of the new registered Euro 3 motorcycles per year emit 20% higher than their type approval value. We also considered that two IUC versions could be decided, one targeting all vehicle families and one targeting only relatively large vehicle families (i.e. corresponding to 20% of the new-registered vehicles).

We found out that with these assumptions, the overall reduction in emissions, expressed as a percentage of total PTW fleet emissions is negligible for all pollutants. Even in the case that all vehicle families are checked via an IUC procedure, the improvement in fleet emissions would not have been more than ~0.04% over the total emissions of motorcycles in the period 2006- 2012. The cost to implement IUC per motorcycle is in the order of 0.5 – 1€/vehicle, including auditing, test organisation and reporting but not including any recall and repair costs which should be a manufacturer's responsibility.

Given the small effect of IUC on total emissions, the potential difficulty to locate appropriate vehicles in small vehicle families, and the relatively higher cost associated with implementing IUC to all vehicle types, one might consider that Policy 3 (i.e. implementing IUC only to large production families) may be a more appropriate decision. It is estimated that the cost-effectiveness of Policy 3 is three times higher than Policy 2.

4.3 Type approval for CO_2 and fuel consumption

4.3.1 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. This task aims at evaluating such approaches.

- **Policy 1:** A proposal from ACEM has been presented in the ad-hoc MVEG group to introduce a CO_2 measurement and fuel consumption calculation (or measurement) in the type approval procedure for motorcycles. This proposal describes the technical procedure which needs to be followed, the necessary calculations that have to be carried out, provides for clarifications for two and three wheeled vehicles and for a distinction between spark ignition (SI) and compression ignition (CI). It also regulates conditions where test and manufacturer declared values differ and it prescribes the methodology to check COP with provisions for a "run-in" period. This legislation proposal seems also to formulate a Commission's perspective which is also adopted for passenger cars (M1) and is also expected for light duty vehicles (N1) towards the labelling of fuel consumption and CO_2

emissions, in an effort to better report and control energy consumption and greenhouse gas emissions.

- **Policy 2:** The proposal set forward by ACEM seems to also correspond to what is expected from a BAT approach, which on the issue of CO_2 for the time being, can only provide for reporting mechanisms. Additional abatement measures that are under consideration are CO_2-related taxation and other fiscal measures, voluntary agreements, economic incentives for new technologies, etc. Due to the low specific CO_2 emissions per passenger from PTWs, compared to passenger cars, such measures can only be seen to promote the use of smaller vehicles. Hence they do not really correspond to a limiting factor for PTWs market share but, on the contrary, might also be considered to provide strong arguments in favour of PTWs use.

- **Policy 3:** CO_2 measurement is also conducted during type approval tests, but data are not reported as type-approval values. Hence, it is not expected that policy 1 will introduce any particular additional cost and can be also adopted as a policy 3 scenario.

- **Policy 4:** European legislation is pioneering in the area of CO_2 and fuel consumption type approval and labelling in the passenger car sector. The same approach has been also adopted as a Policy 1.

With regard to the social and economic impact of such a measure to the consumer, this can only be evaluated drawing from preceding experience in the case of passenger cars, taking into account the different use of the particular vehicles examined here. It is expected that for motorcycles used primarily for transportation in congested urban conditions, low fuel consumption may be a significant motivation for a potential customer. On the other hand it may have limited effect for customers of sports- or super-bikes, where performance is the main market driver. Additionally, CO_2-related taxation may have a significant impact on market shares.

The effect on the development and manufacturing of motorcycles can also be significant but it is not expected to appear with the establishment of the labelling procedure. This is because improvement in the fuel efficiency is a slow process, which cannot be addressed by only establishing a monitoring mechanism.

4.3.2 Technical Description

We consider that the Baseline scenario reflects the evolution of CO_2 emissions from PTWs and their share of total road transport emissions. We have evaluated no more scenarios.

4.3.3 Social 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.

4.3.4 Conclusions

Total CO_2 emissions from PTWs constitute 0.8% of total road transport emissions and PTWs emit at an average 2/3 of the CO_2 emissions of passenger cars per passenger-km. Therefore, linking the CO_2 type approval and labelling procedure to a policy aiming at reducing the greenhouse effect seems to be beneficial for PTWs. However, it is not known whether this may also affect the internal structure of the PTW market (i.e. shift to low-emitting, low consuming PTWs).

In any case, it may be assumed that inclusion of distance specific CO_2 emissions and fuel consumption figure for each new motorcycle, and its subsequent comparison with passenger cars, may eventually act in favour of the PTW sector growth. This argument becomes even stronger when considering the measures adopted by the European Commission to reduce road transport CO_2 emissions, such as the ACEA-commitment, followed by similar commitments from vehicle manufacturer associations from the far east (JAMA, KAMA). Furthermore, the European Commission is considering fiscal measures that would result in an additional reduction of CO_2 emissions (COM(2002) 431 final). These actions concern passenger cars only, on the argument that more than half of the road transport CO_2 emissions is due to by passenger cars. The small contribution of PTWs in road transport CO_2 emissions confirms the exclusion of PTWs from these measures. Moreover, a shift of potential passenger car customers to the PTWs market can result to further CO_2 reductions. First, due to the lower passenger-km specific CO_2 emissions from PTWs and secondly, due to the (potentially) urban congestion reduction by increasing the mean (without increasing the maximum!) urban travelling speed.

4.4 PM regulation from 2-stroke engines

4.4.1 Objective, Background and Policies Definition

The objective of this study is to assess whether the introduction of a regulation to specifically address PM emissions from 2-stroke PTWs and compression ignition three and four wheelers would be necessary.

With regard to PM emissions from two-stroke engines, a recent study on behalf of the European Commission (Rijkeboer et al., 2002) on the introduction of a Step 3 for moped emissions, thoroughly addressed both experimentally and scientifically the potential for

PM type-approval from two-stroke mopeds. The general conclusions of this study showed that although PM emissions from small two-stroke engines cannot be neglected in urban areas, it is not clear whether such emissions pose equivalent health risks to the diesel PM emissions, due to the different particle nature. Additionally, the study addressed technical issues for introducing such a type-approval procedure, particularly raising issues such as the low reproducibility in collecting and determining volatile PM with a conventional CVS procedure, the interference between PM and the already regulated HC emissions, and the absence of any significant experience in monitoring and evaluating the evolution of the relative emission levels. Due to these shortcomings, that study was unable to assess the relevance for transferring a diesel-like approach to the type-approval of PM emissions from mopeds. On the other hand, it recommended that control of HC emissions (and especially of the most heavy fractions) may be a cost-effective approach in controlling PM emissions, it proposed that monitoring and understanding of two-stroke PM emissions should help building a future regulation and it seemed to expect that future emission control technology (pre-cats or SAI systems and DI combustion) may by definition also effectively decrease PM emissions. The results of this study have obviously brought difficulties in clarifying and formulating a PM type-approval regulation proposal. If one would attempt to define four policy options, those would be:

- **Policy 1:** There is no position expressed for PM regulation yet. This has been obviously much considered by the Commission which had already launched the afore mentioned study. Therefore, it is assumed that policy 1 will be structured on the results that different policy options would have. Therefore, the study team wishes to formulate clear boundary conditions for the remaining policy options.

- **Policy 2:** What would be considered today as a BAT approach on a technological level would be to replace all new registrations of CI and 2S engines with new technology 4S ones. This is because in relevant studies, new low polluting 4S engines are still found as lower emitters of even direct injection (DI) 2s engines (ANCMA, 2002; RICARDO/ACEM, 2002). This is not to say that 2S DI engines are high emitters, because their levels are found even below the Euro 4 levels of passenger cars, when PM measurement is conducted following the procedure for diesel cars. But if one wishes to consider what would be the maximum environmental benefit, implementing BAT of today for PM regulation, this would be shifting production to 4-stroke engines. It is therefore proposed that a scenario corresponding to policy 4 may be that all new registrations emit at a level of ~5 mg/km to evaluate the effect of introducing only 4-strokes in the market; this of course discussing the difficulties of such a scenario, including its low social acceptance, the large negative impact to manufacturers who have invested to the development and production of 2-stroke DI engines, etc.

- **Policy 3:** What is rather well established today is that technology evolution to meet gaseous pollutants emission standards is expected to be particularly effective also for the reduction of PM emissions. The report on mopeds regulation proposal

(Rijkeboer et al., 2002) demonstrated that PM from 2-strokes are largely emissions of fuel and lubricant which escape combustion. Hence, introducing strict HC emission standards would also be expected to control PM emissions. However, the lubrication oils specifications may be an additional control for particulate emissions. The same study provided evidence that the use of synthetic oils which can more easily combust than mineral ones may bring additional reductions to PM emissions. There are different levels where regulations may intervene to control the quality of lubrication oils used for two stroke engines, including regulating the production and availability of such lubrication oils, recommendations from the manufacturer to the vehicle owner that the use of such oils is beneficial for engine protection and environmental protection, etc. Therefore, policy 3 could be implemented with no PM TA for 2S engines but taking measures on lubrication oil use. Finally, policy 3 should also consider emissions from CI vehicles. It is not yet known what is the contribution of such vehicles on total emissions, which will be shown from our calculation results. However, this is expected particularly low because this category only concerns a total population of a few thousand vehicles. Therefore, a regulation which would aim to a gradual decrease of PM emissions from such vehicles would have a high cost (on a per vehicle basis) to obtain the TA and a limited environmental benefit. A TA regulation with strict emission standards on the other hand, would probably extinguish the particular vehicle class because it is not expected that the additional development costs would be bearable from the manufacturers for such low volume production.

- **Policy 4:** There is no direct regulation of PM from motorcycles in any country in the world. USEPA have attempted to provide recommendations for repeatable PM measurement from 2-stroke engines, however they have been met with technical difficulties (Spears, 2002). Obviously, any scenarios for direct PM regulation would be based on the approach for diesel PM measurement. The difficulties in such a transfer have been extensively discussed by Rijkeboer et al. (2002). However, some countries in Asia (e.g. Thailand) have introduced white smoke emissions standards since 2001 for new and in-use vehicles which should not exceed 15% and 30% respectively, measured with smoke meters. This approach is something that the regulations may consider. Although it is expected to become of limited interest for new vehicles which would comply with HC emission standards below 0.5 g/km, it may be of some importance for RW tests of older vehicles. As a summary, there is no regulation applicable to other parts of the world that would be directly available today for the measurement of PM from 2S motorcycles. Regulations in Asia however control white smoke emissions from such motorcycles and this might be something to consider.

4.4.2 Technical Description

- Given the analysis in the previous paragraphs, the two options that were examined for reducing PM emissions from 2-stroke vehicles were:

- Scenario 1 (Policy 2) : Replacement of all Euro 3 2-stroke engines with 4-stroke ones.
- Scenario 2 (Policy 3): Mandatory use of synthetic oil instead of mineral one from all 2-stroke motorcycles, including three and four wheelers, starting from 2006, 2007 or 2008.

All this measures should be evaluated keeping in mind that even if no additional measure will be taken, the PM contribution of PTWs is already constantly decreasing, reaching only 0.3 % in 2012 (section 3.2).

4.4.3 Environmental Benefit

The estimated reduction in PM emissions over the baseline scenario from the introduction of the additional legislative measures examined is shown in Figure 4-5. Table 4-6 summarizes the corresponding total reduction in PM emissions for the period 2006-2012, both in absolute levels and as percentage reduction over the baseline motorcycle emissions.

It is noteworthy, that regulating the use of synthetic oil yields 4 to 7 times greater reduction in PM emissions than would be achieved by replacing all 2-stroke motorcycles with new technology 4-stroke ones. This is due to the fact that the former measure would apply to high emitting pre-Euro 3 vehicles too. This also explains the different trends in the effect of these measures shown in Figure 4-5. In particular, the reduction in PM emissions achieved from the mandatory use of synthetic oil is gradually decreasing through the years as older high emitting vehicles are removed. On the other hand, the reduction in PM emissions is constantly increasing through the years as more 4-stroke motorcycles are registered instead of 2-stroke ones. Finally, the reduction in PM emissions caused by the use of synthetic oil from 3 & 4 wheelers is not expected to be greater than 0.3 % due to their small population.

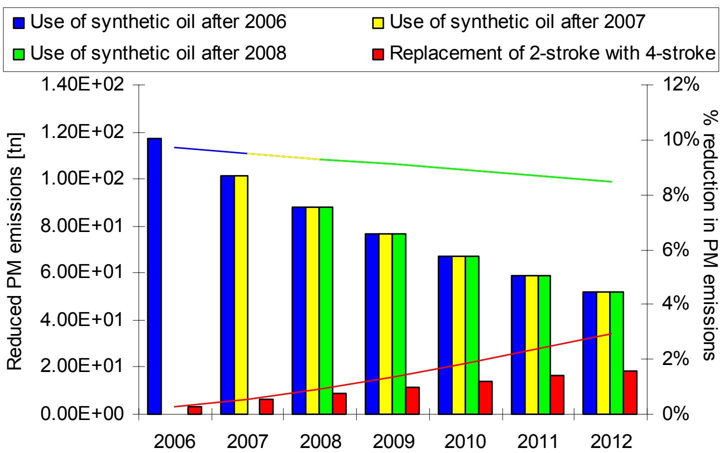


Figure 4-5: Estimated annual reduction in PM emissions due to the introduction of the different additional legislative measures; in absolute levels (bars) and as percentage of the total motorcycle PM emissions (lines).

Table 4-6: Estimated reduction in PM emissions over the baseline scenario due to the introduction of additional legislative measures; in absolute values (1st column) and as percentage of total motorcycle emissions from 2006-2012 (2nd column).

		Reduced PM emissions (t)	% reduction in PM
2-stroke	Use of synthetic oil after 2006	5.4E+02	8.9%
	Use of synthetic oil after 2007	4.3E+02	8.8%
	Use of synthetic oil after 2008	3.3E+02	8.7%
	Replacement of 2-stroke with 4-stroke	7.8E+01	1.3%
3 & 4 Wheelers	Use of synthetic oil after 2006	1.8E+01	0.29%
	Use of synthetic oil after 2007	1.3E+01	0.26%
	Use of synthetic oil after 2008	9.1E+00	0.24%
	Replacement of 2-stroke with 4-stroke	*	*

* A measure that would require the replacement of all 2-stroke 3 & 4 wheelers with 4-stroke ones was deemed impractical and therefore was not evaluated.

4.4.4 Cost Calculation

In order to calculate the total cost of Policy 2, we assume that the transition from 2-stroke to 4-stroke vehicles costs of €130 - €160 per vehicle (Rijkeboer et al., 2002).

The cost to implement policy 3 derives from the difference in the price of the mineral and synthetic oils. It is estimated that the mineral oil costs €4 – €6 per litre, whereas the synthetic oil costs €8 – €10 per litre. Therefore, the price difference is €2 – €6. The oil to fuel mixing ratio is assumed 50:1 for pre-Euro vehicles and 100:1 for Euro 1 and later (oil density: 0.78 kg/l) Combining the above cost data with the average annual fuel consumption during each period and the oil mixing ratio, we calculate the total cost.

The total costs per policy are illustrated in Table 4-7.

Table 4-7: Total marked-up cost (NPV) per policy and implementation year

2-Stroke MCs	2006		2007		2008	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
Scenario 1	240.0	295.3	*	*	*	*
Scenario 2	23.0	69.0	18.4	55.2	14.3	43.0

*Not investigated

4.4.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each policy is illustrated in Table 4-8 and Figure 4-6.

Table 4-8: PM control cost–effectiveness for each scenario and implementation year considered (€/kg ≡ M€/kton).

2-Stroke MCs	2006		2007		2008	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Scenario 1	3081	3792	*	*	*	*
Scenario 2	42	127	43	128	43	129

*Not investigated

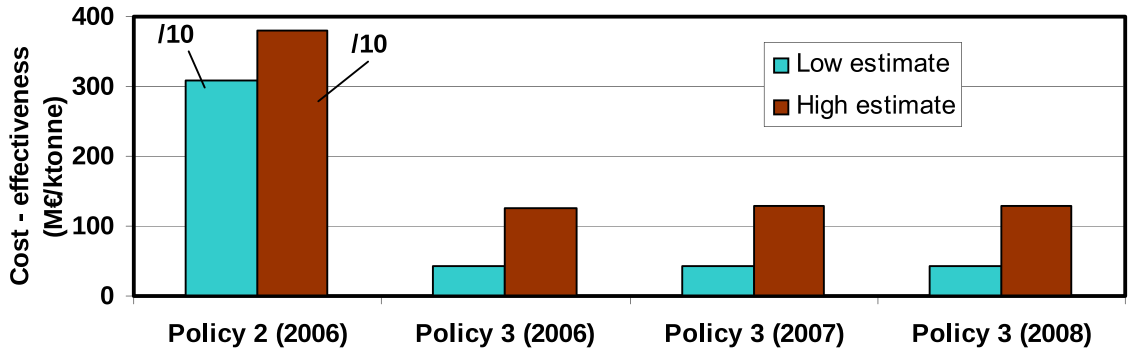


Figure 4-6: PM control cost–effectiveness.

4.4.6 Social Impacts

It should be mentioned that a prospective implementation of policy 2 (shift from 2-stroke Motorcycles to 4-stroke) will have significant effects in the market and will impact the economy of some manufacturers which continue to build 2-stroke engines. Therefore, a large implementation cost can occur with such decision, but its magnitude cannot be accurately estimated. So, developing a direct PM regulation is crucial for the “survival” of the 2–stoke Motorcycles. On the other hand, low PM – hence visually clean – motorcycles may become a good sales argument and potential users would welcome the introduction of non-smoking, but efficient, 2–stoke Motorcycles.

4.4.7 Conclusions

Total PM emissions from PTWs contribute to no more than 1.6% of total road transport emissions today. Also, it is not known whether the semi-volatile PM from 2-stroke engines and diesel soot are equally important from the health effects point of view.

The regulations adopted today to control (mainly) HC emissions are expected to be also effective in controlling PM emissions. The implementation of DI technology and the use of oxidation catalysts are significant technological steps also in the direction of reducing the semi-volatile material exhaust from 2-stroke engines. Even by adopting no further measures, we estimated that the share of PTWs to total PM will continue to decrease reaching down to 1% in 2010 (potential year of implementation of a Euro 5 for passenger cars). This is good evidence that a legislation targeting specifically PM emissions from PTWs might not be necessary.

In order to explore whether a PM regulation would bring a significant additional reduction of PM emissions, we considered that a PM emission standard is set at a level equal to the emission level of the "best available technology" of today, i.e. stoichiometric 4-stroke engines. It was found that even stopping the production of 2-stroke engines and introducing only 4-stroke ones, the mean reduction in emissions in the period 2006-2012 would have been only 1.3%. This is because the contribution of older vehicles is more significant.

