Final Background Document
on the sector

On Road
Mopeds and motorcycles

Prepared by CITEPA, Paris

Summary

Two wheels vehicles

SNAP : 0704 and 0705 or NFR 1 A 3 b iv R.T., Mopeds and Motorcycles

The base case of the European Program AOP II had foreseen an increase of the share of HC emissions emanating from PTWs from 4,1% in 1995 to 20% in 2020 of the total transport HC emissions. This is due to the fact that stricter emission limits are implemented for on-road vehicles (e.g PC, LDV, HDV). That is why a new regulation has been adopted in 2002 to strengthened motorcycle emission limits [1].

ACTIVITY : Consumption of fuel (GJ/year)
POLLUTANTS CONSIDERED : HC, NOx and SO_2. PM are not presented in this document.

1 Data currently used in the RAINS model

Following data are just presented for comparison purposes

Data are derived from reference [12].

- Activity

Activity used in the current stage of development of the RAINS model is the fuel consumed (expressed in PJ).

- Engines considered

Table 1.1 : Sectors considered in RAINS

Abbreviations used in RAINS	Sector
TRA_RD_M4	Motorcycles gasoline four stroke engines
TRA_RD_LD2	Motorcycles, mopeds, cars – gasoline 2-stroke engines

- Emission factors

Table 1.2 : Uncontrolled emission factors used in the RAINS PM module [g/GJ]

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]
TRA_RD_M4	6,0	6,3	6,6
TRA_RD_LD2	94,9	100,5	111,7

- Techniques and associated costs

In its current stage of development, the RAINS model includes three stages of abatement for each type of engines.

Table 1.3 : Associated costs

Technology	Unit investment [€/vehicle]	Fixed O+M [%]
Motorcycles and mopeds, 2-stroke, stage 1	80	9,5
Motorcycles and mopeds, 2-stroke, stage 2	120	7,0
Motorcycles and mopeds, 2-stroke, stage 3	150	6,0
Motorcycles 4-stroke, stage 1	110	7,5
Motorcycles 4-stroke, stage 2	160	5,8
Motorcycles 4-stroke, stage 3	200	5,0

2 Short technology description

Mopeds and small motorcycles are generally equipped with 2-stroke engines whereas bigger motorcycle engines are 4-stroke.
However, 2-stroke engines tend to be replaced by 4-stroke engines even for mopeds.
This has a big importance because pollutants and abatement techniques are different for these two types of engines.
For 2-stroke engines, NOx emissions are relatively low because of the natural exhaust gas recirculation (natural EGR) of these types of engines.
For 4-stroke engines HC emissions are lowered because no intake mixture is directly routed to the exhaust but combustion peak temperature being higher than for 2-stroke engines, NOx emissions are higher.

2.1 2-stroke controlled by a carburettor

2-stroke engines are almost exclusively simple portcontrolled engines. The mixture is inducted into the crankcase and transferred to the cylinder from there. HC emissions are high because 25-30% of the intake mixture is directly scavenged in the exhaust.
The reverse side of the scavenge loss aspects is a high residual amount of burnt gas in the cylinder, acting as a high internal EGR. (exhaust gas recirculation).
CO emissions are moderately high due to the rich adjustment necessary for the carburetion because of the fluctuating air/fuel ratios.

2.2 2-stroke controlled by Direct injection

This technology enables the engine designer to add fuel only after the closure of the exhaust port and thereby to avoid scavenge losses. This reduces HC emissions as well as fuel consumption (by at least 25-30%). Burning temperatures being higher, NOx emissions tend to be more important.

2.3 4-stroke technologies

Carburetion for a long time has been by constant depression carburettors, that control the fuelling by means of a calibrated needle in a jet.
More recently electronically controlled fuel injection has been developed for the top models of the market.
Advanced electronic ignition is already standard for many years.
This leads to relatively high emissions of CO due to the rich adjustment, related emissions of HC due to the same cause (not as high as for 2-stroke engines) and moderate emissions of NOx (higher than for 2-stroke engines) due to a certain degree of internal EGR and the rich adjustment.

