Final Document
on the sector

Off Road
NON-HANDHELD SPARK IGNITION ENGINES
(4-stroke ; < 19 kW)

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Small Spark-Ignition (SI) Non-handheld 4-stroke Engines

SNAP : 0806 and 0807 or NFR 1A4cii Off-road Vehicles and Other Machinery, **SNAP 0808** or NFR 1A2 Manufacturing Industries and Construction, **SNAP 0809** or NFR 1A4bii Household and gardening (mobile motors), **SNAP 0810** or NFR 1A3eii Other mobile sources and machinery.

Small SI Engines represent the category of engines below 19 kW: usually running with petrol, these engines are often used in lawn and garden equipment.

ACTIVITY: Consumption of fuel (GJ/y)
POLLUTANTS CONSIDERED: HC, NOx and SO_2. TSP are not studied in this document.

1 Data currently used in the RAINS model

Following data are just displayed for comparison purposes

Data are derived from reference [7].

- Activity

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

- Emission factors

Table 1.1: Emission factors used in the RAINS PM module for diesel off-road spark ignition engines [g/GJ]

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]
Land based machinery gasoline (4-stroke)	28,0	30,4	33,8
Land based machinery LPG/CNG (4-stroke)	3,90	4,20	4,24
Land based machinery gasoline (2-stroke)	289	381	423

- Engines considered

Table 1.2: Sectors considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_LB	Land based machinery gasoline (4-stroke)
TRA_OT_LB	Land based machinery LPG/CNG (4-stroke)
TRA_OT_LD2	Land based machinery gasoline (2-stroke)

- Techniques and associated costs

In its current stage of development, the RAINS model includes options to control emissions from gasoline engines, equivalent to EURO-I to EURO-V standards for gasoline cars. 2-stroke engines are considered with mopeds.

2 Short technology description

2.1 Current 4-stroke engines

Virtually all automobiles and many trucks are powered by 4-stroke engines. 4 stroke engines are also very common in motorcycles, all-terrain vehicles, boats, airplanes and numerous non-road applications such as lawn mowers, lawn and garden tractors and generators for example.

Description: in a 4-stroke engine, a piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, power and exhaust. Two of the strokes are downward (intake and power) and two are upward (compression and exhaust).

2.2 Emissions

4-stroke engines have considerably lower HC emissions than 2-stroke engines, due to the fact that 4-stroke do not experience short circuiting of raw fuel.
CO emissions are very similar for both technologies since these emissions are the result of inefficient combustion of the air-fuel mixture within the cylinder.
Since the combustion of fuel within the cylinder of a 4-stroke engine is more efficient than that of a 2-stroke engine, combustion temperatures are higher which results in higher NOx emission levels.
SO_2 emission levels are proportional to the sulphur content of the fuel used. The only way to reduce SO_2 emissions is to reduce the sulphur content of petrol.
PM emissions are not a big issue for these types of engines.

3 EU regulation: Directive 2002/88/EC amending Directive 97/68/EC [2]

3.1 Standards developed in the proposal

The EU commission proceeded to an inventory of pollutant emissions for the amendment of the Directive 97/68/EC [3]. Data used for this study date from 1990.

Table 3.1.1: VOCs emissions from spark ignition (SI) engines (kt)

Category per rated power (kW)	Emissions of 2-stroke engines (kt)	Emissions of 4-stroke engines (kt)	Total VOC (kt)
0-2	108,86	24,74	133,60
2-5	323,58	29,18	352,76
5-10	217,57	18,53	236,10
10-18	113,54	3,48	117,02
18-37	29,29	2,65	31,94
37-75	11,72	27,67	39,39
75-130	5,25	6,10	11,35
130-300	5,30	5,52	10,82
Total			932,98

Engines below 18 kW emit 90% of the VOCs of spark ignition category.

Directive 2002/88/EC regulates these small engines which represent the main emission sources for SI off-road engines (as shown above).

2 stages have been adopted for 4 classes of engines defined according to their size (see the definition of the reference engines in Chapter 4).

Table 3.1.2: Stage I emission limit values

Date of entering into force of standards for new engines:
- 01-08-2004 for classes SN1 and SN2,
- 11-08-2004 for classes SN3 and SN4.