In this direction, a measure that could affect emissions from older vehicles may be more effective. Policy 3 (forcing the use of synthetic oil) is not only more economical than Policy 2 (4-stroke engines), but it also achieves 5 to 7 times greater PM reduction.

With discussions of the contractor with the motorcycle industry, manufacturers insist that they already recommend synthetic or semi-synthetic oils for use in their products and this recommendation is printed in the vehicle's owner manual. They also use such oils for periodic maintenance at their official dealers' workshops. Therefore, motorcycle manufacturers believe that it is the oil distribution market that needs to be controlled for effective regulation. So, ACEM do not believe that there is much that can be done on their side to force improved oil use over the life of the vehicle. The contractor, while mostly agrees with the ACEM arguments because the vehicle maintenance is not at manufacturer's control after any vehicle is sold, still believes that further steps from the manufacturers' side can be taken. These include the recommendation to use synthetic oils which may become mandatory on owners' manual, the inclusion of an embossed statement stating why the use of such oils is better for engine protection and environmental protection, the application of a sticker carrying the same message on the bike could be enforced, etc.

4.5 Euro 3 emission standard for mopeds

4.5.1 Objective, Background and Policies Definition

The report on the formulation of an emission regulation for Euro 3 mopeds (Rijkeboer et al. 2002) came forward with three proposals on moped emission standards:

1. Limits 30 % lower; no cold start, no durability requirement.

2. Addition of cold start and durability requirements; no reduction of the numerical limits relative to Euro 2.

3. Limits 30 % lower, together with a cold start and a durability requirement.

The three proposals aimed at providing an effective regulation of moped emissions. The first one, corresponds to the rule of thumb decrease in the emission standards that, in average, any new emission regulation brings over the previous step; this applying to all vehicle categories and not only mopeds. The second option attempted one different approach, i.e. implementing control of the cold-start emissions from mopeds which may potentially prove a significant urban pollution problem, particularly since they are still by no means controlled by the legislation. The third option tried to synthesize the two first options, however resulted to particularly stringent emission levels which it would not be able to meet, unless significant compromises were decided (such as the extinction of conventional 2-stroke engines).

For these reasons, the second option appeared to be the favourite one, because it effectively tackles the issue of cold-start overemission, without imposing unbearable burden to the manufacturers. Amongst others, it is also consistent with the Euro 3 emission standards formulation for motorcycles. The third option was not discussed further.

4.5.2 Technical Description

Three proposals on the Euro 3 emission standard for mopeds have been evaluated in this study. These are namely:

- Proposal 1: 30 % lower limits; no cold start.
- Proposal 2: No reduction of the numerical limits relative to Euro 2; addition of cold start requirement with a weighting factor of 30% for the cold start part.
- Proposal 3: No reduction of the numerical limits relative to Euro 2; addition of cold start requirement with a weighting factor of 50% for the cold start part.

Our aim was to estimate representative Euro 3 emission factors for each of these proposals.

For the first proposal, a 70 % reduction has been assumed over the hot Euro 2 regulated emissions. However, the cold-start part of the Euro 2 emission factor has been transferred directly to the Euro 3 emission factor. Hence, the Euro 3 emission factor is calculated as:

$$EF_{Euro3} = 70\% \cdot EF_{Euro2Hot} + EF_{Euro2Cold} \quad \text{Eq. 4-1}$$

The problem in estimating the effect of the remaining two proposals is the difference in the type approval cycles considered in the Euro 2 and Euro 3 cases. In order to find the expected reduction of the Euro 3 emission factor (which includes a cold-start part), over the Euro 2 (which only refers to hot conditions), we estimated a Euro 2 equivalent emission standard. This hypothetical emission standard ($ES_{Euro2Cold}$) corresponds to the equivalent Euro 2 emission standard, in case the Euro 2 type approval was given on the basis of the Euro 3 cycle (cold start). Therefore, the Euro 3 emission factor would be calculated as:

$$EF_{Euro3} = EF_{Euro2} \cdot \frac{ES_{Euro3}}{ES_{Euro2Cold}} \qquad \text{Eq. 4-2}$$

The hypothetical cold Euro 2 emission standard was calculated according to:

$$ES_{Euro2Cold} = ES_{Euro2} \cdot \left[(1 - WF) + WF \cdot \left(\frac{Cold}{Hot} \right)_{Euro2} \right] \qquad \text{Eq. 4-3}$$

Where, WF is the weighting factor for the cold part of the cycle (30 % for proposal 2 and 50 % for proposal 3), and Cold/Hot is the assumed contribution of cold start emissions for Euro 2 mopeds (Table 2-5).

The above two approaches have been used in order to estimate the emission factors for the regulated pollutants only. For CO_2 emissions it has been assumed that all Euro 3 mopeds will be 4-stroke or DI 2-stroke ones (Table 2-7) exhibiting 30 % lower ultimate CO_2 emissions than their carburettor equipped Euro 1 predecessors.

Figure 4-7 shows the emission factors calculated for each of the three proposals examined. Euro 2 emission factors are also shown for comparison. All three proposals are expected to result in a reduction of HC and CO emissions. In general, the regulation of cold start emissions resulted in greater reduction of CO and HC emissions. However, the estimated CO emissions under proposal 2 were greater than under proposal 1, since the cold start effect assumed (Table 2-5) was more than offset from the reduction of hot emissions. Finally, a reduction in NO_x emissions was realized only under proposal 1 since cold start operation actually results in slightly lower NO_x emissions. Obviously, there is a significant uncertainty in calculating the actual emission factors for technologies to appear in the future. However, despite these uncertainties, the calculation scheme of the equations above is considered to capture in a systematic way the effect of an emission standard formulation to the actual emission factor.

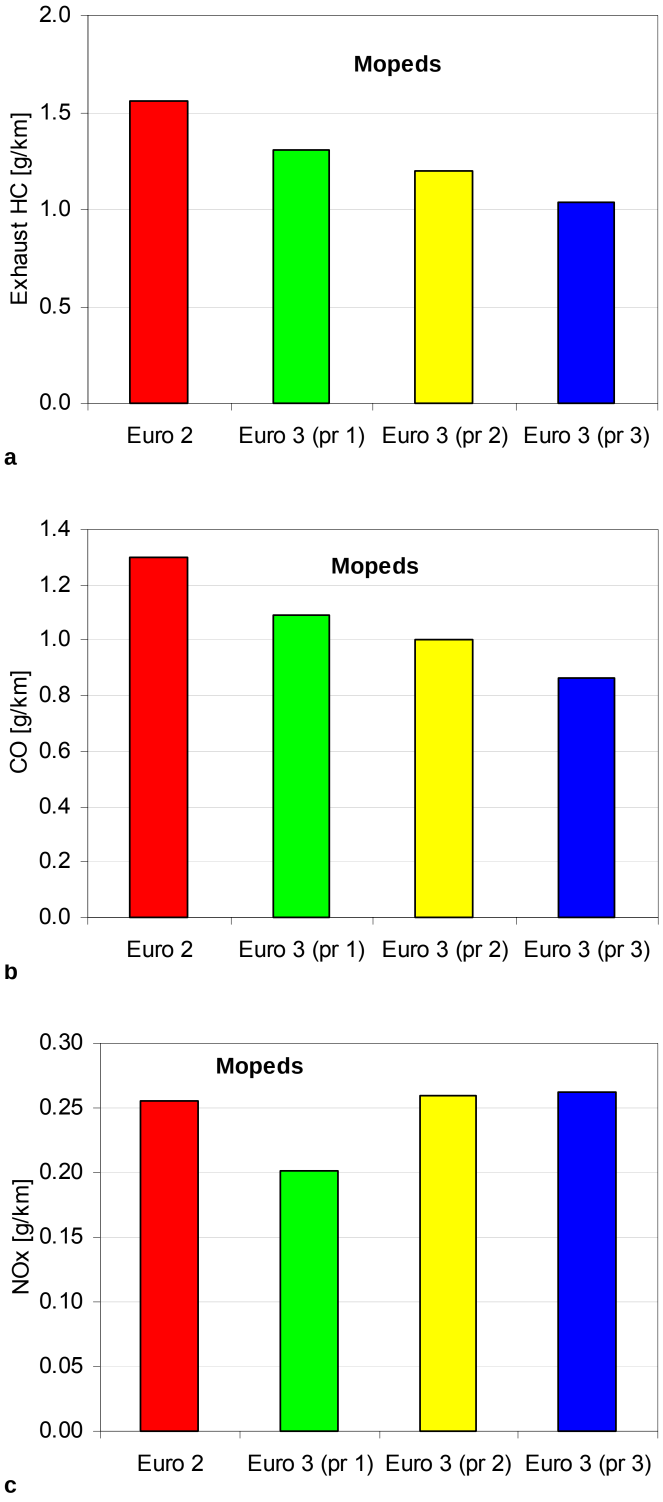


Figure 4-7: Proposed emission factors for Euro 2 and Euro 3 mopeds for each of the three different proposals considered. "Pr" stands for "Proposal". (pr 1: 70% lower hot emissions & no cold start regulation; pr 2: Euro 2 emission limits & cold start with 30 % weighting; pr 3: Euro 2 emission limit & cold start with 50 % weighting).

4.5.3 Environmental Benefit

The emission reduction over the baseline scenario for each proposal is shown in Figure 4-8 and Figure 4-9. As expected, the regulation of cold start emissions led to a higher reduction of HC and CO emissions. Moreover, the reduction becomes more important as the weighing of the cold part increases too. However, this is not the case for NO_x, which seems to decrease for regulation of the hot part only. The other two proposals are actually expected to result in increased NO_x emissions.

With regard to PM and CO_2, reductions come from the fact that the new technology introduced for HC control is both a lower PM emitter and leads to more efficient engines. Therefore, the introduction of the Euro 3 standard is also expected to result in a significant reduction of moped PM emissions reaching almost 20 % in 2012. Finally, an additional reduction in CO_2 emissions is also expected from the introduction of a Euro 3 standard for mopeds, as 4-stroke and DI 2-stroke vehicles are expected to replace all the carburettor 2-stroke ones. We have not assumed any differentiation of the non-regulated pollutants for the different scenarios because we have assumed that they depend on the technology and not the actual emission standard for regulated pollutants.

Table 4-9 summarizes the estimated total reduction in moped emissions for each proposal both in absolute levels and as percentage reduction over the baseline moped emissions. It is worth mentioning that introduction of a Euro 3 standard for mopeds is also expected to decrease evaporative emissions due to the increased production of FI mopeds.

Table 4-9: Estimated total reduction in moped emissions due to the introduction of the three alternative Euro 3 standards in absolute levels (upper table) and as percentage of the total moped emissions over the baseline scenario from 2006 to 2012 (lower table).

Reduced emissions [tn]	HC exhaust	HC evaporative	CO	NO_x	PM	Ultimate CO_2
Euro 3 (hot)	2.6E+04	4.1E+03	9.7E+03	3.9E+03	1.1E+03	3.6E+05
Euro 3 (30%/70%)	3.5E+04	4.1E+03	1.3E+04	-2.8E+02	1.1E+03	3.6E+05
Euro 3 (50%/50%)	4.2E+04	4.1E+03	1.7E+04	-4.8E+02	1.1E+03	3.6E+05

% reduction in emissions 2006-2012	HC exhaust[1]	HC evaporative[1]	CO	NO_x	PM	Ultimate CO_2
Euro 3 (hot)	1.6%	0.3%	0.6%	10.9%	8.7%	3.7%
Euro 3 (30%/70%)	2.1%	0.3%	0.8%	-0.8%	8.7%	3.7%
Euro 3 (50%/50%)	2.5%	0.3%	1.1%	-1.3%	8.7%	3.7%

1: Over the total HC emissions.

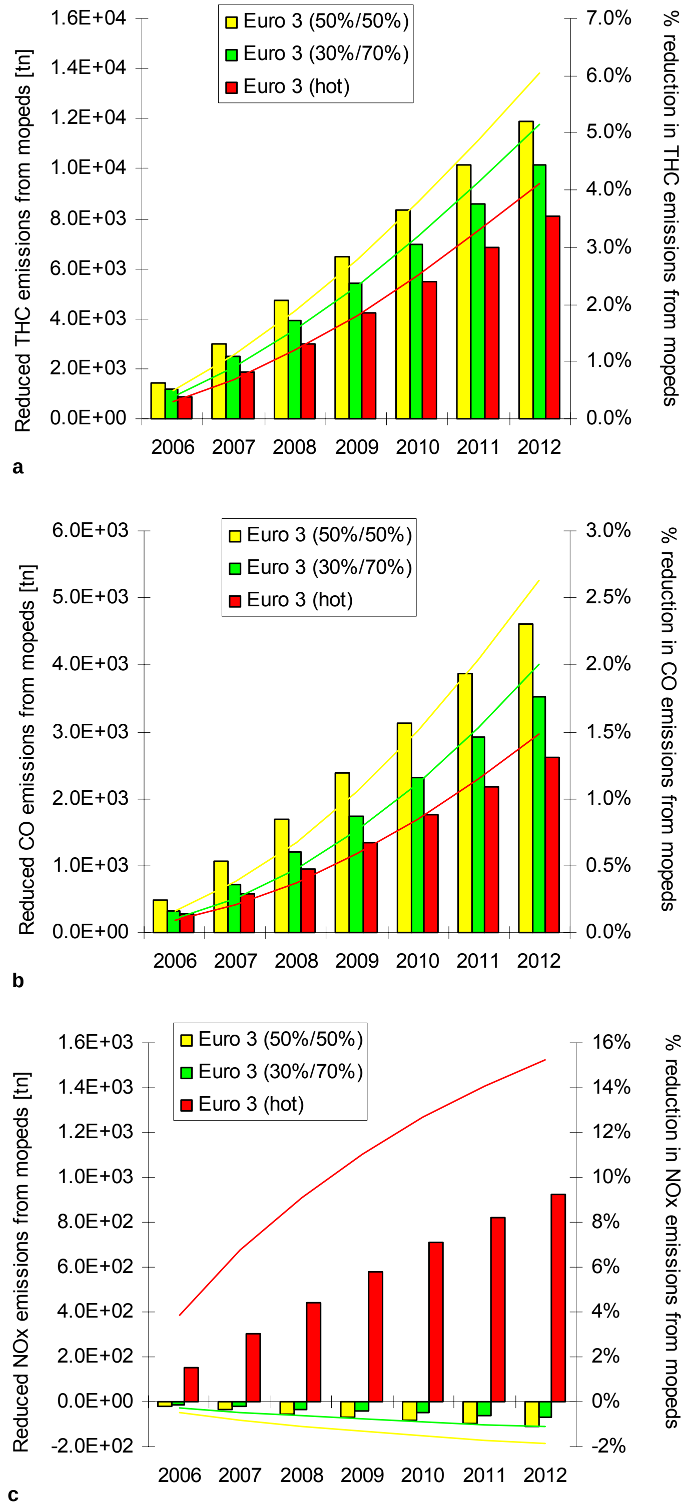
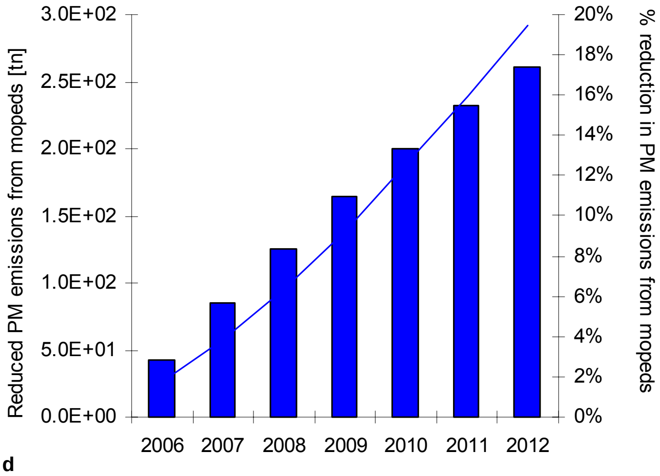


Figure 4-8: Estimated annual reduction in moped emissions due to the introduction of the different legislative measures in absolute values (bars) and as percentage of the total moped emissions over the baseline scenario (lines).



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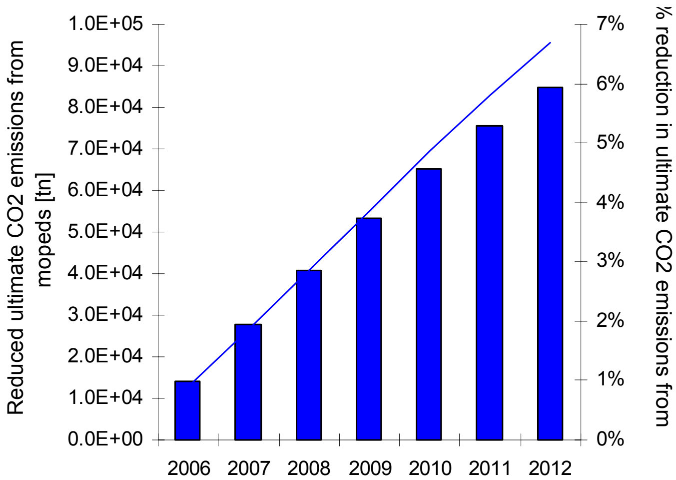

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Figure 4-9 Estimated annual reduction in ultimate CO_2 and PM emissions from mopeds due to the introduction of the Euro 3 standard; in absolute values (bars) and as percentage of the total moped emissions over the baseline scenario (lines).

4.5.4 Cost Calculation

The costs to implement improved emission control from mopeds have been also estimated by Rijkeboer et al. (2002). According to this, the cost to implement proposal 1 is calculated at €25 – €40 per vehicle for 2–stroke mopeds and €30 – €40 per vehicle for 4–stroke mopeds. These costs concern the installation of additional equipment and hardware.

In order to achieve the emission reductions of proposal 2, we consider a development and calibration cost of M€1.5 – M€2.0 for 2–strokes and M€1.0 – M€1.5 for 4-stroke vehicles. Then, in order to calculate the total cost, we require the number of new types and type approvals of mopeds. This is given in Table 4-10, which is a product of the information supplied by the industry and the distribution of 2–stroke and 4–stroke mopeds in the total fleet.

Table 4-10: New types of mopeds and type approvals in Europe per year

Moped Category	New Types	Type Approvals
2-Stroke	4	9
4-Stroke	8	21

The cost involved in the case of 2–stroke mopeds during the first year of implementation of the new emission standards is defined by the development and calibration cost applied to all type approvals for the particular year. The annual (development and calibration) cost thereafter is considered only for the new types of motorcycles launched. For each vehicle, and additional cost of €40 – €60 (Rijkeboer et al., 2002) is added for the new devices and electronic equipment required to meet the limits.

The same cost elements are used for the 4-stroke case, with the cost of the additional equipment and electronic hardware to reach €90 – €115 (Rijkeboer et al., 2002) per vehicle.