3 Regulations

3.1 Directive 97/24/EC [2]

This Directive has been implemented to reduce two and three wheels vehicles air pollutant emissions : standards have been adopted in two steps for mopeds and one step for motorcycles. This Directive foresees that stricter standards (for motorcycles only) should be implemented in the two years following the date of compliance with stage I (i.e : 1999).

Table 3.1.1 : Standards [g/km]

Type of engine	Dates of Appliance	Stage	HC + NOx [g / km]	HC [g / km]	NOx [g / km]
Mopeds	17/06/1999	Stage I	3,0	-	-
Mopeds	17/06/2002	Stage II	1,2	-	-
Motorcycle 2-stroke	17/06/1999	Stage I	-	4,0	0,1
Motorcycle 4-stroke	17/06/1999	Stage I	-	3,0	0,3

3.2 Directive 2002/51/EC [3]

This Directive implements new standards for motorcycles only (as shown in paragraph 3.1) on the bases of researches on technical feasibility. Mopeds are not considered by this amendment because a stage II is already provided for in Directive 97/24/EC.
Standards are implemented in two phases as shown in table 3.2.1. No distinction is made between two- and four-stroke engines.

Table 3.2.1 : Standards [g/km]

Type of engine	Dates of Appliance	Stage	HC [g / km]	NOx [g / km]
Motorcycle < 150cc	01/04/2003	Stage II	1,2	0,3
Motorcycle > 150cc			1,0	0,3
Motorcycle < 150cc	01/01/2006	Stage III *	0,8	0,15
Motorcycle > 150cc			0,3	0,15

* In 2006 a new test cycle will be used to be more representative of real emissions.

The Commission shall consider a new set of limit values (stage III) for mopeds, including particulate emissions in accordance with the results of technical studies, to be applied from 2006.The provisions on durability requirements and the obligation to measure specific CO_2 emissions in type approval will also be applied to mopeds.

3.3 Sulphur content of fuels

Only petrol is used to drive the two wheels vehicles. We assume that petrol used in two wheels vehicles is the same as petrol used in other on-road vehicles (e.g. PC, LDV, HDV).

Table 3.3.1 : Regulations on sulphur content of fuels

Directive References	Scope	Exemptions
98/70/EC [4] *2003/17/EC [10]*	Quality of petrol and diesel fuels	-

Table 3.4.2 : Sulphur content of fuels : standards (ppm) implemented by the Directives

Fuels	2000	2005	2008
Petrol	150	50	10

4 Definition of Reference Engines

In this document, reference engines are defined to determine costs incurred by the reduction of emissions in the different countries. For total emission assessment, European models such as COPERT III [5] can be used. Five different reference engines are describe according to the techniques used and the different engine sizes.

Table 4.1 : Reference engines

Reference engine code REC	Description
01	Moped engine < 50 cc
02	Motorcycle 2-stroke > 50 cc
03	Small motorcycles 4-stroke 50-150 cc
04	Medium motorcycles 4-stroke 150-400 cc
05	Large motorcycles 4-stroke > 400 cc

5 Emission abatement techniques and costs

5.1 Emission abatement techniques

5.1.1 Mopeds

To comply with stage I standards manufacturers have used oxidation catalysts (OC) for 2 stroke engines.
For the second stage of the regulation, three approaches are possible : either the use of a more efficient catalyst with second air injection (SAI) or the use of electronic fuel injection (EFI) with a catalyst or the use of a 4 stroke engine.
The completion with a stage III could be obtain with the use of direct injection (DI) technology.

5.1.2 Motorcycles

Standards of stage I have been reached by engine modifications (EM).
Three technologies have been used to reduce further 4-stroke engines emissions :

- Secondary air injection (SAI) with an efficiency on HC emissions of about 25%.
- Oxidation catalysts (OC) with or without SAI with an efficiency on HC emissions of about 50-60%.
- Closed loop three way catalyst (TWC) with an efficiency on HC emissions of about 60-80%. Only this technique allows to reduce NOx emissions.

For 2-stroke motorcycle engines, the oxidation catalyst (OC) and the direct injection (DI) are technically feasible. With the use of DI, HC emissions have been reduced to the level achieved with 4-stroke engines (reduction of 70% of HC emissions). This technique also reduces fuel consumption. The only drawback is the increase of NOx emissions. DI will probably be the only technique allowing 2 stroke engines to comply with Stage III (2006).