Engine class	HC + NOx [g/kWh]
Class SN 1	50
Class SN 2	40
Class SN 3	16,1
Class SN 4	13,4

Table 3.1.3: Stage II emission limit values

Date of entering into force of standards for new engines:
- 01-08-2004 for classes SN1 and SN2,
- 01-08-2006 for class SN4,
- 01-08-2008 for SN3.

Engine class	HC + NOx [g/kWh]
Class SN 1	50
Class SN 2	40
Class SN 3	16,1
Class SN 4	12,1

A list of exemptions is available. Some examples are listed below:
- Recreational boats (which should be regulated by a modification of directive 94/25/CE),
- Recreational vehicles as snowmobiles (a majority of these engines are rated above 19 kW).

We assume that petrol used in small SI engines is the same as petrol used in on-road vehicles. Sulfur content of this type of fuel is regulated by Directive 98/70/EC [4] and Directive 2003/17/EC [13] relating to the quality of petrol and diesel fuels.

3.2 Sulphur content of fuels

Table 3.2.1: Sulphur content of petrol : standards (ppm) implemented by the Directives

Dates of compliance	2000	2005	2008
Sulphur content in petrol (ppm)	150	50	10

Some Member States have implemented more stringent national standards. This is a country specific information which has to be provided by national experts (chapter 6).

4 Definition of Reference Engines

The four engine classes are considered as reference engines. A distinction has to be made between 2- and 4-stroke engines because uncontrolled emission levels are very different [5].
An average nominal output power of 6 kW is taken into account [9].

Table 4.1: Reference engines

Reference Engines Codes REC	Description	Examples
01	SN 1 < 66 cm^3 / Average power 6 kW	Walk-behind lawnmowers, tiller, snow blower, generator
02	SN 2 66 - 100 cm^3 / Average power 6 kW	Walk-behind lawnmowers, tiller, snow blower, generator
03	SN 3 100 - 225 cm^3 / Average power 6 kW	Walk-behind lawnmowers, tiller, snow blower, generator
04	SN 4 ≥ 225 cm^3 / Average power 6 kW	Lawn and garden tractors, mower, comm. Turf, snow blower, pumps

5 Emission abatement techniques and costs

5.1 Definition of abatement techniques

Overhead valve engine (OHV): means a 4-stroke engine in which the intake and exhaust valves are located above the combustion chamber within the cylinder head.
Side valve engine (SV): means a 4-stroke engine in which the intake and exhaust valves are located to the side of the cylinder, not within the cylinder head.

5.1.1 Measures to meet Stage I standards

According to the reference [1], the American market mix is represented as follows:

- Class SN1, SN2, SN3: the majority of engines are produced for the low cost consumer market and are of side valve design (88%).
- Class SN4: these engines are nearly equal in number of engine population of 4-stroke side valve and overhead valve designs according to EPA [1].

5.1.2 Measures to meet Stage II standards

The regulation of small SI engines will lead to increase the use of automotive-style overhead valve (OHV) technology. Current OHV engines will be improved: improvements in combustion chamber design and intake system allow engines to run more efficiently. Improvements in emission durability will be achieved by refinement of piston profile and improved piston ring.
The use of catalysts is not required for any reference engine.

Detailed data being lacking, only two aggregated measures are defined table 5.1.1.

Table 5.1.1: Technology improvements to reach stage I and stage II standards

Measure Codes (MC)	Technologies
00	None
01	Mix of technologies to reach stage I standards
02	Mix of technologies to reach stage II standards

5.2 Emission factors and cost data for the different combinations

Table 5.2.1: Emission factors for each combination code

REC MC	EF VOC (g/kWh)	Q	CI %	EF NOx (g/kWh)	Q	CI %
01 00	26,9	2	30	1,8	2	30
01 01	16,1	2	30	4,3	2	30
01 02	16,1	2	30	4,3	2	30
02 00	8,7	3	30	3,5	3	30
02 01	7	2	30	4,7	2	30
02 02	7	2	30	4,7	2	30
03 00	15,9	2	30	3,8	2	30
03 01	11,6	2	30	5,1	2	30
03 02	9,4	2	30	5,1	2	30
04 00	11,1	2	30	1,3	2	30
04 01	9,3	2	30	2,6	2	30
04 02	7,4	2	30	2,6	2	30