For proposal 3 we increase estimations of proposal 2 by 20% to account for the better materials and more sophisticated calibration required.

The total cost per policy is illustrated in Table 4-11.

Table 4-11: Total marked-up cost (NPV) for each proposal.

Mopeds	Low Estimate (M€)	High Estimate (M€)
Proposal 1	663	930
Proposal 2	2034	2711
Proposal 3	2445	3253

The implementation cost of this Task results to a mean additional cost per new vehicle for every manufacturer, which is illustrated in Table 4-12.

Table 4-12: Mean additional cost per new moped (€/vehicle).

Mopeds	Low Estimate	High Estimate
Proposal 1	25	40
Proposal 2	47	125
Proposal 3	56	150

4.5.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each policy is illustrated in Table 4-13 and in Figure 4-10 to Figure 4-12.

Table 4-13: Euro 3 moped cost–effectiveness for different proposals(€/kg ≡ M€/kton).

Mopeds	Low Estimate	High Estimate
HC		
Option 1	20	27
Option 2	47	63
Option 3	48	63
NO_x		
Option 1	6	9
Option 2	*	*
Option 3	*	*
PM		
Option 1	39	55
Option 2	120	160
Option 3	145	195
CO_2		
Option 1	2	3
Option 2	6	7
Option 3	7	9

* Increase in NO_x emissions over the Baseline Scenario

4.5.6 Social Impacts

The social impacts of this task are estimated to be similar to the General Social Impacts (§2.6), except for the fact that this task refers only to mopeds and to businesses involved in the production and distribution of such vehicles only.

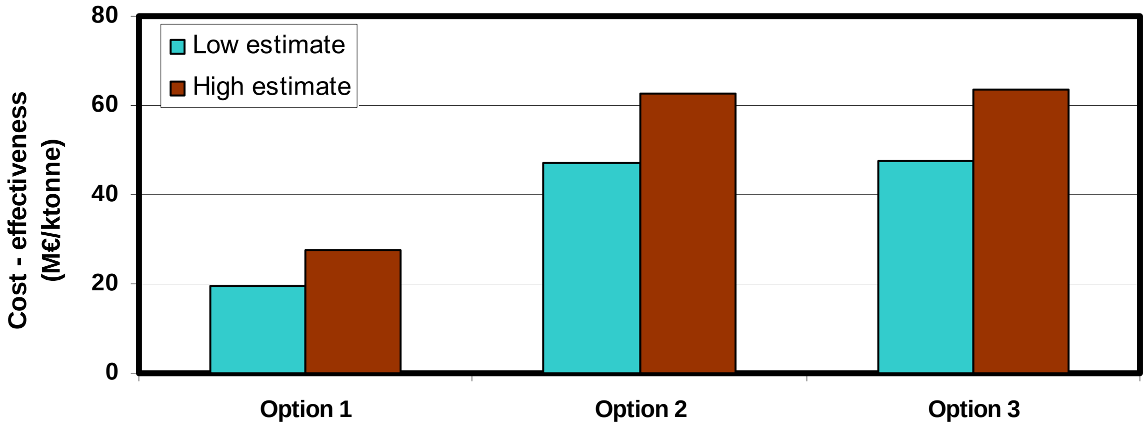

Figure 4-10: HC cost–effectiveness for moped Euro 3.

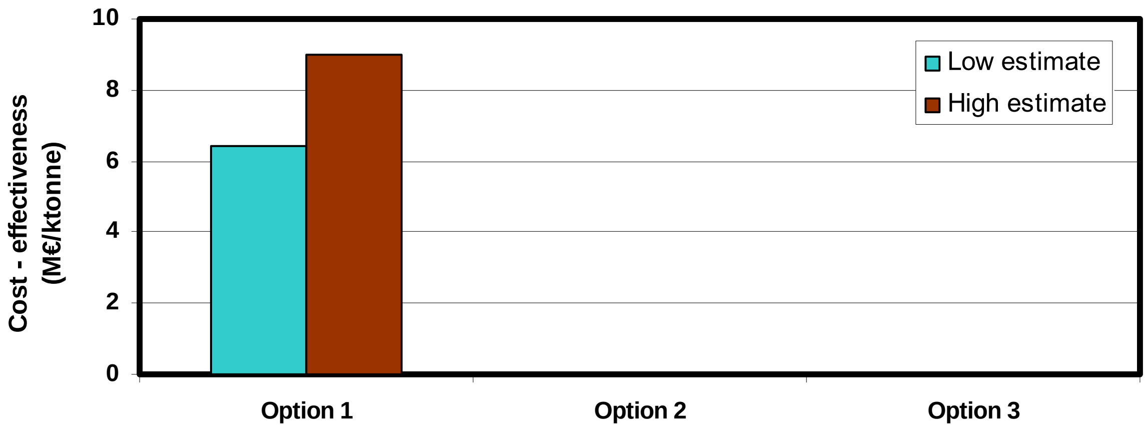

Figure 4-11: NO_x cost–effectiveness for moped Euro 3.

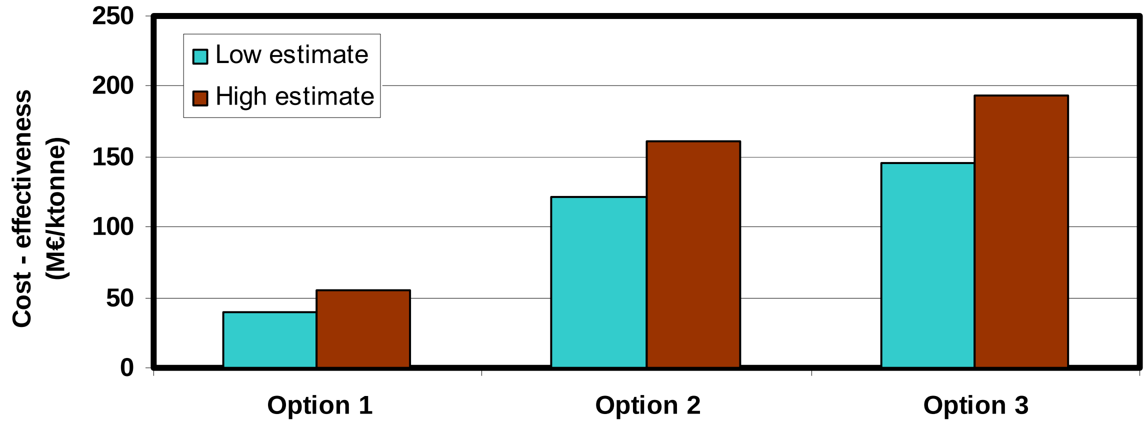

Figure 4-12: PM cost–effectiveness for moped Euro 3.

4.5.7 Conclusions

The Baseline scenario demonstrated that control of HC emissions from mopeds will be necessary, otherwise the moped share of total road transport HC will increase. We tried to evaluate what would be the effect of the emission standard formulation on the actual emissions from Euro 3 mopeds to come, on the basis of the emission performance of current Euro 2 vehicles. In that respect, we formulated three scenarios, one assuming that the cold start part will not be regulated (hence will remain the same), one assuming that a cold-start standard is adopted with 30% weighing factor and a third one where a cold-start standard with 50% weighing factor is adopted.

We found out the environmental benefit is proportional to the stringency of the emission standard. The HC reduction in 2012 equals an incremental 1% difference over the total moped fleet emissions, depending on the standard selection (4% for hot, 5% for 30/70 cold and 6% for 50/50 cold). The respective values for CO are 1.5%, 2.0%, and 2.5%. This translates to increments of 4 kt of CO and 800 t of HC reduction in the period 2006-2012, depending on the stringency of the emission standards. A hot emission standard is the only one that also reduces NO_x emissions, but the potential increase from cold-start related ones is not more than 1%. We also estimated that the technology introduced for Euro 3 implementation will result to 20% reduction in total moped PM and 7% in total CO_2 emissions by 2012. This is not expected to differentiate much for different scenarios of the emission standards. Clearly, the major environmental benefit is expected from the introduction of cold-start related emission standards because emissions are controlled also during the initial period of engine operation, which is important in urban areas.

4.6 OBD introduction

4.6.1 Objective, Background and Policies 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 are already in-use for almost 10 years in the US, whereas their application in Europe is more recent. 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 is then supposed to 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. This may be even more so in the case of motorcycles.

The next generation of OBD (OBD2) additionally monitors the catalyst performance and misfiring. 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 at a European level 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-sroke 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 vehicle 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. The details of the industry position are attached in Annex I.

Following these views and the discussions in the MVEG, the following policy options may be considered for OBD regulation development:

- **Policy 1:** There is no policy direction expressed openly by the Commission, and the different options discussed in this project would be considered.
- **Policy 2:** It seems that there is no mature "available" technology of OBD systems today for all motorcycle categories. In discussions with the manufacturers, those of them experienced with such systems, propose techniques which only monitor the integrity of the emission control system and not its actual performance (i.e. an OBD1 type of approach). Manufacturers are particularly sceptical for systems which monitor misfiring and catalyst efficiency because they suggest that such OBD systems are only being developed for 4S passenger cars engines (and aftertreatment systems) of a lower performance and operation range than two wheelers engines. Hence, such technology should not be considered "available" for motorcycles. Another issue raised by the manufacturers are the costs associated for the development, manufacturing and distribution to official dealers of "scan tools" for the off-board communication of the OBD with the maintenance personnel. The industry believes that the principles of OBD should be put forward by the regulation (i.e. that it should be possible to diagnose failures) and the manufacturer should be left to decide how this information will be communicated to the maintenance personnel.
- **Policy 3:** Policy 3 should be formulated following, rather than forcing, new technology developments in the area of OBD. This means that the major legislative tools for the monitoring of emission control systems operation would be durability, IUC and RW procedures, rather than OBD. However, for large motorcycles (i.e. Category 3), legislation can adopt the technical specifications of systems already in use today and possibly force their application to all models of this category.

- **Policy 4:** OBD systems are only available for other vehicle categories and not for two wheelers. Various development stages have appeared, with OBD1 first appeared in California (1988) and later in US (1994). This concerned monitoring the correct operation of different engine and emission control subsystems (EGR, battery and charging system, O_2 sensor, coolant temperature, etc.) but it did not provide any reference to emission standard values. OBD1 was later developed to OBD2 (1995 in California, 1998 is the rest of US) which in addition to more advanced monitoring of emissions, it also ties a malfunction threshold to tailpipe emissions. OBD in Europe was developed much later with the introduction of regulation 98/69/EC and is today under consideration in order to tie malfunction thresholds to emission standards. The current state of development OBD systems in both US and Europe for passenger cars is much more advanced than the motorcycle sector can support. This is obviously even more so for new DI two stroke engines, which still are in their infant stages.

4.6.2 Technical Description

In order to estimate the environmental benefit from the installation of an OBD system in motorcycles, emission factors in the baseline scenario have been deliberately deteriorated to simulate emission control system malfunctions in Euro 2 and Euro 3 vehicles. Three types of impairments/malfunctions are considered for motorcycles, each resulting to a different relative increase of regulated emissions:

- Malfunction requiring a minor repair.
- Malfunction requiring a major repair.
- 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 4-14 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 4-15. Finally,

Table 4-16 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 4-14: 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 4-15: 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 4-16: 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

One might obviously question the validity of these assumptions and their relevance in real-world conditions. With regard to the values of

Table 4-16, we assume that the catalyst is 90% effective in reducing emissions, therefore emissions increase by 10 times when it needs replacement. A major failure would mean injector or lambda sensor failure which may lead to high HC emissions or rich mixtures, and in that case emission levels increase by 5 times. This might not have brought much difference to Euro 1 vehicles but it is important for the more sophisticated Euro 2 and the catalyst-equipped Euro 3 ones. Finally, a minor failure would mean a weak spark, oil contamination, small shift of the lambda value, etc. We consider such failures to double the emission level. The possibilities for a minor or major repair or catalyst replacement have been obtained from CITA (2002). Finally, the probability as a function of age is based on a rough engineering approach, except of malfunctions in the first year which have been obtained from information submitted by the industry.

We expect these deterioration values to correspond to a more-or-less maximum estimate for failure-induced degradation. Hence, as in most tasks of this analysis, we try to explore the maximum potential benefit that introduction of a measure can bring. Therefore, in order to investigate the potential of OBD systems to reduce regulated emissions, three alternative scenarios were investigated:

- Scenario 1: Introduction of OBD systems to all 4-stroke Euro 3 motorcycles according to OBD 1 specifications and additionally monitoring the catalyst performance, to explore the benefit of introducing such a function. We have excluded 2-stroke motorcycles because no OBD technology has been developed for them. This scenario would correspond to a policy 2 approach (policy 2.i).

- Scenario 2: Similar to Scenario 1 but introduction of OBD only to large (Class 3 >750 cm^3) motorcycles. This could also correspond to a policy 2 approach (policy 2.ii) but we have limited the OBD to large motorcycles which already carry some kind of OBD, in order to limit the total cost of OBD introduction.

- Scenario 3: Introduction of an OBD 1 type system to Class 3 motorcycles, with no catalyst performance monitoring. Such a requirement could be included in a policy 3 approach.

Additionally, three different implementation years for these OBD requirements were investigated: 2006, 2007 and 2008.

No OBD has been assumed for Euro 2. In our calculations we have assumed that the introduction of an OBD 1 system would identify all malfunctions corresponding to minor and major failures and that a catalyst performance monitoring would also reveal the malfunctions requiring the replacement of the aftertreatment device. In the same respect, it has been assumed that the motorcycle owners will take all necessary remedial measures whenever the MIL is activated and that the maintenance performed will bring the emission levels back to the original levels. Therefore, the resulting environmental benefit would correspond to ideally operating OBD systems and fully cooperative motorcycle owners.

4.6.3 Environmental Benefit

The estimated total reduction in regulated emissions achieved with the introduction of the three alternative OBD scenarios is shown in Figure 4-13, both in absolute levels and as percentage of the total motorcycle emissions, over the baseline scenario. Furthermore, the effect of implementing OBD in three alternative dates is also shown.

Introduction of an OBD system that would also monitor catalyst performance is 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 expected to be greater than 0.5 % for HC and CO emissions and 1.6 % for NO_x. This greater decrease in NO_x emissions is due to the assumption that NO_x emissions of non TWC equipped vehicles are not degraded. Furthermore, the annual expected reduction in regulated emissions is shown in absolute levels in Table 4-17 and the corresponding annual percentage reduction of the total motorcycle emissions over the baseline scenario is shown in Table 4-18.

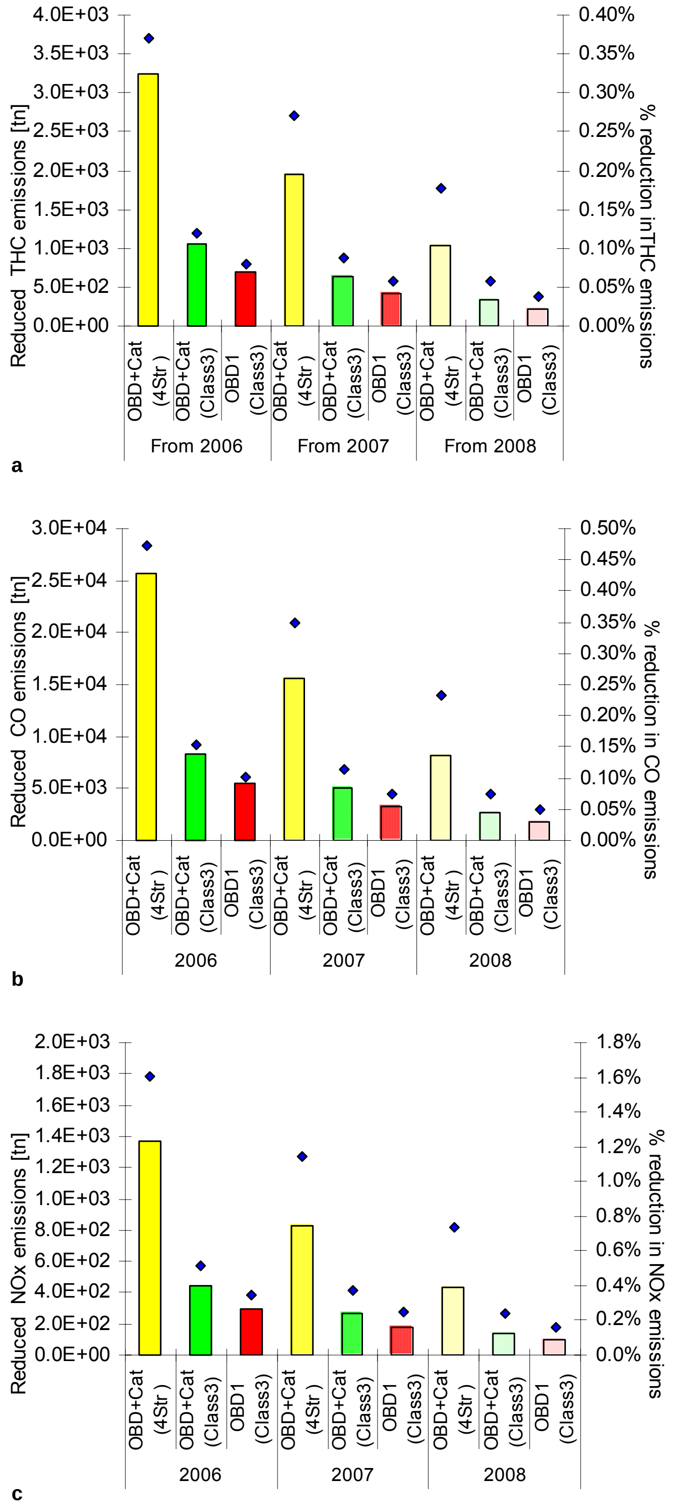

Figure 4-13: Estimated reduction in motorcycle emissions for different OBD scenarios in absolute levels (bars) and as percentages over the baseline scenario (dots).

Table 4-17: Annual reduction (t) of regulated emissions for different OBD Scenarios.