Table 5.1.1 : Techniques used to reach the standards

REC	Stage I	Stage II	Stage III
01	OC	EFI	DI
02	EM	DI	DI/OC
03	EM	OC	SAI/OC
04	EM	SAI/OC	TWC
05	EM	SAI/OC	TWC

5.1.3 Aggregated abatement techniques

Table 5.1.3.1 : Aggregated abatement techniques

Measure Code MC	Description
00	Pre-control engines
01	Stage I
02	Stage II
03	Stage III

5.2 Emission factors and costs data for the different combinations

5.2.1 Emission factors

Mopeds are mostly driven under “urban” driving conditions and therefore only an urban emission factor value is proposed in reference [14].

Table 5.2.1.1 : Emission factors and consumption factors for pre-controlled mopeds

Pollutant	CO	NOx	VOC	Fuel consumption
EF [g/km]	15,00	0,03	9,00	25,00

Table 5.2.1.2 : Emission and consumption reduction percentage for improved mopeds applied to pre-controlled ones

Pollutant	CO	NOx	VOC	Fuel consumption
Stage I [%]	50	0	55	40
Stage II [%]	90	67	78	56

The VOC reduction percentage has to be equally applied to the NMVOC emission factors and to the CH_4 emission factors.

Different types of motorcycles are considered in reference [14] (i.e. 2 stroke, 4-stroke < 250 cm^3, 4-stroke 250 < cc < 750 cm^3, 4-stroke > 750 cm^3).
For each type of motorcycles, emission factors can be calculated from an equation depending of the speed of the vehicle. 32 equations are given to represent the pre-controlled and the Stage I engines. These equations are not studied hereafter.

5.2.2 Investments and operating costs

Only average investments are displayed hereafter in table 5.2.2.1.

Table 5.2.2.1 : Investments and operating costs

REC MC	Investment (€$_{2000}$)	Q	CI %	OC * (€$_{2000}$/y)
01 00	1 200	3	30	-
01 01	1 248	3	30	-
01 02	1 296	3	30	-
01 03	1 440	3	30	-
02 00	2 800	3	30	-
02 01	2 870	3	30	-
02 02	2 996	3	30	-
02 03	3 133	3	30	-
03 00	3 250	3	30	-
03 01	3 300	3	30	-
03 02	3 373	3	30	-
03 03	3 488	3	30	-
04 00	4 500	3	30	-
04 01	4 560	3	30	-
04 02	4 699	3	30	-
04 03	4 860	3	30	-
05 00	8 000	3	30	-
05 01	8 105	3	30	-
05 02	8 360	3	30	-
05 03	8 608	3	30	-

* No information is available to assess operating costs

6 Data to be provided by national experts for the completion of the database for their own country

The following tasks are required :

6.1 Validation work

For representing costs in this sector, the national expert is invited to comment data provided by the Secretariat.

- Validate of investments provided or,
- Provide other costs for the same combination of techniques and justify them.

6.2 Provision of specific data

Tables to be filled in by national experts

- Fuel parameters

Table 6.2.1 : Fuel parameters

	2000	2005	2008	2010	2015	2020
Heat value of petrol [GJ/t]						

Table 6.2.2 : Fuel prices (net of taxes)

	2000	2005	2008	2010	2015	2020
Petrol 150 ppm (€$_{2000}$/l)						
Petrol 50 ppm (€$_{2000}$/l)						
Petrol 10 ppm (€$_{2000}$/l)						

- Activity level

IIASA uses international fuel statistics to define fuel consumption in each country.

Although IIASA tries to derive fuel consumption in each sub-sector from international energy statistics and available energy projections, a high uncertainty still exists. Thus the experts are requested to give the total fuel use for the base year (2000) and a national projection up to 2020 in 5-years intervals. As the use of fuel containing less sulphur is considered as a measure to reduce SO_2 emissions, the consumption of each type of fuels is requested hereafter for 2000 up to 2020 in 5-years.