Table 5.2.2: Investments and operating costs compared to the reference situation

REC MC	Investment (€$_{2000}$)	Q	CI %	Operating costs (€$_{2000}$/y)
01 00	0	-	-	-
01 01	6	3	20	-
01 02	6	3	20	-
02 00	0	-	-	-
02 01	6	3	20	-
02 02	6	3	20	-
03 00	0	-	-	-
03 01	6	3	20	-
03 02	27,8	3	20	-
04 00	0	-	-	
04 01	6	3	20	-
04 02	20	3	20	-

* Operating costs are a mix of different components. See chapter 7.2.2 for further explanations

6 Data to be provided by national experts for the completion of the database or 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

Ø 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)						

Ø 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.

Ø Emissions

National experts do not need to calculate the emissions for individual engine/vehicle categories. The calculations will be done by the RAINS model. However, experts are requested to provide country-specific data for calculations. Below the formulas used and the appropriate coefficients are presented.

Annual SO_2 emissions can be calculated as follows :

$$\textbf{Emissions [t/y]} = 2 \times \textbf{Fuel Consumption (t/y)} \times \textbf{S content (\%)} / 100$$

For other pollutants, two methods can be used to estimate emissions from non road engines:

- Annual emissions per engine of NOx and HC can be calculated with the following equation :

$$\textbf{E [t/y]=Load Factor} \times \textbf{Power [kW]} \times \textbf{Annual use [h/y]} \times \textbf{Emission Factor [g/kWh] / } \mathbf{10^6}$$

Country specific data (engine characteristics) are required for each reference engine :

- Load factor (<1 : gives the average power delivered by the engine),
- Annual use (h/y),
- Operating lifetime (year),

- Consumption method: emission factors are expressed in g of pollutant / GJ using the engine's efficiency.

According to IIASA, engine's efficiency is considered to be about 35% for SI engines. Currently, no better data have been provided.

$$\textbf{E [t/y]= Fuel consumption [GJ/y]} \times \textbf{Emission Factor [g/GJ] / } \mathbf{10^6}$$

This method is used in the RAINS model.

Ø Distribution of engine's sizes

- Distribution of power ranges (% of total activity (fuel use)) has to be determined for the base year 2000 and projection years 2005, 2010, 2015, 2020. This corresponds to data provided in table 6.2.3.

Table 6.2.4: Distribution of the different engine sizes (% of total activity (fuel use))

REC	**Proportion [%] in 2000**	**Proportion [%] in 2005**	**Proportion [%] in 2010**	**Proportion [%] in 2015**	**Proportion [%] in 2020**
01					
02					
03					
04					
Total	**100**	**100**	**100**	**100**	**100**

Ø Number of engines

For cost calculations, number of engines in the base year (2000) is necessary. If this information is available, this should be specified in column 2 of table 6.2.5. Alternatively, data about load factor and annual engine use (columns 3 and 4) should be estimated. In both cases a typical operating lifetime of each engine category (column 5) should be given.

Table 6.2.5: Engine characteristics in the base year 2000

To be completed	Either 2	Or 3 and 4		And 5
Type of engine REC	**Total number of engines**	**Load factor**	**Annual use (h/y)**	**Operating lifetime (years)**
01				
02				
03				
04				

In this document, only average figures are required

Ø Other parameters

Engine characteristics given in Table 6.2.5 are valid for the base year 2000. For other years, two additional parameters should be specified:

- fuel efficiency improvement (Table 6.2.6),
- change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.7).

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

Table 6.2.6: 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 6.2.7: 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	100		100		100		100	

Ø Application rate and applicability

IIASA experts assume a certain lifetime of engines and from this they calculate what proportion of total fuel use will be by vehicles purchased after the date of enforcing of a certain regulation.
Since national experts may have more detailed data, it is worth to ask them about application rates and applicability factors.