	From	4-Stroke	Total	2006	2007	2008	2009	2010	2011	2012
exhaust HC	From 2006	OBD+Cat (4Str)	3.2E+03	*	8.4E+00	1.2E+02	3.3E+02	6.0E+02	9.2E+02	1.3E+03
		OBD+Cat (Class3)	1.0E+03	*	2.8E+00	3.9E+01	1.1E+02	1.9E+02	3.0E+02	4.1E+02
		OBD1 (Class3)	6.9E+02	*	1.8E+00	2.6E+01	7.1E+01	1.3E+02	2.0E+02	2.7E+02
	From 2007	OBD+Cat (4Str)	2.0E+03	*	*	8.3E+00	1.2E+02	3.2E+02	5.9E+02	9.1E+02
		OBD+Cat (Class3)	6.3E+02	*	*	2.7E+00	3.8E+01	1.1E+02	1.9E+02	2.9E+02
		OBD1 (Class3)	4.2E+02	*	*	1.8E+00	2.5E+01	7.0E+01	1.3E+02	1.9E+02
	From 2008	OBD+Cat (4Str)	1.0E+03	*	*	*	8.2E+00	1.2E+02	3.2E+02	5.9E+02
		OBD+Cat (Class3)	3.4E+02	*	*	*	2.7E+00	3.8E+01	1.0E+02	1.9E+02
		OBD1 (Class3)	2.2E+02	*	*	*	1.8E+00	2.5E+01	6.9E+01	1.3E+02
CO	2006	OBD+Cat (4Str)	2.6E+04	*	6.7E+01	9.4E+02	2.6E+03	4.8E+03	7.3E+03	1.0E+04
		OBD+Cat (Class3)	8.3E+03	*	2.2E+01	3.1E+02	8.5E+02	1.5E+03	2.4E+03	3.2E+03
		OBD1 (Class3)	5.5E+03	*	1.5E+01	2.0E+02	5.6E+02	1.0E+03	1.6E+03	2.2E+03
	2007	OBD+Cat (4Str)	1.6E+04	*	*	6.6E+01	9.3E+02	2.6E+03	4.7E+03	7.2E+03
		OBD+Cat (Class3)	5.0E+03	*	*	2.2E+01	3.1E+02	8.4E+02	1.5E+03	2.3E+03
		OBD1 (Class3)	3.3E+03	*	*	1.4E+01	2.0E+02	5.6E+02	1.0E+03	1.5E+03
	2008	OBD+Cat (4Str)	8.2E+03	*	*	*	6.5E+01	9.2E+02	2.6E+03	4.7E+03
		OBD+Cat (Class3)	2.7E+03	*	*	*	2.2E+01	3.0E+02	8.3E+02	1.5E+03
		OBD1 (Class3)	1.8E+03	*	*	*	1.4E+01	2.0E+02	5.5E+02	1.0E+03
NOx	2006	OBD+Cat (4Str)	1.4E+03	*	3.6E+00	5.1E+01	1.4E+02	2.5E+02	3.9E+02	5.3E+02
		OBD+Cat (Class3)	4.4E+02	*	1.2E+00	1.7E+01	4.5E+01	8.2E+01	1.2E+02	1.7E+02
		OBD1 (Class3)	2.9E+02	*	7.9E-01	1.1E+01	3.0E+01	5.5E+01	8.3E+01	1.1E+02
	2007	OBD+Cat (4Str)	8.2E+02	*	*	3.5E+00	5.0E+01	1.4E+02	2.5E+02	3.8E+02
		OBD+Cat (Class3)	2.7E+02	*	*	1.2E+00	1.6E+01	4.5E+01	8.1E+01	1.2E+02
		OBD1 (Class3)	1.8E+02	*	*	7.8E-01	1.1E+01	3.0E+01	5.4E+01	8.2E+01
	2008	OBD+Cat (4Str)	4.4E+02	*	*	*	3.5E+00	4.9E+01	1.4E+02	2.5E+02
		OBD+Cat (Class3)	1.4E+02	*	*	*	1.2E+00	1.6E+01	4.4E+01	8.0E+01
		OBD1 (Class3)	9.4E+01	*	*	*	7.6E-01	1.1E+01	2.9E+01	5.3E+01

* No degradation assumed for new registrations

Table 4-18: Relative annual reduction (%) of regulated emissions over the Baseline for different OBD Scenarios.

	From	4-Stroke	Total	2006	2007	2008	2009	2010	2011	2012
exhaust HC	2006	OBD+Cat (4Str)	0.37%	*	0.006%	0.09%	0.27%	0.52%	0.85%	1.24%
		OBD+Cat (Class3)	0.12%	*	0.002%	0.03%	0.09%	0.17%	0.27%	0.40%
		OBD1 (Class3)	0.08%	*	0.001%	0.02%	0.06%	0.11%	0.18%	0.27%
	2007	OBD+Cat (4Str)	0.27%	*	*	0.006%	0.10%	0.28%	0.55%	0.89%
		OBD+Cat (Class3)	0.09%	*	*	0.002%	0.03%	0.09%	0.18%	0.29%
		OBD1 (Class3)	0.06%	*	*	0.001%	0.02%	0.06%	0.12%	0.19%
	2008	OBD+Cat (4Str)	0.18%	*	*	*	0.007%	0.10%	0.30%	0.57%
		OBD+Cat (Class3)	0.06%	*	*	*	0.002%	0.03%	0.10%	0.19%
		OBD1 (Class3)	0.04%	*	*	*	0.001%	0.02%	0.06%	0.12%
CO	2006	OBD+Cat (4Str)	0.47%	*	0.007%	0.11%	0.34%	0.68%	1.13%	1.68%
		OBD+Cat (Class3)	0.15%	*	0.002%	0.04%	0.11%	0.22%	0.36%	0.54%
		OBD1 (Class3)	0.10%	*	0.002%	0.03%	0.07%	0.15%	0.24%	0.36%
	2007	OBD+Cat (4Str)	0.35%	*	*	0.008%	0.12%	0.37%	0.73%	1.21%
		OBD+Cat (Class3)	0.11%	*	*	0.003%	0.04%	0.12%	0.24%	0.40%
		OBD1 (Class3)	0.07%	*	*	0.002%	0.03%	0.08%	0.16%	0.26%
	2008	OBD+Cat (4Str)	0.23%	*	*	*	0.009%	0.13%	0.40%	0.78%
		OBD+Cat (Class3)	0.08%	*	*	*	0.003%	0.04%	0.13%	0.25%
		OBD1 (Class3)	0.05%	*	*	*	0.002%	0.03%	0.09%	0.17%
NOx	2006	OBD+Cat (4Str)	1.64%	*	0.029%	0.42%	1.18%	2.19%	3.40%	4.75%
		OBD+Cat (Class3)	0.53%	*	0.009%	0.14%	0.38%	0.71%	1.10%	1.53%
		OBD1 (Class3)	0.35%	*	0.006%	0.09%	0.25%	0.47%	0.73%	1.01%
	2007	OBD+Cat (4Str)	1.17%	*	*	0.029%	0.42%	1.19%	2.20%	3.41%
		OBD+Cat (Class3)	0.38%	*	*	0.010%	0.14%	0.39%	0.71%	1.10%
		OBD1 (Class3)	0.25%	*	*	0.006%	0.09%	0.26%	0.47%	0.73%
	2008	OBD+Cat (4Str)	0.75%	*	*	*	0.029%	0.42%	1.19%	2.20%
		OBD+Cat (Class3)	0.24%	*	*	*	0.010%	0.14%	0.39%	0.71%
		OBD1 (Class3)	0.16%	*	*	*	0.006%	0.09%	0.26%	0.47%

* No degradation assumed for new registrations

4.6.4 Cost Calculation

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 3 (in Scenario 3 we exclude the costs associated with catalyst performance monitoring) and only to Class 3 vehicles in Scenario 2.

The total costs associated with each scenario are shown in Table 4-19 and the same costs are shown per new registration in Table 4-20. We should make clear that we have also distributed the inspection and maintenance cost of failed vehicles to each new motorcycle sold, just for the sake of comparison to other measures considered. The actual increase of the motorcycle should be less than that.

Table 4-19: Total marked-up cost (NPV) per scenario considered.

	2006		2007		2008	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
Scenario 1	274	522	243	429	219	345
Scenario 2	28	40	20	29	15	20
Scenario 3	26	36	17	24	13	18

The implementation cost of the OBD installation results to a mean additional cost per new vehicle for every manufacturer, which is illustrated in Table 4-20.

Table 4-20: Mean cost per new registration (€/vehicle). (Note: Not to be considered as price increase; inspection and maintenance cost of failed vehicles also included).

	2006		2007		2008	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Scenario 1	11.7	32.9	13.6	34.5	16.4	36.8
Scenario 2	6.2	17.4	7.2	18.3	8.7	19.5
Scenario 3	5.6	15.8	6.6	16.6	7.9	17.7

4.6.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis for each scenario is illustrated in Table 4-21, and the same results are also shown in Figure 4-14 and Figure 4-15.

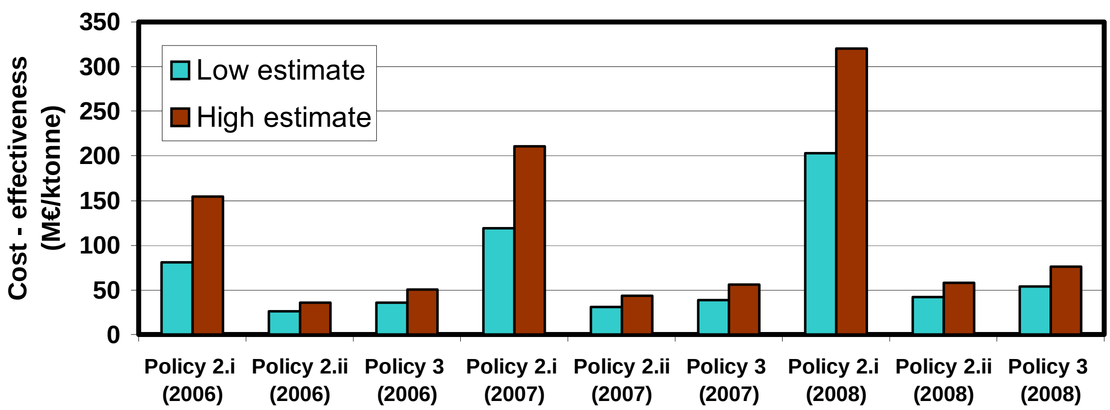

Figure 4-14: HC cost–effectiveness of OBD introduction

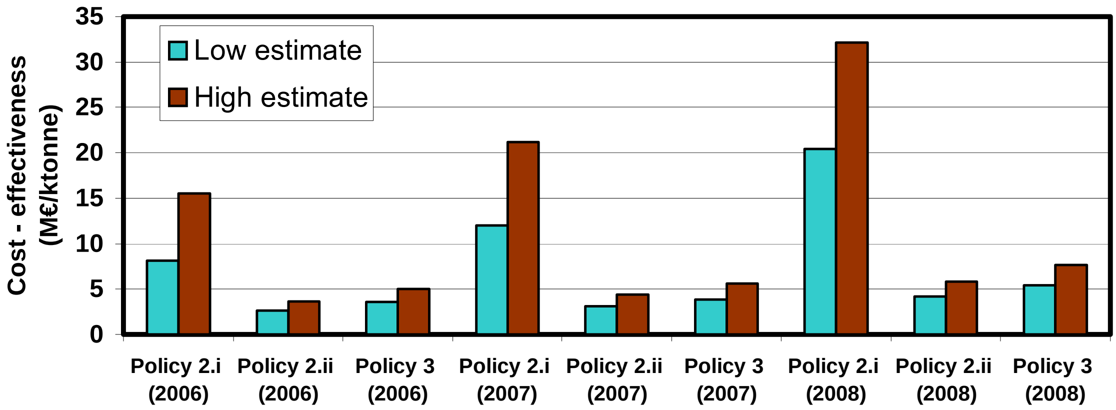

Figure 4-15: CO cost–effectiveness of OBD introduction

Table 4-21: Cost–effectiveness of OBD introduction (€/kg ≡ M€/kton).
(No emission reduction calculated for PM).

4-Stroke MCs	2006		2007		2008	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
HC						
Scenario 1	81	155	119	211	203	320
Scenario 2	26	36	31	44	42	58
Scenario 3	36	50	39	56	54	76
NO_x						
Scenario 1	8	16	12	21	20	32
Scenario 2	3	4	3	4	4	6
Scenario 3	4	5	4	6	5	8

4.6.6 Social 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 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.

4.6.7 Conclusions

The environmental benefit of OBD for passenger cars is still rather unknown because, similar to IUC, the reported effect of OBD in diagnosing malfunctioned vehicles may be only part of its efficiency. The other (commonly larger) effect is that it a-priori forces manufacturers to improve their emission control systems in order to decrease the disturbance to their customers and to reduce their warranty costs.

In order to simulate the maximum potential benefit from an OBD system, we assumed that the emission control failure is a function of vehicle age and that these failures are distributed according to their severity. The type of failure increases both its effect on emissions and the cost to repair it. Additionally, we tried to simulate the need for inclusion of a catalyst performance monitoring function by including a small fraction of major failures that require catalyst replacement.

The reduction in emissions achieved with OBD introduction was calculated 0.5% of the total motorcycle fleet emissions in the period 2006-2012 (maximum benefit 3.3 kt HC and

26 kt CO). Emission reductions achieved were proportional to the stringency in OBD application, i.e. inclusion or not of catalyst performance monitoring and the scale of its application (i.e. class 3 vs. all 4-stroke motorcycles). Therefore, with the reasonable assumptions made in this study, the OBD effect is sensitive to the details of its application. In order to maximize the benefit, one might consider including OBD to all 4-stroke motorcycle types and include catalyst performance monitoring requirements. However, the most cost-effective option appears to be the introduction of OBD only to Class 3 motorcycles, which already carry some kind of OBD system, including catalyst performance monitoring. On the other hand, one might be forced to apply a measure that neither maximizes the benefit nor is the most cost-effective, for technical limitations (e.g. manufacturers insist that no technique has been tested so far for reliable catalyst monitoring on motorcycles).

4.7 Evaporative emissions

4.7.1 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.

The work conducted at UBA (Kolke, 2003b) indicated that there is a significant environmental benefit with the introduction of evaporation control measures. It was also found that evaporation control is a cost-effective measure for reducing total HC emissions. In order to further examine the cost-effectiveness of evaporation control measures, the study team asked from the industry to provide an "evaporation package" (similar to the OBD one) which would provide the technology and a cost estimate for implementation of evaporation control on two wheelers. The industry responded to this request by describing the components of such a system and the cost associated with this.

According to the industry, evaporation control systems is a mature technique for motorcycles larger than 600 cm^3 because such vehicles are also sold to California where evaporation related legislation already exists. However, such systems have not been installed so far to smaller vehicles. In principle, the evaporation control system consists of a purge control valve, a rollover valve, the carbon canister and a series of hoses and connectors. The industry performed an internal survey for costs associated with such a system and came up with a figure of €50 for each emission control system. However, it is expected that this will be reduced for larger volumes. Based, on these estimates, a rough cost-effectiveness analysis was conducted which estimated the cost for implementing evaporation control at 3 – 11 k€/ton of HC saved.

Based, on these considerations, the following policy options are foreseen:

- **Policy 1:** The Commission has not expressed any direct policy option for evaporation.
- **Policy 2:** BAT in this case would correspond to technology much similar to the one applied in the passenger car sector. This has been made possible, since, as it is expected, carburettors are being replaced by fuel injection systems which significantly reduce soak losses. Also, the addition of a canister to vent the fuel tank is an established technology which can be easily transferred to motorcycles. Furthermore, new tanks and fuel lines can be constructed of low permeation materials to further reduce losses. On a regulatory side, BAT would correspond to an evaporation test procedure, much alike to the Type IV test (SHED) applied to passenger cars and vehicles should have to comply with an emission standard. Such an approach is today applicable in California (Policy 4).
- **Policy 3:** One might consider that policy 3 is either a policy where no additional measure is taken against evaporation losses (no policy scenario) or that simple technology measures are taken to control losses (e.g. canister and low permeation lines) but without the need from the manufacturer to comply with an emission test.
- **Policy 4:** In California, model 2001 and subsequent motorcycles are tested according to the diurnal and hot soak portion of the SHED tests to determine evaporation losses, while requirements for evaporation durability are also implemented (CARB, 1999). The US Federal regulations require a simplified procedure from 2008 year models where only the permeability of tanks and fuel line is tested and no evaporation test is considered for the motorcycle. Both these options may be considered for introduction in Europe.

4.7.2 Technical Description

Evaporation losses have been calculated according to 2.2.3. Figure 4-16 shows the estimated contribution of evaporative losses over the total HC emissions (exhaust & evaporation) from motorcycles in the period 1999 to 2012 under the baseline scenario. The evaporation contribution steadily increases from about 13 % in 1999 to 21 % in 2012. This is due to the significant reduction in exhaust HC emissions, with levels in 2012 being half of the 1999 ones, due to the introduction of the more stringent emission standards in this period.

Figure 4-17 shows the evolution of the contribution of the different evaporation sources in the baseline scenario. The small reduction in diurnal losses reflects the estimated reduction of vehicle fleet. A somehow greater decrease is expected in soak and running losses as a result of the increased production of fuel injected motorcycles.

Further potential in the decrease of evaporation losses

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. Moreover, the effect of introducing such a measure in 2006, 2007 and 2008 was also examined.

Additionally, the evaporative emissions strongly depend on the RVP of the fuel used. The calculations in the baseline scenario were made using the RVP values proposed in COPERT III. As shown in Table 2-12, the RVP of the gasoline fuel is higher during the winter to assist cold start ignition. Moreover, the RVP differs from country to country in accordance to the typical ambient conditions encountered in each country. Due to the European commitment to increase the share of biofuels as a road transport energy source, we would wish to explore how these low volatility fuels will affect emissions. Based on these, the following scenarios were considered.

- Scenario 1: Canister use to all motorcycles from 2006, 2007 or 2008 using the RVP values of COPERT III
- Scenario 2: Canister use to all motorcycles from 2006 and summer RVP (60 kPa)
- Scenario 3: Canister use to all motorcycles from 2006 and biofuel RVP (68 kPa)
- Scenario 4: Canister use to all motorcycles from 2006 and winter RVP (80 kPa)

Figure 4-19 shows the evolution of the total evaporative emissions for the baseline and the three alternative scenarios examined. Significant reductions over the baseline are shown for each scenario. However, it should be noted that use of low RVP fuels for all countries year-round may not be feasible.

4.7.3 Environmental Benefit

Table 4-22 shows the estimated total reduction in evaporative emissions for use of a canister from year of implementation up to 2012. A significant reduction in evaporative HC emissions is expected, ranging from 16 % to 21 % of the total evaporative emissions. This corresponds to a 1.8 to 2.3 % reduction in total HC emissions. Moreover, the later this measure is introduced, the lower the percentage reduction. This is due to the increased population of motorcycles equipped with fuel injection by the time the measure is introduced. Figure 4-18 shows the corresponding annual reduction in THC emissions over the baseline scenario.

Table 4-22: Estimated reduction in evaporative emissions by regulating the use of canister; in absolute levels but also as percentage of the evaporative and total HC emissions.