Table 6.2.3 : Fuel consumptions (GJ / y)

Type of fuel used	Activity (GJ) 2000	CI %	Activity (GJ) 2005	CI %	Activity (GJ) 2010	CI %	Activity (GJ) 2015	CI %	Activity (GJ) 2020	CI %
Petrol 150 ppm sulphur										
Petrol 50 ppm sulphur										
Petrol 10 ppm sulphur										
Default values proposed for CI		10		20		50		100		100

For explanations on the coefficient of variation (CI), please refer to the Methodology.

- Determination of the vehicle fleet in use in 2000

Data are provided as default values for certain countries in table 6.2.3 [6].

Table 6.2.4 : Number of mopeds and motorcycles in use in European countries for the base year 2000

Country	Mopeds	Motorcycles
Austria	342 557	278 118
Belgium	-	276 933
Finland	101 734	90 258
France	1 442 000	968 100
Germany	1 724 945	3 337 848
Greece	-	638 064
Italy	6 375 000	3 373 064
Luxemburg	21 286	11 488
Netherlands	533 000	437 798
Portugal	590 000	144 000
Spain	2 202 521	1 445 644
Sweden	150 000	163 346
United Kingdom	162 972	994 741

✓ Determination of the shares of the different types of engines

Table 6.2.5: Application rate and Applicability (% of total activity (fuel use))

REC MC	Application rate in 2000 [%]	Application rate in 2005 [%]	Appl. [%]	Application rate in 2010 [%]	Appl. [%]	Application rate in 2015 [%]	Appl. [%]	Application rate in 2020 [%]	Appl. [%]
01 00									
01 01									
01 02									
01 03									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
02 03									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
03 03									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
04 02									
04 03									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00									
05 01									
05 02									
05 03									
Total REC 05	**100**	**100**		**100**		**100**		**100**	

➢ Other parameters

Table 6.2.6: km driven per vehicle in the years 1990 and 2000

REC	[km / vehicle] 1990	[km / vehicle] 2000
01		
02		
03		
04		

Table 6.2.7: Fuel use per vehicle in the years 1990 and 2000

REC	[GJ / vehicle] 1990	[GJ / vehicle] 2000
01		
02		
03		
04		

Two additional parameters should be specified:
- Fuel efficiency improvement (Table 6.2.8),
- Change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.9).

If country specific data are not available, default values already included in the following tables will be used.

Table 6.2.8: Fuel efficiency improvement for individual engine sizes relative to the base year (Fuel consumption per unit of output in year 2000 = 100 %)

REC	2000	2005	2005	2010	2010	2015	2015	2020	2020
01	100	98		96		94		92	
02	100	98		96		94		92	
03	100	98		96		94		92	
04	100	98		96		94		92	

Table 6.2.9: Change in activity per engine relative to the base year (Activity per engine in year 2000 = 100 %)

REC	2000	2005	2005	2010	2010	2015	2015	2020	2020
01	100	100		100		100		100	
02	100	100		100		100		100	
03	100	100		100		100		100	
04	100	98		96		94		92	

7 Explanatory notes

7.1 Emission factors

Emission factors are only presented for mopeds (see Chapter 5.2.1). Equations are too numerous for motorcycles. Complex models such as COPERT III already exist [5] or are under elaboration as the program ARTEMIS [7].

7.2 PM size profile

PM size fractions are presented in table 7.2.1 as reported from [8].

Table 7.2.1 : PM size profile

Size profile	% of TSP
PM_{10}	85
$PM_{2.5}$	67

7.3 Costs

7.3.1 Investments

Average investments for mopeds are derived from reference [13] and investments for motorcycles are derived from [1], [9]. These costs are presented in table 7.3.1.1. Whenever possible, cost ranges are given into brackets. Costs will vary from a manufacturer to an other according to their production size.

Table 7.3.1.1 : Investments [$€_{2000}$ / engine]

REC MC	Investments [$€_{2000}$ / engine]	Q	CI %
01 00	1200	3	30
01 01	1236-1260	3	30
01 02	1296	3	30
01 03	1440	3	30
02 00	2800	3	30
02 01	2870	3	30
02 02	2996 (2926-3080)	3	30
02 03	3133 (2982-3402)	3	30
03 00	3250	3	30
03 01	3300	3	30
03 02	3373 (3341-3458)	3	30
03 03	3488 (3406-3562)	3	30
04 00	4500	3	30
04 01	4560	3	30
04 02	4699 (4626-4734)	3	30
04 03	4860 (4860-4860)	3	30
05 00	8000	3	30
05 01	8105	3	30
05 02	8360 (8048-8800)	3	30
05 03	8608 (8384-8800)	3	30

7.3.2 Operating costs

As defined in IIASA reports, operating costs (OC) are composed of fixed and variable costs. Fixed costs are expressed as a percentage of total investment (Maintenance costs); variable costs are defined with the different quality of fuels and the variation in fuel consumption.

- Fuel consumption variations

Application of certain technologies leads to fuel consumption variations.
The use of direct injection for 2-stroke engines leads to 25-30% of fuel consumption savings.
For the other technologies no information is available.

- Additional costs for the use of low sulphur fuel

Sulfur content of petrol fuel is regulated by Directive 98/70/EC [4] and Directive 2003/17/EC [10] relating to the quality of petrol and diesel fuels.

Costs of the different types of fuel have to be entered only once in the tool in table "Fuel characteristics".

Additional investment and refinery operating costs associated with lowering the sulphur content from a maximum of 50 ppm to a maximum of 10 ppm. The main driver of cost difference between north and south EU is the quality of the crude oil (in particular the sulphur content) that the refineries are currently to handle.

Table 7.2.2.1 : Costs of lowering the sulphur content of petrol [11]

	Min. (€/l)	Max. (€/l)	Average (€/l)
EU, North	0,001	0,003	0,002
EU, South	0,002	0,003	0,0025

- Repair and Maintenance

Repair and Maintenance costs are expressed as a percentage of investments.

No data concerning these costs are available.

8 References

[1] Proposal for a directive of the European Parliament and of the Council amending Directive 97/24/EC on certain components and characteristics of two or three-wheel motor vehicles/* COM/2000/0314 final - COD 2000/0136.

[2] Directive 97/24/EC of the European Parliament and of the Council of 17 June 1997 on certain components and characteristics of two or three-wheel motor vehicles.

[3] 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 (Text with EEA relevance) - Statement by the Commission - Commission declaration as complement.

[4] Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC [Official Journal L 350, 28.12.1998].

[5] L. NTZIACHRISTOS, Z. SAMARAS. COPERT III. Computer programme to calculate emissions from road transport. Methodology and emission factors (Version 2.1). November 2000. http://themes.eea.eu.int/Specific_media/air/reports

[6] ACEM Associations des Constructeurs Européens de Motocycles. http://www.acembike.org/html/start.htm

[7] ARTEMIS Assessment and Reliability of Transport Emission Models and Inventory. http://www.trl.co.uk/artemis/introduction.htm

[8] CEPMEIP database 2001. http://www.air.sk/tno/cepmeip/

[9] Motorcycle emissions : air quality and emission inventory; Costs and benefits for emission abatement technologies, Possibilities for next stages. 20 October 1999. European Commission.

[10] Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels.

[11] The costs and benefits of lowering the sulphur content of petrol & diesel to less than 10 ppm. Prepared by Directorate-General Environment. 9 September 2001.

[12] Z. KLIMONT; J. COFALA ; I. BERTOK ; M. AMANN ; C. HEYES and F. GYARFAS. Modelling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Costs. Interim Report. IR-02-076. IIASA. 2002. http://www.iiasa.ac.at/rains/reports/ir-02-076.pdf

[13] Personal communication. Anonymous contact. 03/12/02.

[14] L. NTZIACHRISTOS; Z. SAMARAS. COPER III. Computer programme to calculate emissions from road transport. Technical report N°49. European Environment Agency. November 2000.

9 Modifications compared to the draft document

Chapter 6: Mr. COFALA from IIASA has asked us to add some tables in chapter 6.

If available from national experts, the following parameters are required:

For the base year 1990:
- km driven per vehicle in the base year,
- Fuel use per vehicle in the base year (GJ/vehicle).

For each projection year:
- change in activity per vehicle relative to the base year,
- Fuel efficiency improvement relative to the base year.