		Reduced HC emissions [t]	% reduction of evaporative HC emissions	% reduction of total HC emissions
Evaporative HC	Canister from 2006	2.0E+04	21%	2.3%
	Canister from 2007	1.5E+04	19%	2.1%
	Canister from 2008	1.1E+04	16%	1.8%

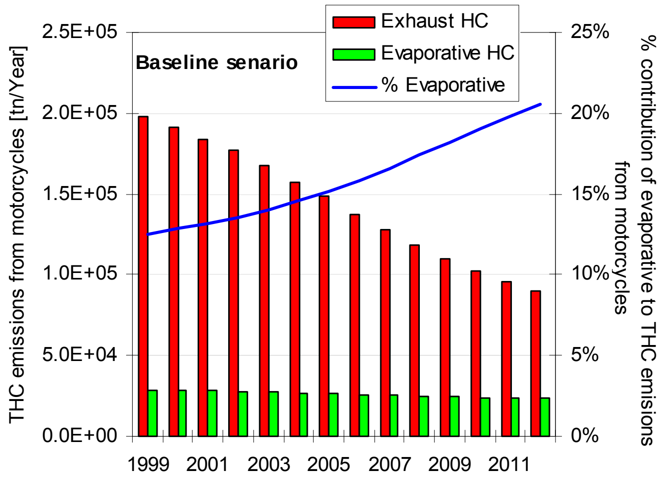

Figure 4-16: Evolution of exhaust and evaporative HC emissions from motorcycles and % contribution of evaporative losses to total HC emissions for the baseline scenario.

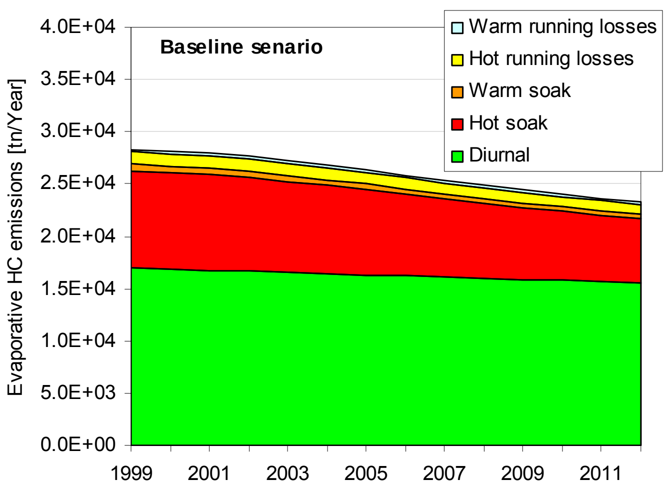

Figure 4-17: Evolution of the different sources of evaporative HC emissions from motorcycles for the baseline scenario.

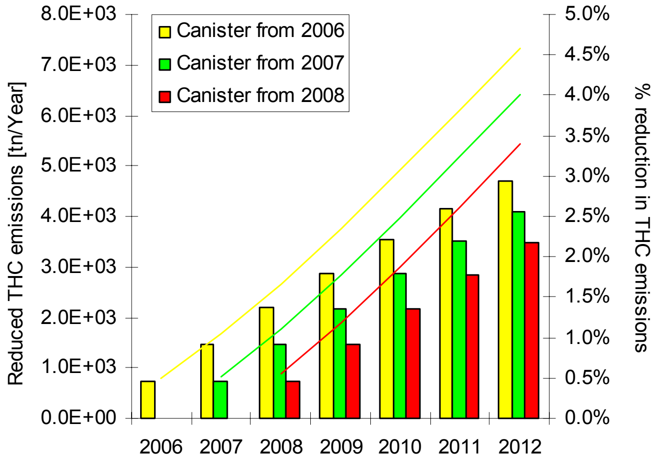

Figure 4-18: Estimated reduction in HC emissions from the mandatory use of charcoal canister in all motorcycles for three different implementation years.

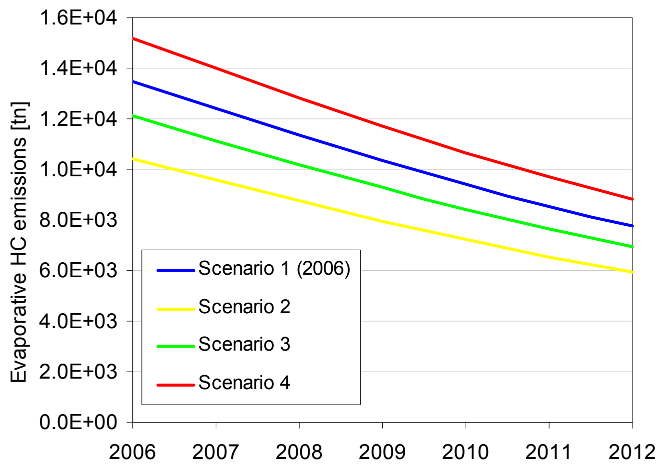

Figure 4-19: Effect of RVP value of the gasoline fuel in evaporative emissions.

4.7.4 Cost Calculation

The costs to introduce an evaporation control system are estimated from different sources:

- **1st Estimation:** ACEM estimated the component cost of an evaporative system from €40 to €50 per Motorcycle.
- **2nd Estimation:** Kolke (2003b) estimated this cost from €9.2 to €10.9 per Motorcycle.
- **3rd Estimation:** EPA (2000) calculated a cost of €10 to €30 per motorcycle.

Therefore, estimates range from €10 to €50 per vehicle. We built our scenarios using the whole range of these values. However, we would expect that this large range appears because the motorcycle industry probably takes the mark-up cost of the production chain also into account (which we estimate as a factor of 4 on production costs - §2.4.1), while they consider that total evaporation control cost may potentially reach €40/vehicle. Therefore the UBA estimate, which refers to production costs only, yields also €40/vehicle if it is multiplied with the mark-up factor. Therefore, we assume €40/vehicle as a reasonable additional cost per new motorcycle. Based on these considerations, the total cost per implementation year and for each motorcycle type is illustrated in Table 4-23.

Table 4-23: Total cost (NPV) of canister introduction per motorcycle type and implementation year.

Motorcycles	**2006**		**2007**		**2008**	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
2-Stroke	5	23	4	19	3	15
4-Stroke	45	225	38	189	31	153
Total	50	248	41	207	34	168

4.7.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis per implementation year and for each motorcycle type is illustrated in Table 4-24 and in Figure 4-20.

4.7.6 Social 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.

Table 4-24: Evaporation control cost–effectiveness per implementation year and motorcycle type (€/kg ≡ M€/kton).

Motorcycles	**2006**		**2007**		**2008**	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
2-Stroke	2.9	14.6	3.2	16.2	3.7	18.6
4-Stroke	2.5	12.4	2.8	13.8	3.1	15.6
Total	2.5	12.6	2.8	14.0	3.2	15.8

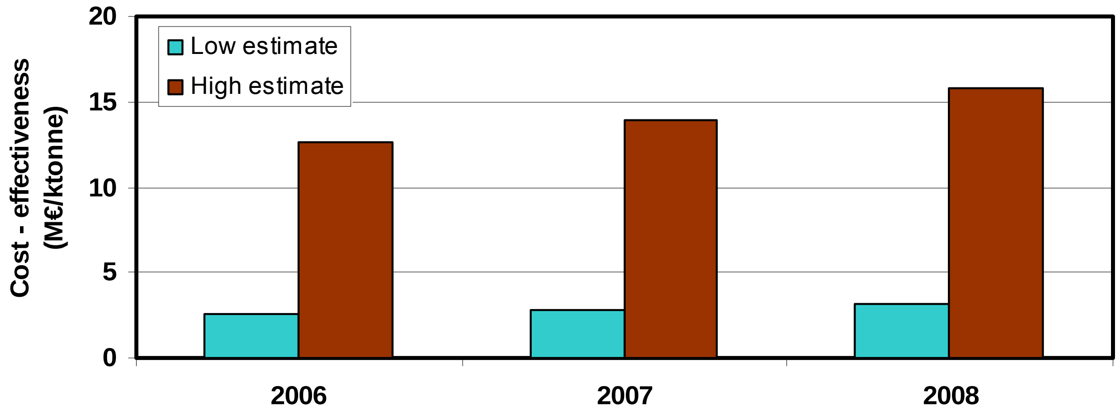

Figure 4-20: Evaporation control cost–effectiveness.

4.7.7 Conclusions

The share of evaporation HC to total HC emissions from motorcycles increases from less than 15% in 2004 to more than 20% in 2012, if no evaporation-specific regulation is introduced. This increase would have been higher if exhaust legislation did not force the replacement of air-open carburettors with sealed fuel injection systems. This shift in fuel system technology reduces (almost halves) soak losses – the second more important source of evaporation emissions. However, the relative increase in the importance of evaporation emissions comes from the fact that the primary source of evaporation losses – the fuel tank – is not controlled at all. If nothing is decided on this, diurnal losses will correspond to 70% of total evaporation emissions.

However, diurnal losses may be significantly reduced by forcing the use of a carbon canister via which to vent the fuel tank. We have simulated the effect of the canister introduction in Euro 3 vehicles and we found out that it may reduce total fleet evaporative emissions by 21%, if its introduction is set at 2006, corresponding to 2.3% reduction of total (evaporation & exhaust) HC emissions. An additional benefit may be obtained by using fuel of lower RVP such as biofuels. The EU15-wide use of biofuel year-round (at 68 kPa) may lead to an additional 10% reduction in total evaporation HC emissions. However, it is not known whether this maximum benefit may be realized without introducing subzero cold start engine ignition problems.

Cost figures to estimate the total cost for evaporation control measures were provided from different sources (in the range of 10 – 50 €/veh.). It appears that a realistic price change to the final customer will be in the order of €40/vehicle, including the type-approval cost. Based on this figure, we estimated that the cost effectiveness of evaporation control is in the order of 10€/kg of pollutant which is a very good figure for HC emissions, compared to the specific cost of some other measures proposed.

4.8 Replacement & retro-fit catalysts

The Italian delegation at MVEG has presented a document which allows for the type-approval of replacement and retrofit catalysts as separate technical units. This document has been discussed for long in this special group and the final revision seems to satisfy all parties involved. The Italian proposal includes definitions for "replacement", "original replacement" and "original equipment" catalysts and prescribed the TA procedure for each case. It also provides the specification for the type-approval marks and certificate.

Since this is the case, and because this is a particularly specialized issue which mainly aims at improving the market functioning of SMEs, no policy options are clarified, because this is not relevant anymore. It can only be said, than an equivalent replacement catalyst TA is also adopted for passenger cars (policy 4). Finally, this is an issue for which ACEM members understand its necessity, although they state that it can still marginally harm their business of replacement parts production. Furthermore, the industry gives particular emphasis to the need to differentiate between "replacement" and "original replacement" parts, as the most current proposal from Italy already does.

4.9 Time-frame for full introduction of the WMTC

The WMTC was developed – among other reasons - in order to help the legislator to regulate emissions that are likely to occur in real-world driving conditions for two and three wheel vehicles. This has been a major concern against the ECE40 cycle which is considered to underestimate driving dynamics of such small vehicles. The work in the UN/ECE WP29 on the development of a revised cycle has provided a few alternatives on such a cycle, complemented by significant experimental and research work on the comparability issues between ECE40 and WMTC and the expected impacts of the introduction of this new cycle. The WMTC technical specifications, including vehicle categories for each part of the WMTC, weighing factors for average emissions at each part of the cycle, and provisions for vehicles of low maximum speed have been extensively reviewed and discussed in the ad-hoc MVEG. Therefore, an impact assessment for these issues is not scope of the present analysis.

What now remains to be mainly decided is the introduction of WMTC as a sole type approval test in Europe. There are still a number of issues which remain to be resolved for this introduction:

- What would be the equivalence ratio with the corresponding Euro 3 driving cycle so that the introduction of WMTC does not modify the stringency of the emission standards (the same was also performed when NEDC replaced ECE15+EUDC).
- How is it possible to accurately estimate the equivalency ratios for motorcycle technologies that are not yet available.

- What is the real benefit of introducing WMTC as a sole test in Europe before, not only it is not approved as a Global Technical Regulation (GTR), but even before it is established in any other part of the world.

Due to these constraints, the industry is not willing to propose a date for type approval issuing on the WMTC only.

The contractor basically agrees with the argumentation brought forward by the industry, concerning the technical difficulties of adapting today's emission standards to a new driving cycle. However, it is not today possible to precisely calculate the equivalency ratio between ECE40 and WMTC emission values mainly because the actual emission performance of catalyst-equipped vehicles is controlled by their engine calibration. It is obvious that vehicles will be differently calibrated for a WMTC type approval than an ECE40 cycle and therefore the actual equivalency of the emission levels cannot be predicted on a hardware basis only. Therefore, it needs to be stressed that the lack of equivalency should not be considered as a strong argument in delaying the introduction of a driving cycle which better describes driving behaviour and hence can be used to more accurately represent the actual (real-world) emission behaviour of PTWs. Therefore, the contractor would propose that the WMTC could be introduced as a sole type-approval test soon after the introduction of motorcycle Euro 3 (i.e. 2008), with emission limits that will necessarily be based on ECE40 type of calibration. These emission limits may then be more effectively controlled at a next regulatory step, if this is considered necessary.

4.10 Emission road-worthiness procedure

4.10.1 Objective, Background and Policies Definition

Any Roadworthiness regulation which targets exhaust emissions establishes a procedure for the periodic inspection and maintenance of fleet vehicles. Usually, a simplified test is conducted and the vehicle tested is characterised in a pass/fail manner. In case a failure is diagnosed, the vehicle needs to be maintained and re-checked to be issued a roadworthiness statement. The Commission considers whether a roadworthiness type of test needs to be established also for PTWs.

The objectives of the particular task were also the targets of the study conducted by TNO on behalf of CITA (Elst et al. 2002). Obviously, the conclusions and recommendations of the particular study are drawn from a complete and dedicated analysis of a selected sample and therefore any conclusions can be directly transferred to the present document.

The main characteristics of this study can be summarized to:

- The RW emission test procedure regarded both emission and noise tests. For emissions, idle testing was performed at a low, a medium and a high engine speed and CO and HC measurements were conducted.

- In total, 112 motorcycles were tested and a particular effort was given to collect motorcycles from different categories, type approval limits and emission technologies. However, the sample was mainly consisted of 4S motorcycles without aftertreatment. The split between Euro 1 / Pre Euro was 60/40 respectively.

- Initial findings included that 74% of the tested 2S vehicles exceeded the TA test for either CO or HC and 20% of the 4S ones. Also, 11% of the sample exceeded the Type II (idle) TA limit. The authors suggested that these numbers may even be an underestimation of the actual situation, because the sample vehicles were mostly provided by the manufacturers and were rather new and well maintained. Also, the often tampered in-use small class was underrepresented. Vehicles that exceed the TA values were considered "high emitters".

- The large number of high emitters (25% of the sample) seemed to justify the introduction of a RW procedure according to the investigators.

- The recommended test procedure, suggested by the study, is an idle test executed at low and high speeds using standard equipment used for RW of passenger cars, with modifications to account for the high HC emissions of some 2S motorcycles.

- The study also found out that it is possible to control errors of omission and commission by identifying optimal idling speeds and threshold values (which for the vehicles examined ranged between 3.5-80 % CO and between 4000-8000 ppm for HC).

- However, the study reserved from making a conclusion for more recent vehicle technologies and expressed the need for additional research to determine the suitability of the proposed idle RW for more recent vehicle technologies.

- Finally, the study presented a cost-effectiveness evaluation of a RW approach, drawing from the experimental data collected in the framework of the project.

Today RW procedures looking mainly at safety noise issues are in force in 6 European countries and appear with a period between one and three years. These tests can be complemented with emission tests if this is found necessary.

In other parts of the world, periodic inspection and maintenance schemes (I&M) are in force in Taiwan, Thailand and Japan, while in Taiwan, an irregular test by the police on roadside is also in force. In US there is an irregular test of motorcycles over the Type Approval test. In Italy, a periodic inspection scheme was established starting from

January 2004. The test provides for differentiations between 2S and 4S engines, and vehicles compliant to Euro 1 or Euro 2 emission standards.

As in some of the previous tasks which were mainly regulation and not technology oriented, no effort was made to distinguish different policy priorities in this task either, especially due to the fact that this issue has not been thoroughly discussed in the MVEG and no clear position from the Commission can be identified. Only the Italian delegation has been talking in favour of a periodic inspection system. The main argument raised by the Italian delegation is that a RW procedure is the only one which can effectively control in-use emission levels of well maintained vehicles and increased emission levels occurring in tampered vehicles. This is a strong argument because the end effect of an ideal I&M procedure would be the combined benefit of OBD, IUC and durability requirements. However, RW shifts the main responsibilities of non-compliance to the owner rather than the manufacturer and this is something which needs to be considered.

4.10.2 Technical Description

The main difference of a RW procedure, in contrast to the measures considered so far, is that it could be also applied to pre-Euro 3 motorcycles. However, due to the small share of pre-Euro 2 vehicles for the period investigated (initial implementation year is post-2008) it has been assumed that the application of this measure would only control the emissions of the Euro 2 and Euro 3 motorcycles. Furthermore, it has been suggested that the maximum potential of a road worthiness procedure would be the identification of all Euro 2 and Euro 3 vehicles exhibiting increased emissions due to malfunctioning components.

In that respect, an alternative scenario was examined with the additional requirement (over the baseline[1]) of an ideal annual road worthiness procedure for all Euro 2 and Euro 3 motorcycles. A further assumption made in this alternative scenario was that the remedial measures will bring the actual emissions of these motorcycles back to their original levels. Finally, the effect of implementing this measure in 2006, 2007 and 2008 was also examined.

4.10.3 Environmental Benefit

The estimated annual reduction in motorcycle emissions from the introduction of a road worthiness procedure is shown in Figure 4-21. A significant reduction (the greatest from all measures examined) is expected for all regulated emission, which in 2012 are expected to be about 5 %, 6 % and 11.5 % for HC, CO and NO_x, respectively. Again the

[1] In the original baseline scenario the additional deterioration due to malfunctioning subsystems has only been applied to 4-stroke motorcycles. To compensate for this, a modified baseline scenario has been used in this task, which extended this approach to 2-stroke motorcycles too. The probabilities used were those of the Euro 2 4-stroke motorcycles.

two times greater reduction expected in NO_x emissions is due to the assumption that only the NO_x emissions of the Euro 3 4-stroke motorcycles are deteriorating.

The total estimated reduction in motorcycle emissions up to 2012 is given in Table 4-25 both in absolute levels and as percentage of the total motorcycle emissions. It is worth mentioning the percentage reduction increases as the RW introduction is delayed because the Euro 2 and Euro 3 vehicle grow older and their emissions degrade.

Table 4-25: Estimated reduction in motorcycle emissions due to the introduction of a road worthiness procedure up to 2012; in absolute levels (upper table) and as percentage of the total motorcycle emissions (lower table).

Reduced emissions (tn)		**THC**	**CO**	**NO_x**
2 Stroke	RW from 2006	4.39E+03	1.71E+04	6.26E+02
	RW from 2007	4.23E+03	1.64E+04	6.05E+02
	RW from 2008	3.94E+03	1.52E+04	5.67E+02
4 Stroke	RW from 2006	1.47E+04	1.22E+05	4.36E+03
	RW from 2007	1.41E+04	1.17E+05	4.19E+03
	RW from 2008	1.31E+04	1.09E+05	3.89E+03

% reduction in emissions		**THC**	**CO**	**NO_x**
2 Stroke	RW from 2006	0.50%	0.31%	0.75%
	RW from 2007	0.59%	0.37%	0.85%
	RW from 2008	0.68%	0.43%	0.97%
4 Stroke	RW from 2006	1.68%	2.24%	5.12%
	RW from 2007	1.95%	2.64%	5.82%
	RW from 2008	2.25%	3.07%	6.57%

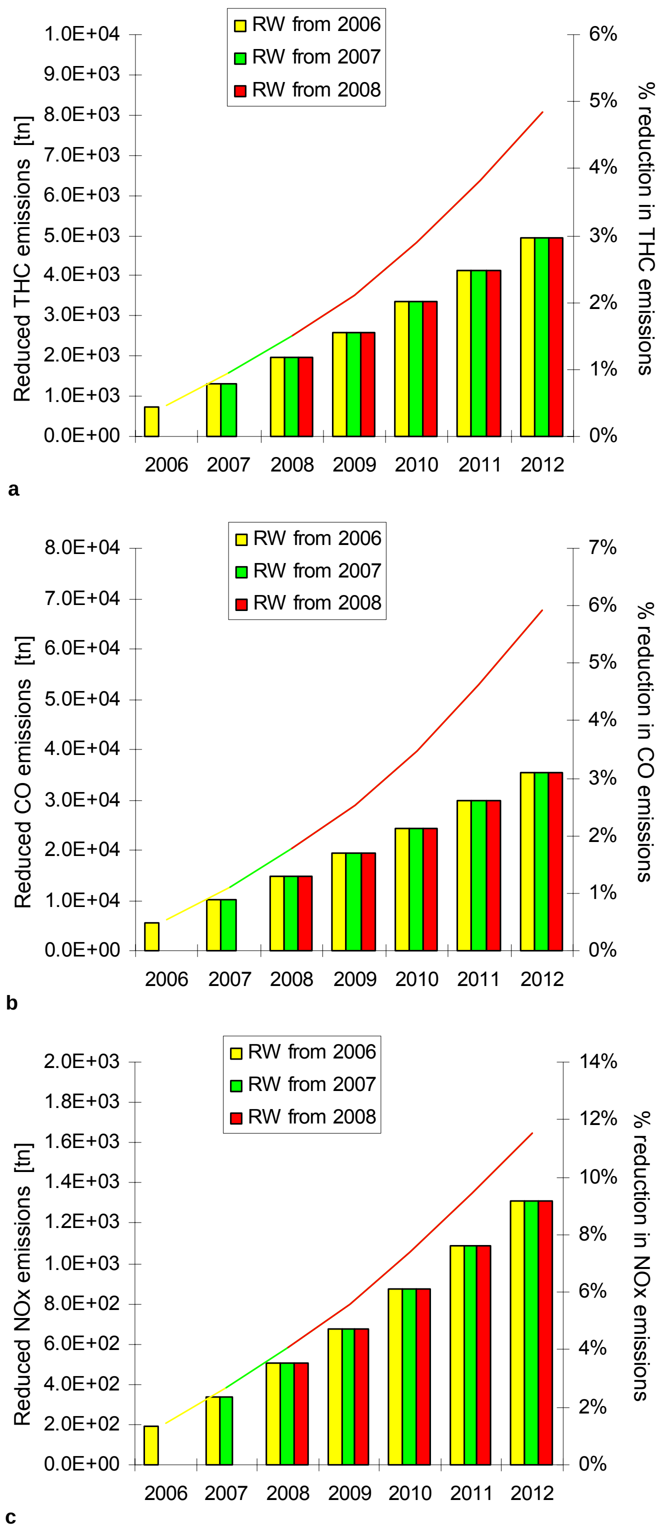

Figure 4-21: Annual reduction of motorcycle emissions due to the introduction of an annual road worthiness procedure from 2006, 2007 and 2008.

4.10.4 Cost Calculation

In order to calculate the aggregated annual inspection cost we first assumed a 2-year warranty period for every malfunction that may appear to any vehicle. Furthermore, we estimated that the cost per inspection per consumer (per motorcycle) is €7.2 – €25 (ACEM 2003). Added to this, the cost of the time lost by the motorist for the vehicle's inspection, (time to commute to the service station and net inspection time), was estimated by valuing a time loss of 40 - 60 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 €2 – €3 per vehicle inspected (CITA 2002). The aggregated annual inspection cost derives by considering the sum of the above costs and the Euro 2 & 3 population of motorcycles.

Then we consider that the cost of maintenance is similar to the OBD-related maintenance cost (§4.6.4), with a distinction between TWC equipped vehicles and non-TWC equipped ones. For the calculations, all Euro 3 4-strokes and 57% Euro 2 4-strokes were assumed to be equipped with TWC

The total cost per implementation year and for each motorcycle type is illustrated in Table 7.1.

Table 4-26: RW total cost (NPV) per implementation year and motorcycle type

Motorcycles	2006		2007		2008	
	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)	Low Estimate (M€)	High Estimate (M€)
2-Stroke	19	22	18	21	17	19
4-Stroke	190	215	182	207	169	191
Total	209	237	200	227	185	210

4.10.5 Cost-Effectiveness

The outcome of the cost-effectiveness analysis per implementation year and for each motorcycle type is illustrated in Table 4-27 and in Figure 4-22 and Figure 4-23.

Table 4-27: RW cost–effectiveness analysis results per implementation year, pollutant and motorcycle type (€/kg ≡ M€/kton).

Motorcycles	2006		2007		2008	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
HC						
2-Stroke	4.1	4.7	4.1	4.7	4.0	4.7
4-Stroke	12.4	14.1	12.4	14.1	12.4	14.0

Total	10.5	11.9	10.5	11.9	10.4	11.9
NO_x						
2-Stroke	1.2	1.4	1.2	1.4	1.2	1.4
4-Stroke	1.8	2.0	1.8	2.0	1.8	2.0
Total	1.7	1.9	1.7	1.9	1.7	1.9
PM						
2-Stroke	*	*	*	*	*	*
4-Stroke	*	*	*	*	*	*
Total	*	*	*	*	*	*

* No emissions reduction

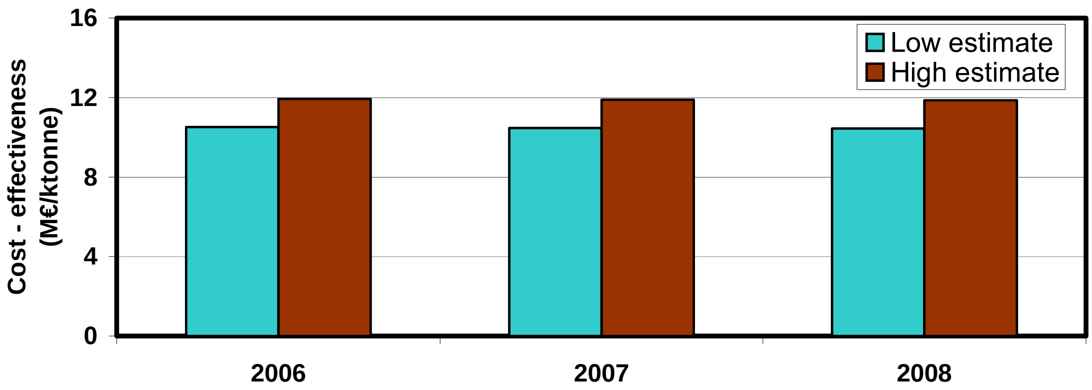

Figure 4-22: HC cost–effectiveness for road-worthiness introduction.

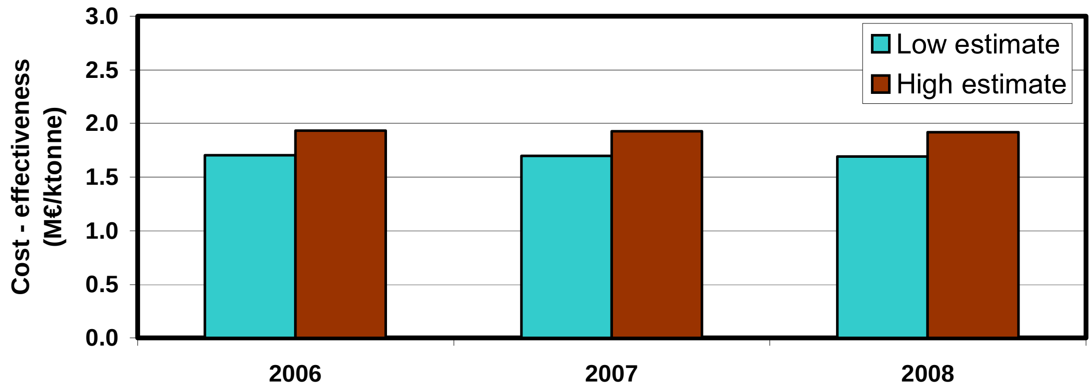

Figure 4-23: NOx cost–effectiveness for road-worthiness introduction.

4.10.6 Social Impacts

The study team estimates that the annual roadworthiness procedure is the most probable/effective procedure to reduce tampering, resulting to noise reduction and environmental benefits. Of course, this will happen only if the roadside tests are taking place alongside the roadworthiness test. Moreover, this is one of the few measures that affects not only the new registered vehicles, but also older ones (Euro 2 technology). Furthermore, it is beneficial for new businesses due to the fact that inspection and maintenance will be carried out by specialized private SMEs. Nevertheless, motorcycle owners might rather dislike this procedure because the cost involved in this will be passed entirely on them. Experience in countries who have implemented safety roadworthiness checks may provide background information on this.

4.10.7 Conclusions

Similar to the use of synthetic oil or improvement in fuel specifications, implementation of an emissions road-worthiness procedure is effective because it targets all fleet vehicles. Additionally, its effects may be demonstrated directly - with no delay that usually occurs from the need to replace fleet vehicles before an improvement is seen (i.e. when improving emission standards of new registrations). We assumed that RW will be implemented for all Euro 2 and Euro 3 motorcycles and that it is an ideal RW, with no errors of omission and commission. This means that this RW-test will make possible the diagnosis of all failures occurring in all Euro 2 and Euro 3 vehicles and that no false diagnosis is conducted. As in previous cases, we examine in this way the maximum potential of a RW procedure.

As a result of its application also to Euro 2, RW is one of the most effective measures that can be taken to reduce emissions. The decrease of emissions achieved in 2012 is 5% for HC and 6% for CO saving in the period some 19 kt of HC and 140 kt of CO. For example, the reduction in CO is 8 times higher than changing the durability distance of Euro 3 motorcycles from -30% to +50% or introducing a Euro 3 emission standard for mopeds, and more than 80 times higher than introducing an IUC. For the same reason, it is also a costly measure. The total cost effectiveness however is better than the introduction of some of the emission standards so far.

5 Summary and Conclusions

5.1 Emission situation of PTWs today

The analysis preceded in this chapter may be used to give a thorough picture of the effectiveness of the different motorcycle emission legislation measures and the contribution of motorcycles to the total road transport generated pollution.

1. PTWs are negligible sources of NO_x. Their contribution so far has been less than 0.5% even in urban areas. NO_x emission was physically limited by the fact that PTWs used to operate on rich mixtures to increase their specific power and their appeal to the potential customer. With the implementation of Euro 2 (2003), NO_x emission standards were established at about the same level with passenger cars for 4-stroke motorcycles and are continue to be much less for 2-stroke ones. The technology of 4-stroke motorcycles has been starting to look more as its passenger car equivalent (stoichiometric closed-loop catalyst engines) and hence emission behaviour starts to be more or less the same. Therefore, developing NO_x emission standards which follow the passenger car trend should be expected now on, only keeping in mind that motorcycles have a wider engine operating range and higher specific power-to-weight ratio.

2. The total (ultimate) CO_2 emitted from PTWs is again less than 1% of the total road transport generated CO_2. This is obviously due to the small fleet and annual mileage driven, compared to other vehicle categories, especially compared to the heavy duty long commuters. However, the important message is that the average CO_2 per passenger-km is only 83.5 g/pkm for PTWs compared to 126 g/pkm for passenger cars. This would mean that for each car km which could be potentially replaced by PTWs, the reduction in CO_2 would be in the order of 30%. In practice though, it is expected that passenger car fleet size and activity grows, unlike the motorcycle activity which seems to shrink in the years to come. The increase in the car activity should be expected to have even worse CO_2 behaviour, especially in the already condensed urban road network of the south, by increasing congestion thus reducing mean travelling speed. It is known that the increase of CO_2 at speeds less than 20 km/h is an exponential function of mean speed.

3. Lately, much attention has been focused on emissions of 2-stroke PM. Particulate matter collected on a gravimetric filter sampling from the diluted exhaust may be higher in concentration than even diesel passenger cars, including also a significant solid fraction (occurring due to the rich mixture). However, it has been recognised that much of the material collected on the filter consists of semi-volatile hydrocarbons which are scavenged in 2-stroke engines during the compression stroke. An effective control of PM emission would therefore be reducing the losses of the mixture escaping combustion. Indeed, the regulation which has been forced to control HC emissions seems in principle effective also in the reduction of PM. PM

measurements on late-model 2-stroke engines have demonstrated reductions of up to 90% over their conventional counterparts, achieved by using a direct-injection technology, where fuel is injected late in the cylinder, after the exhaust valve has been closed. In that respect, the contribution of PTWs today is calculated at only 1.6% of total road-transport PM emissions.

4. PTWs are significant contributors of CO (at ~7,5% of total road transport) and primarily HC emissions (18%). This is due to the fact that legislation so far was not equally demanding from small PTWs compared to larger cars. This was made in purpose, in order to give PTWs the benefit of keeping their higher power-to-weight ratios compared to passenger cars, which is one of the sales arguments for this vehicle sector. More importantly, the motorcycle sector is the only one where the 2-stroke engine technology continues to be active due its lightweight characteristics and any regulation appearing has been trying to control 2-stroke emissions but not in a degree that could potentially risk its existence. Part of the problem has also been that no cold-start requirement was set so far; however this has been seen to change with the introduction of Euro 3 for motorcycles.

5. The regulation of small three and four wheelers' emissions is also included in the motorcycle emission package. These vehicles are used for small-distance urban commuting and transportation of light goods and carry either an older technology small diesel engine or a 2-stroke one. Their total contribution is at or less than 1% of the total PTWs emission levels, i.e. maximum 0.15% of the total fleet emissions. This is due to the small size of their fleet, despite these vehicles implement an older technology. Therefore, given this small size, the effect of any regulation on three and four wheelers would correspond to less than 0.1% of total fleet emissions.

5.2 Expected evolution of PTW emissions

Emission legislation today has decided on the emission standards of motorcycles at a Euro 3 level (2006) while for mopeds, no updated emission values to Euro 2 (2003) have been agreed yet. Assuming that legislation does not become more stringent, and not taking into account the Euro 5 introduction for passenger cars, this would mean:

1. Hydrocarbon emissions will continue to decrease as the vehicle fleet is refreshed and new vehicles are launched. However, the relative share of HC emissions would still increase significantly, reaching 20% of the total fleet emissions by 2012. Up to 2005, the share of motorcycles is seen to increase at a rate of 0.4% per year, despite the Euro 2 introduction. The implementation of Euro 3 in 2006 indeed seems to relax this trend and the relative share seems to stabilize (but it is not decreasing) over the total fleet emissions. The moped share is also increasing, especially after 2006 because no Euro 3 regulation has been assumed for them. If no Euro 3 were introduced, mopeds alone would contribute to 13% of total fleet

emissions by 2012. This shows that the introduction of a Euro 3 standard for mopeds is necessary. However, it is expected that HC emissions from PTWs will continue to require control in the future, as the passenger cars become ultra clean in the future. It is particularly important to make sure that future legislation will continue to effectively address HC emissions from power two wheelers to improve air quality in urban areas.

2. CO emissions seem to be effectively addressed already by today's regulation. With regard to motorcycles, CO contribution seems to be stabilised, ranging from 2% of total fleet emissions today, down to 1.7% in 2012. This has been the result of the Euro 3 regulation which decreases emissions down to almost 2005-levels of passenger cars and the expected reduction of the motorcycle activity. Even mopeds' share seems to decrease. Indeed, Euro 2 legislation has been particularly stringent for mopeds, reducing emissions down to 1 g/km in urban conditions (but not considering a cold-start). The reduction in moped share is predicted assuming that the technology will be the same of today. However, it is not known how the catalyst equipped vehicles to come for HC-control will behave under cold-start conditions. This may be only predicted if a cold-start regulation is adopted.

3. NO_x emission share increases significantly, but its absolute levels remain very low. PTWs share increases from 0.4% in 2004 to 0.7% in 2012 as an outcome of the higher fuel efficiency of new technologies. In any case, one would not expect that NO_x from motorcycles will become a significant relative contributor in the future (even in urban areas), unless the expected Euro 5 regulation for passenger cars is very strict with NO_x emissions.

4. A significant reduction of the PM share is predicted for the coming years, for both motorcycles but especially mopeds. The PTW share decreases from 1.6% in 2004 to 0.9% in 2012, despite the introduction of PM specific measures only for larger vehicles. This is the outcome of the transition to new technologies, with most significant that replacement of conventional 2-stroke engines with DI ones and the widespread use of oxidation catalysts on two-wheelers. Probably, a faster reduction would not be achieved with more strict PM regulations for new registrations, but with measures also affecting older technologies (such as synthetic oil use). In any case, the reduction in PM share with no PM-directed regulation, justifies the reluctance of the European Commission so far to introduce such a measure.

5. The relative contribution of PTWs to ultimate CO_2 emissions ("ultimate": all carbon in fuel is assumed eventually to transform to CO_2 in the atmosphere) continues to decrease, as a combined effect of three reasons: The slight decease of total PTW activity, the corresponding increase in the activity of other road transport sectors, and the improvement in the efficiency of new two-wheelers. In 2012, PTWs are expected to contribute at only 0.6-0.7% of total CO_2, with 90% of this originating

from motorcycles. The improvement in the efficiency came from the reduced scavenged losses and the more efficient utilization in 2-stroke DI vehicles (this was mainly beneficial for mopeds). Four-stroke CO_2 levels seem to decrease as new engines work at stoichiometry rather than fuel-rich regionss, thus again improving fuel utilization (although power to weight ratio may decrease).

5.3 Evaluation of additional measures

Based on the different scenarios and policies that we have addressed in this study, it is possible to compare the absolute effect and the cost to implement any of the proposed measures. This is presented in Figure 5-1 to Figure 5-4. The horizontal axis designates the total implementation cost associated with each scenario estimated in this study. There is a large area for each measure, which depends on the input parameters for each measure (for example, the most economical OBD scenario is OBD introduction only to Class 3 vehicles with no catalyst performance monitoring, and the most expensive one is OBD introduction to all motorcycles with catalyst monitoring). The details of each scenario can be found in the corresponding sections. The cost estimate to introduce new emission standard levels for each vehicle category are also shown for comparison.

Euro3 emission standards for motorcycles are separately evaluated for the period 2006-2012 (M/C E3 2012) and the period 2006-2008 (M/C E3 2008), for comparison with the emission standards in the previous periods. Areas that are high and left in the chart are policies with a high impact (reduction) and low cost, hence they are beneficial. Cost estimates correspond to the total implementation cost which is calculated for each measure in chapter 4. No cost estimate was possible for CO because no external costs for CO are reported by the European Commission.

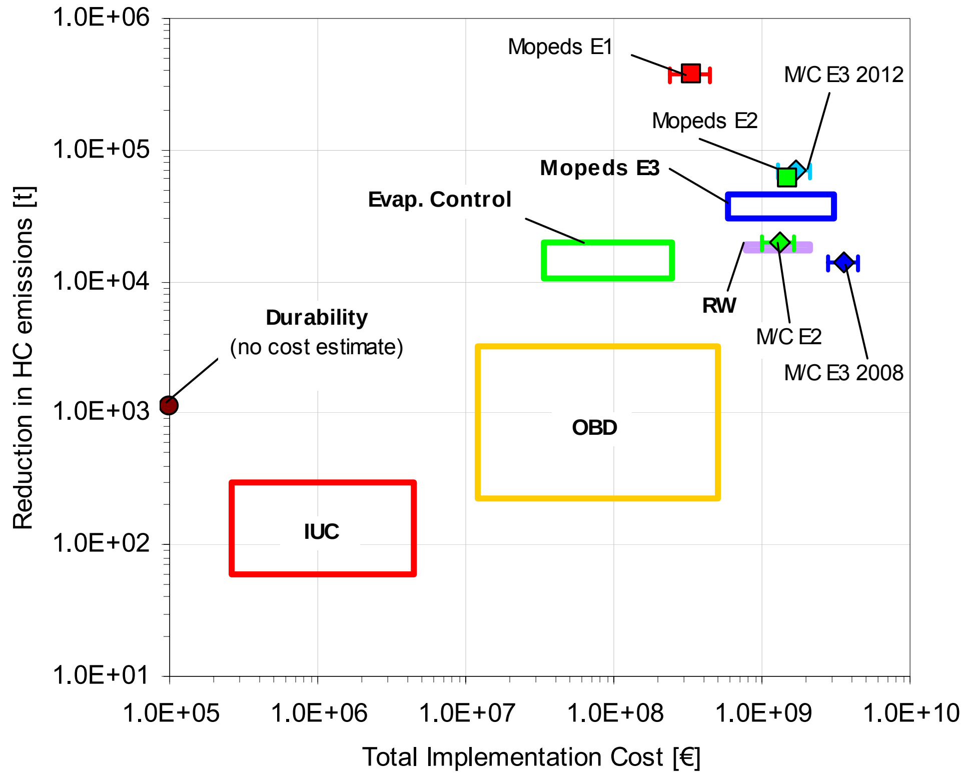

Figure 5-1: Reduction in **HC** emissions vs. implementation cost for different measures. Note that axes are in logarithmic scale. Areas correspond to the different scenarios examined in this study. Older emission standards are used for comparison (M/C: Motorcycle, E: Euro Level).

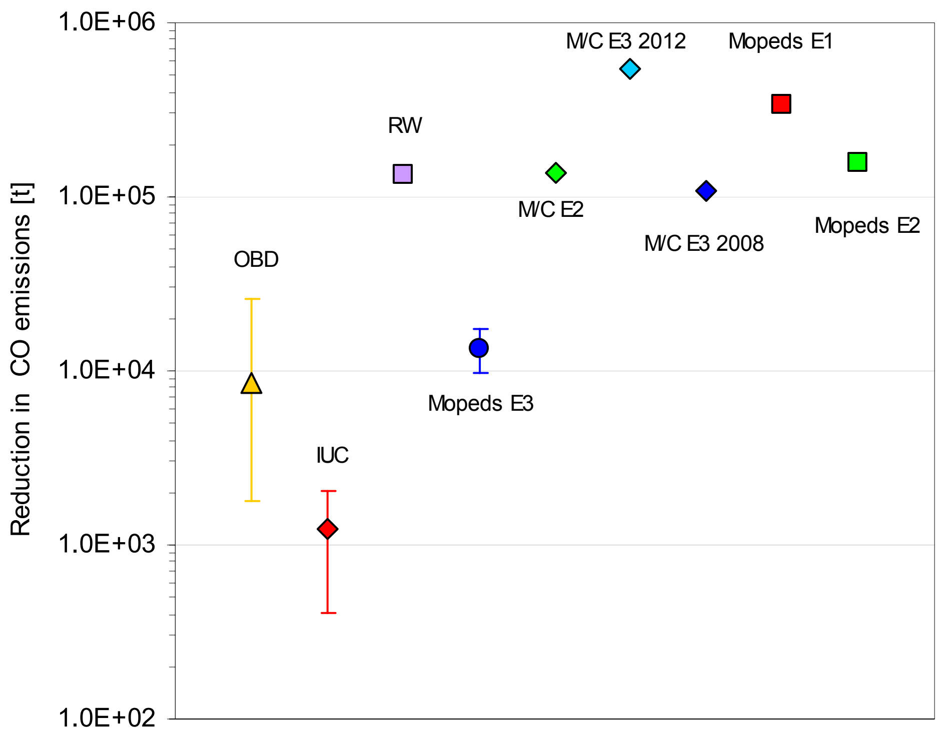

Figure 5-2: Reduction in **CO** for different measures. No share of total cost was Note remarks in Figure 5-1 caption.

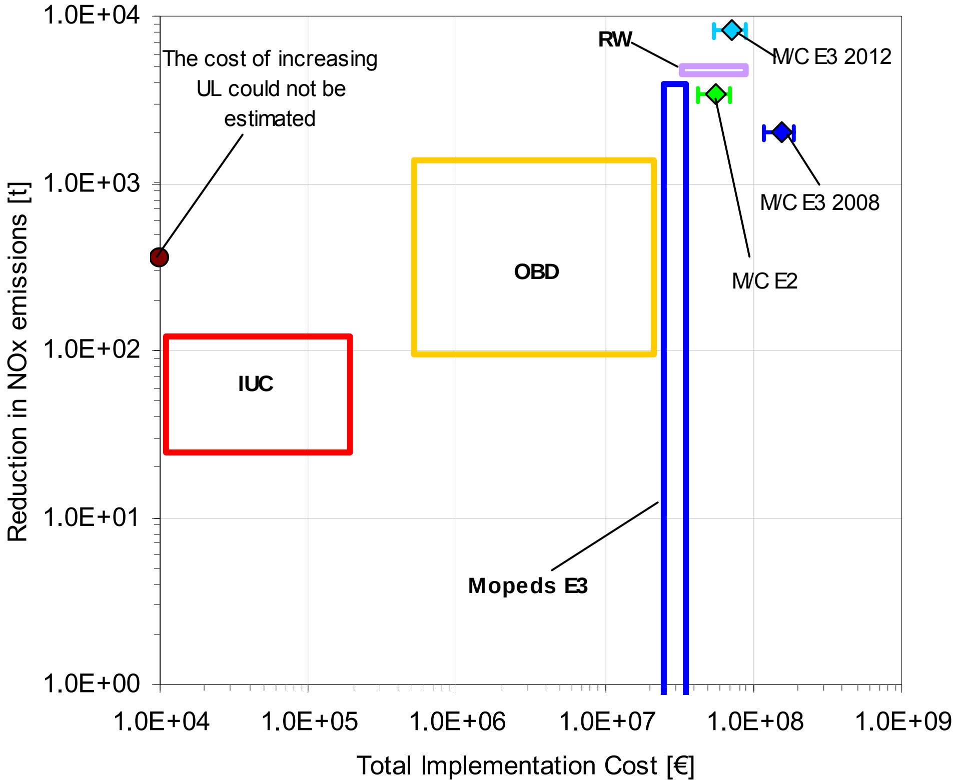

Figure 5-3: Reduction in NO_x emissions vs. implementation cost for different measures. Note remarks in Figure 5-1 caption.

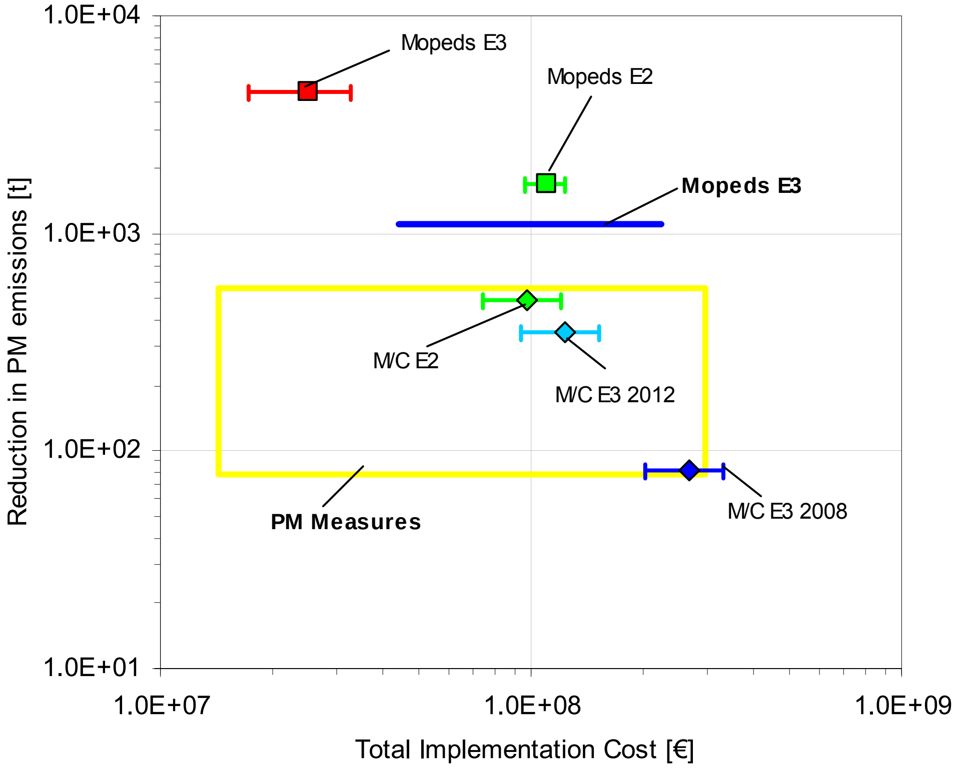

Figure 5-4: Reduction in **PM** emissions vs. implementation cost for different measures. Note remarks in Figure 5-1 caption.

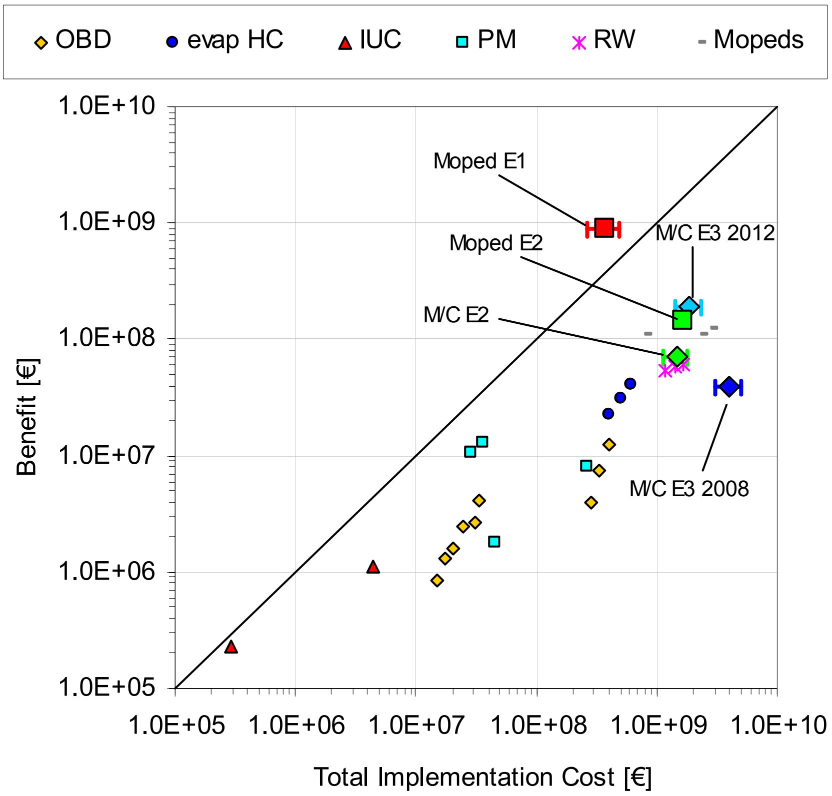

Figure 5-5: Benefit vs. Implementation Cost for each measure. Benefits have been calculated according to the marginal external costs of Air Pollution for NO_x, HC and PM_{10} (no CO is included) provided by DG Environment (2004).

Table 5-1: Impact Matrix - Assessment of each impact for each policy option for SMEs

Impact on SMEs		Financial Impact on Manufacturers	Decline in Sales of New Motorcycles	Second-hand Passenger cars' Sales Increase	Withdrawal of 2-stroke Motorcycles	Impact on Employment	Impact on Competitiveness
Task 100	Likelihood of impact	Probable	Probable	Probable	Unlikely	Probable	Unlikely
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Uncertain
Task 200 (Policy 2)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Unlikely	Certain	Unlikely
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Uncertain
Task 200 (Policy 3)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Unlikely	Probable	Unlikely
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Uncertain
Task 300	Likelihood of impact	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
	Characterization of impact	Uncertain	Negative	Negative	Negative	Positive	Uncertain
Task 400 (Policy 2)	Likelihood of impact	Certain	Certain	Probable	Certain	Certain	Certain
	Characterization of impact	Negative	Negative	Negative	Negative	Uncertain	Negative
Task 400 (Policy 3)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
	Characterization of impact	Uncertain	Negative	Negative	Negative	Uncertain	Uncertain
Task 500 (Option 1)	Likelihood of impact	Probable	Probable	Unlikely	Unlikely	Probable	Probable
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 500 (Option 2)	Likelihood of impact	Certain	Probable	Probable	Probable	Probable	Probable
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 500 (Option 3)	Likelihood of impact	Certain	Certain	Probable	Probable	Probable	Certain
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 600 (Policy 2.i)	Likelihood of impact	Certain	Certain	Certain	Probable	Certain	Certain
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 600 (Policy 2.ii)	Likelihood of impact	Certain	Probable	Probable	Probable	Certain	Certain
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 600 (Policy 3)	Likelihood of impact	Probable	Probable	Unlikely	Unlikely	Probable	Probable
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Negative
Task 700	Likelihood of impact	Certain	Probable	Unlikely	Unlikely	Probable	Unlikely
	Characterization of impact	Negative	Negative	Negative	Negative	Positive	Uncertain
Task 800	Likelihood of impact	Probable	Unlikely	Unlikely	Unlikely	Certain	Probable
	Characterization of impact	Positive	Negative	Negative	Negative	Possible	Positive
Task 900	Likelihood of impact	Probable	Unlikely	Unlikely	Unlikely	Unlikely	Probable
	Characterization of impact	Uncertain	Negative	Negative	Negative	Positive	Positive
Task 1000	Likelihood of impact	Unlikely	Probable	Unlikely	Unlikely	Certain	Probable
	Characterization of impact	Uncertain	Negative	Negative	Negative	Positive	Positive

Table 5-2: Impact Matrix - Assessment of each impact for each policy option for Consumers

Impact on Consumers		Sales Price Increase	Extended Lifetime of Motorcycles	I / M Demand Increase	Public Acceptance of the Technology and Regulation
Task 100	Likelihood of impact	Probable	Certain	Unlikely	Probable
	Characterization of impact	Negative	Positive	Negative	Positive
Task 200 (Policy 2)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Probable
	Characterization of impact	Negative	Positive	Negative	Negative
Task 200 (Policy 3)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Probable
	Characterization of impact	Negative	Positive	Negative	Negative
Task 300	Likelihood of impact	Unlikely	Unlikely	Unlikely	Certain
	Characterization of impact	Negative	Positive	Negative	Positive
Task 400 (Policy 2)	Likelihood of impact	Certain	Certain	Probable	Certain
	Characterization of impact	Negative	Positive	Negative	Negative
Task 400 (Policy 3)	Likelihood of impact	Unlikely	Unlikely	Unlikely	Probable
	Characterization of impact	Negative	Positive	Negative	Positive
Task 500 (Option 1)	Likelihood of impact	Possible	Probable	Probable	Probable
	Characterization of impact	Negative	Positive	Negative	Positive
Task 500 (Option 2)	Likelihood of impact	Certain	Probable	Probable	Probable
	Characterization of impact	Negative	Positive	Negative	Positive
Task 500 (Option 3)	Likelihood of impact	Certain	Probable	Probable	Probable
	Characterization of impact	Negative	Positive	Negative	Positive
Task 600 (Policy 2.i)	Likelihood of impact	Certain	Certain	Certain	Probable
	Characterization of impact	Negative	Positive	Negative	Negative
Task 600 (Policy 2.ii)	Likelihood of impact	Certain	Probable	Certain	Probable
	Characterization of impact	Negative	Positive	Negative	Negative
Task 600 (Policy 3)	Likelihood of impact	Possible	Unlikely	Certain	Probable
	Characterization of impact	Negative	Positive	Negative	Negative
Task 700	Likelihood of impact	Certain	Unlikely	Unlikely	Probable
	Characterization of impact	Negative	Uncertain	Negative	Positive
Task 800	Likelihood of impact	Unlikely	Probable	Unlikely	Certain
	Characterization of impact	Negative	Positive	Negative	Positive
Task 900	Likelihood of impact	Unlikely	Unlikely	Unlikely	Unlikely
	Characterization of impact	Negative	Uncertain	Negative	Uncertain
Task 1000	Likelihood of impact	Unlikely	Probable	Certain	Certain
	Characterization of impact	Negative	Positive	Negative	Negative

References

ACEM, 2003. Facts and Figures on PTWs in Europe. ACEM Yearbook 2003. Internet Reference at http://www.acembike.org/

ACEM, 2002a. ACEM position on 2006 emission limits for mopeds. Presentation to the MVEG ad-hoc group (Moto 23).

ACEM, 2002b. ACEM response on Evaporative Emissions. Presentation to the MVEG as-hoc group (Moto 56).

ANCMA, 2002. presentation to the MVEG ad-hoc group (Moto 21).

Bonnel P., G. Martini, A. Krasenbrink, G. De Santi (2003) . Effect of motorcycle engine technology upon physical properties of nanoparticles. Presentation at the 7th ETH Conference on Combustion Generated Particles, Zurich, Switzerland.

Cornelis E., De Nocker L., Panis L. Int. and De Vlieger I., 2002. Final Report: Estimation of Costs and Benefits of Inspecting OBD Systems. CITA. P:38-44.

CITA: Cornelis E., De Nocker L., Panis L. Int. and De Vlieger I., 2002. Final Report: Estimation of Costs and Benefits of Inspecting OBD Systems.

DG Environment, 2004: Estimates of marginal external costs of air pollution in Europe. http://europa.eu.int/comm/environment/enveco/studies2.htm#Marginal%20external%20costs%20air%20pollution

European Commission, 2002a. Directive 2002/51/EC of the European Parliament and of the Council of 19 July 2002 on the reduction of the level of pollutant emissions from two- and three-wheel motor vehicles and amending Directive 97/24/EC. Official Journal of the European Communities, L 252/20.

European Commission, 2002b. Commission Directive 2002/80/EC adapting to technical progress Council Directive 70/220/EEC relating to measures to be taken against air pollution by emissions from motor vehicles. Official Journal of the European Communities, L 291/20.

European Commission, 2002c. Communication from the Commission on Impact Assessment, COM(2002) 276 final, Brussels, Belgium.

European Commision, 2002d. A HANDBOOK FOR IMPACT ASSESSMENT IN THE COMMISSION: How to do an Impact Assessment.

Elst, D.A.M.M., Gense, N.L.J., Rijkeboer, R. (2002) 2nd CITA Research Study Programme on Emissions. Study 2: Motorcycle Exhaust Emissions and Noise. TNO Automotive, TNO Report 02.OR.VM.044.1/DE.

Ericsson, 2003. Principles and Elements: Emissions Durability and In-Use Compliance for MC. Presentation to the MVEG ad-hoc group 28/1/2003 (Moto61).

EURO-WMTC, 2003. Correlation study conducted by JRC using test data obtained from the WMTC project, JRC and ACEM in-house testing activities.

Federal Environmental Agency, Germany 2002. Evaporative Emission Determination for Motorcycles. Presentation to the MVEG ad-hoc group (Moto 31).

Faiz A., C. Weaver, M. Walsh (1996). Air Pollution from Motor Vehicles – Standards and Technologies for Controlling Emissions. The World Bank, Washington D.C., USA.

Heinz S., 2002. Worldwide Harmonised Motorcycle Emissions Certification Procedure, Draft Technical Report, UN/ECE-WP 29 – GRPE WMTC Working Group.

INTA, 2002. Measurement of CO2 emissions and Fuel Consumption According to WMTC and R-40 cycles. Presentation to the ad-hoc MVEG (Moto38).

Kolke, R. 2002. Berechnung der Verdunstungsemissionen von motorisierten Zweirädern (MZR). Presentation to the MVEG ad-hoc group (Moto 66).

Kolke, R. 2003a. Evaporative Emissions From Motorcycles. Presentation to the MVEG ad-hoc group (Moto 67).

Kolke, R. 2003b. Cost-Effectiveness of Evaporative Emission Control for Motorcycles. Presentation to the ad-hoc MVEG (Moto68).

Kojima M., C. Brandon, J. Shah (2000) Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles. The World Bank, Washington D.C., USA.

LAT, Aristotle University of Thessaloniki, Greece – INRETS, France – TV Rheinland, Germany – TNO, The Netherlands – TRL, United Kingdom ; 1998. *The Inspection of In-Use Cars in Order to attain Minimum Emissions of Pollutants and Optimum Energy Efficiency.*

Martini G., P. Bonnel, A. Krasenbrink, G.De Santi (2003). Particulate emissions from mopeds: effect of lubricant and fuel. Presentation at the 7th ETH Conference on Combustion Generated Particles, Zurich, Switzerland.

Mills B., 2004. Personal communication with Mr. Bob Mills.

Netcen: Mike Holland and Paul Watkiss, 2000. *Benefits Table database: Estimates of the marginal external costs of air pollution in Europe*. Created for European Commission DG Environment.

Noda, T., 2001. Overview of Motorcycles Emission Standards in Asia. ADB Regional Workshop: Reducing Emission of 2-3 Wheelers, September 5-7, 2001, Hanoi, Vietnam.

Ntziachristos L. and Samaras Z. (2000), "COPERT III-Computer Programme to calculate Emissions from Road Transport - Methodology and emissions factors (version. 2.1)", Technical Report 49, European Environment Agency, Copenhagen, Denmark, p.86. Internet reference at http://vergina.eng.auth.gr/lat/mech/copert/copert.htm.

Ntziachristos L., Giechaskiel B., Pistikopoulos P., Fysikas E. and Samaras Z. 2003. "Particle Emissions Characteristics of Different On-Road Vehicles", JSAE 20030087.

RICARDO/ACEM, 2002. Unregulated Emissions from PTWs. Presentation to the MVEG ad-hoc group (Moto 22).

Rijkeboer, R., Bremmers, D.A.C.M., Samaras, Z., Ntziachristos, L. 2002. Emission Regulation of Power Two Wheelers, Report to the European Commission, Enterprise DG, TNO Report 03.OR.VM.004.1/RR, Delft, Netherlands.

Rijkeboer, 2002b. Presentation to the MVEG ad-hoc group (Moto 42).

Samaras, Z., Zachariadis, Th., Aslanoglou, M., 1997. Evaporative emissions. LAT report, n°9717, Thessaloniki, Greece, 37p.
Internet reference at http://www.inrets.fr/infos/cost319/

Samaras Z., T. Zachariadis, R. Joumard, D. Hassel, F.-J. Weber and R. Rijkeboer "An Outline of the 1994-1998 European Inspection and Maintenance Study – Part I: Design, tests and results of experimental methods", *J. Air & Waste Manage. Assoc*. **51**:913-938, 2001.

Samaras Z. and G. Mellios (2002). Feasibility study of a large scale data gathering exercise of the emissions produced by vehicles in-use. Final Report to CITA. LAT Report No: 0210, Thessaloniki. Greece

Shu, J.P.H., 2001. Strategies to Reduce Two-Stroke Motorcycle in Taiwan. ADB Regional Workshop: Reduction of Emission from 2-3 Wheelers, September 5-7, Hanoi, Vietnam.

Spears, M., 2001. Particulate Matter Measurement of Particulate Matter Measurement of Uncontrolled 2-Stroke Vehicles. ADB Regional Workshop: Reduction of Emission from 2-3 Wheelers, September 5-7, Hanoi, Vietnam.

State of California Air Resources Board (CARB), 1999. California evaporative emission standards and test procedures for 2001 and subsequent model motor vehicles, USA.

Suksod, J., 2001. Automotive Emission in Thailand. ADB Regional Workshop: Reduction of Emission from 2-3 Wheelers, September 5-7, Hanoi, Vietnam.

TERM, 2004. Indicators of Transport and Environment Integration, Data Submitted for inclusion in 2004 Version, European Environment Agency.

TRENDS, 2003. Calculation of Indicators of Environmental Pressure caused by Transport - Main report. European Commission, Office for Official Publications, Luxembourg. http://forum.europa.eu.int/Public/irc/dsis/pip/library?l=/environment_trends/trends_documentation/environment_trends_repor&vm=detailed&sb=Title

TRL, 2003. Assessment and reliability of transport emission models and inventory systems (ARTEMIS), DGTREN Contract 1999-RD.10429, Internet reference at http://www.trl.co.uk/artemis/.

U.S.E.P.A., 1999. Regulatory Impact Analysis - Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements. Engine Programs and Compliance Division Office of Mobile Sources.

USEPA, 2000. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines. Assessment and Standards Division - Office of Transport and Air Quality. P:101.

USEPA, 2002. Draft Regulatory Support Document: Control of Emissions from Spark-Ignition Marine Vessels and Highway Motorcycles. EPA 420-D-02-003, July 2002.

USEPA, 2003. Final Regulatory Support Document: Control of Emissions of Air Pollution from Highway Motorcycles. Assessment and Standards Division - Office of Transport and Air Quality. P:5-4 & 5-13.

Annex I

This Annex includes communication from ACEM on OBD and evaporation packages.

Evaporative Emissions

Status of Industry/Technological Feasibility

There have been evaporative emission control requirements for motorcycles in California for a considerable period of time. The technology, related directly to CARB's 2 gram per test standard, is well established for large capacity motorcycles irrespective of the fuel system (carburettors or fuel injection). However, motorcycles below 600cc engine capacity, scooters and mopeds are not typically sold in California and so the design and development costs for these categories of PTW will be much greater than for those established in California already.

Typically, for a fuel-injected motorcycle, the control system consists of a carbon canister; purge control valve, rollover valve and a series of hoses and connectors. In many cases hoses will be pre-formed and will be multi-layered to prevent collapse under vacuum. Some manufacturers also use a pressure control and non-return valve system to contain vapour within the fuel tank until a predetermined pressure is reached.

For carburettor-equipped motorcycles, where float chambers must be open to atmosphere when the engine is running, solenoids are used to seal the float chamber vents when the ignition is switched off. The solenoids open when the ignition is turned on, thus exposing the float chambers to atmosphere. In many cases, a separate carbon canister is used for the float bowls, in addition to that used to control fuel tank evaporation.

Of course, a mounting system and space envelope is also necessary for the components, which also adds to the component inventory and design/development task.

Cost

ACEM has surveyed its members to ascertain the true component cost of an evaporative system. The average figure for those who responded was €50.00.

This possibly reflects the maximum cost of an evaporative system due to the relatively small volume of vehicles manufactured for California. However, we estimate that use of evaporative components in greater volumes will not significantly lower the cost. This is because truly large volumes, such as those typical of the passenger car industry, are required to gain more significant savings from higher volumes.

ACEM does not agree with the component cost figures put forward by UBA. They seem to overlook many of the components and processes relating to evaporation controls on motorcycles and relate more to passenger cars and the associated manufacturing volumes. For example, non-metallic fuel tanks are relatively common on motorcycles. To ensure compliance with any evaporative standard, these fuel tanks must undergo a costly internal sealing process. This and other items are not mentioned in UBA's estimation of component cost.

It is also worth reiterating that small motorcycles and scooters are not currently sold in California. The cost of development, and the task of packaging the components, would be significantly higher for these manufacturers, than for anyone currently active in that market.

Emission Benefit

In early MVEG motorcycle group meetings, ACEM did not fully understand the nature of the tests carried out by UBA and could not, in fact, replicate them based on our then understanding. Only when the test method was fully explained at one of the later meetings were ACEM able to replicate the tests and evaluate UBA's emission data. Having carried out this exercise, ACEM broadly agrees with the emission figures put forward by UBA.

Cost/Benefit Analysis

The attached spreadsheet data shows ACEM cost/benefit analysis related to evaporative emission controls.

ACEM regards the cost/benefit related to savings of 1.3 kg per year per motorcycle as being realistic, and include figures for 5 kg per year only because the contracting party mentioned this amount. We do not agree with a 5 kg figure based on analysis of typical riding behaviour and the testing conducted by UBA and ACEM.

ACEM further regards the figures that include development costs as being the more accurate. An evaporation test coupled with a Euro 3 tailpipe emissions test imposes a significant extra development burden in addition to that which would be imposed by not insignificant evaporation standard itself. In short, purging an evaporative canister on the tailpipe emissions test cycle would require a significant period of extra development to ensure neither test result is compromised.

Figures for useful life of both 5 and 10 years have been included, however, we also believe that true motorcycle useful life, as defined by the durability test distance, is nearer 5 years than 10.

Example 1

System cost (€)	Kg saved/year	Useful life (years)	Cost/benefit €/ton - 1	Cost/benefit (€/ton) - 2	Achievable by industry?
50	1.3	10	5519.23	3846.15	Current cost to Industry
45	1.3	10	5134.62	3461.54	Potentially if volumes are increased
40	1.3	10	4750.00	3076.92	Uncertain
35	1.3	10	4365.38	2692.31	No

Example 2

System cost (€)	Kg saved/year	Useful life (years)	Cost/benefit €/ton - 1	Cost/benefit (€/ton) - 2	Achievable by industry?
50	1.3	5	11038.46	7692.31	Current cost to Industry
45	1.3	5	10269.23	6923.08	Potentially if volumes are increased
40	1.3	5	9500.00	6153.85	Uncertain
35	1.3	5	8730.77	5384.62	No

Example 3

System cost (€)	Kg saved/year	Useful life (years)	Cost/benefit €/ton - 1	Cost/benefit (€/ton) - 2	Achievable by industry?
50	5	10	1435.00	1000.00	Current cost to Industry
45	5	10	1335.00	900.00	Potentially if volumes are increased
40	5	10	1235.00	800.00	Uncertain
35	5	10	1135.00	700.00	No

Example 4

System cost (€)	Kg saved/year	Useful life (years)	Cost/benefit €/ton - 1	Cost/benefit (€/ton) - 2	Achievable by industry?
50	5	5	2870.00	2000.00	Current cost to Industry
45	5	5	2670.00	1800.00	Potentially if volumes are increased
40	5	5	2470.00	1600.00	Uncertain
35	5	5	2270.00	1400.00	No

On Board Diagnostics

Current Status of Industry

Undeniably, some of the latest 'top of the range' motorcycles are already fitted with OBD-like systems. However, these systems should not, in most cases, be confused with those fitted to passenger cars. They range from so-called "blink code indicators" where a light on the instrument panel flashes in a coded sequence, to pseudo car OBD systems (always without catalyst monitor) that communicate fault codes with an off board scan tool. However, we must stress that such systems are not commonplace and, should any OBD requirement be passed into legislation, most motorcycle manufacturers would be faced with a substantial workload and high level of expenditure to realise even the most basic system.

Currently, where manufacturers have pseudo car OBD systems, the level of sophistication is likely to have been present in a ready-made engine management system rather than designed in specifically. Typically, the manufacturer will have purchased an engine management system from a third party supplier, who has a main customer base in other branches of the automotive industry. Only the least sophisticated of OBD systems are likely to have been designed into a motorcycle specific engine management system.

Potential Solutions

Motorcycle manufacturers faced with a legislated OBD requirement will have two distinct ways in which to ensure their products comply with the new regulation.

1. Add OBD to their existing engine management systems and products.
2. Add OBD compliant engine management systems to their products.

Under scenario 1, manufacturers will keep their existing engine management system, but their supplier will need to modify the ECU internals to add the necessary hard and software to achieve OBD status. In reality, this means a complete redesign and retooling of the ECU. Modifications would also be required to motorcycle wiring, instruments and possibly sensors. Full calibration of the OBD system will also be required.

Scenario 2 will typically require calibration of the engine management and OBD systems, extensive packaging and wiring modifications, further engine development and proving, together with the same other modifications as scenario 1.

Costs

As with previous submissions, we have found it impossible to accurately cost the addition of OBD to a motorcycle. An industry supplier previously approached continues to require two weeks consultancy fee to even estimate the costs. We can only, therefore, estimate costs based on our member's knowledge and past experience, bearing in mind that particularly in scenario 2, true costs are often not transparent even to those manufacturers with OBD.

Scenario 1

1. ECU modifications/retooling - €1.25 million
2. On-motorcycle modifications - €0.5 million
3. Calibration - €0.25 million
4. Peripheral costs - €0.1 million

Total development cost - €2.1 million

Scenario 2

1. On Motorcycle modifications - €0.75 million
2. Calibration €0.75 million
3. Peripheral costs €0.1 million
4. Other testing - €0.4 million

Total development cost - €2.0 million

Benefits

We are aware that the true environmental benefit of car OBD is currently being debated. In practice we know the car industry, and the delegations of some member states, are doubtful if OBD ensures that factory gate emission levels are maintained throughout the life of the product. There are several reasons put forward for this which include:

- Owners reluctant to pay for OBD repairs outside the warranty period
- MIL tampering/disablement
- Lack of enforcement (i.e. no I/M programme)

For these reasons, the motorcycle industry also shares the view that OBD may not realise any substantial benefit in environmental terms.

The robust and reliable nature of the systems and components used in motorcycle engine management systems must also be borne in mind. A survey of five ACEM member manufacturers showed failure rates of OBD monitored components to be, on average, below 0.2%. Of course, without a substantial research programme we are unable to put an environmental value on the failure of an individual component and therefore a true cost benefit analysis is currently impossible. However, it would appear that failure rates are very low and our own experience tells us that, in emissions terms, a failed component often does not increase emissions by any substantial amount. It is safe to assume, therefore, that a true cost/benefit ratio would prove to be very expensive indeed in terms of emissions saved.

Potential Motorcycle System

Should the Commission find that OBD is necessary for motorcycles, the suggested specification given over-page would minimise the impact on motorcycle manufacturers. What is essential is that in specifying a motorcycle OBD system in regulation, the Commission do not preclude the use of the more sophisticated systems used by some manufacturers, yet should not see these systems as the minimum specification. Nearly all-current motorcycle OBD systems will produce the same basic result, even if they are achieved in a variety of ways.

General Specification

1. The system shall be capable of identifying circuit/electrical faults in emissions related components controlled by the engine management system. It shall not be required to detect out of range faults or faults in components that are not part of the engine management system.
2. The system shall not be required to monitor catalyst performance or detect misfire conditions.
3. Faults shall be identified to the rider by means of a malfunction indicator light (MIL) visible from the riding position.
4. The MIL must remain illuminated under normal operating conditions until the fault is cleared.
5. The MIL shall illuminate in the engine-run key position before engine cranking to indicate that the MIL is functional and shall, when illuminated by the on-board computer, display a symbol in conformity with ISO 2575 or shall display the words "CHECK ENGINE" or "SERVICE ENGINE SOON".

Communications

1. Identified faults must be individually identifiable by means of a manufacturer specific or OBD standardised code system. In either case, the code system must be published in the manufacturer's service literature.
2. Communication of the fault code may be on board only, or on board to an off board device (i.e. a scan tool).
3. In the case of on board only systems, faults shall be displayed by means of the instrument panel or warning lights.
4. In the case of off board communications, the manufacturer must offer a dedicated tool and/or the system must communicate to a generic OBD scan tool.

Applicability

1. An OBD system shall be fitted to all category L vehicles except those described below.
    a. Mopeds

b. Vehicles falling in WMTC classes 1 and 2
c. Vehicles with compression ignition engines
d. Three and four wheeled vehicles (tricycles and quadricycles)

Type Approval Test

1. Type approval testing shall take place on the emissions cycle or during a steady state test (manufacturer's choice).
2. Faults may be simulated by electronic means (e.g. a break-out box etc.)

Implementation

1. Entry into force shall not be before 730 days have elapsed from the publication of the OBD requirements in the Official Journal.
2. The requirements shall not apply to series production vehicles due to the complexity and cost of adding OBD to an existing vehicle type.