Table 6.2.8: 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									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
04 02									
Total REC 04	**100**	**100**		**100**		**100**		**100**	

7 Explanatory notes

7.1 Emission factors

Table 7.1.1: MC 00 (pre-control) emission factors (g/kWh) [15]

REC	NMVOC EF	NOx EF	Q	CI %
01	26,.9	1,8	2	30
02	8,7	3,5	2	30
03	15,9	3,8	2	30
04	11,1	1,3	2	30

For MC 01 and MC 02, NOx and NMVOC standards are given as the sum of both pollutants. Emission factors given in table 7.1.2 come from reference [15] which provides data for all engine types. NOx emission factors are assumed to be higher because of the engine’s adjustments.

Table 7.1.2: MC 01 emission factors (g/kWh)

REC	NMVOC EF	NOx EF	Q	CI %
01	16,1	4,3	2	30
02	7	4,7	2	30
03	11,6	5,1	2	30
04	9,3	2,6	2	30

Table 7.1.3: MC 02 emission factors (g/kWh)

REC	NMVOC EF	NOx EF	Q	CI %
01	16,1	4,3	2	30
02	7	4,7	2	30
03	9,4	5,1	2	30
04	7,4	2,6	2	30

7.1 Derivation of cost data

7.1.1 Investments

In [8], costs are given in $\$_{1995}$. $\$_{2000}$ are calculated from the inflation rate [10]. The following equivalence is used : 1 US$\$_{1995}$ = 1,13 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$ [11]. 1 US$\$_{1995}$ = 1,22 €$_{2000}$.
In [6], costs are given in $\$_{1999}$. $\$_{2000}$ are calculated from the inflation rate [10]. The following equivalence is used : 1 US$\$_{1999}$ = 1,03 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$ [11]. 1 US$\$_{1999}$ = 1,11 €$_{2000}$.

Investments are derived from [8] for MC 01 and from [6] for MC 02. For REC 01 and 02 (classes SN1 and SN2), the same costs are used for MC 01 and 02 because no further reduction of the emissions is required.

Average retail price of equipment that uses non-handheld engines ranges from 100 to 11 000€. According to reference [8], the sales weighted average increase in cost should be around 6€. This value is used for all classes.
According to [6], weighted average increase in costs (compared to stage I) are 21,8 € for REC 03 (class SN3) and 14€ for REC 04 (class SN4).

Table 7.2.1.1: Incremental costs assumed to reach Stage I and Stage II emission limits [€$_{2000}$]

Combination codes REC MC	Investments [€$_{2000}$]	Q	CI %
01 00	0	-	-
01 01	6	3	30
01 02	6	3	30
02 00	0	-	-
02 01	6	3	30
02 02	6	3	30
03 00	0	-	-
03 01	6	3	30
03 02	21,8	3	30
04 00	0	-	-
04 01	6	3	30
04 02	14	3	30

7.2.2 Operating costs

- Fuel consumption variations

According to [8], completion with Stage I is expected to decrease fuel consumption by 26% in average.

For completion with stage II requirements, abatement techniques are believed to cause a decrease in fuel consumption of approximately 15% leading to operating cost savings. Side-valve (SV) engines will be phased-out and replaced with more fuel efficient OHV engines [6].

Table 7.2.2.1: Average fuel consumption variation [%] compared to MC 00

MC	Consumption variation [%]	Q	CI %
00	0	-	-
01	- 26	3	25
02	- 39	3	25

- Additional costs for the use of low sulphur fuel

We assume that petrol used in small SI engines is the same as petrol used in on-road vehicles. Sulfur content of this type of fuel is regulated by Directive 98/70/EC [4] and Directive 2003/17/EC [8] 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 [14]

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

- Maintenance and repair

No quantification is available.

8 References

[1] Final Regulatory Impact Analysis. Phase 2: Emission Standards for New Non-road Non-Handheld Spark-Ignition Engines At or Below 19 Kilowatts. Office of Mobile sources. USEPA. EPA420-R-99-003. March 1999.

[2] Directive 2002/88/EC of the European Parliament and of the Council of 9 December 2002 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.

[3] Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery [Official Journal L 59, 27.02.1998].

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[6] Regulatory announcement. Office of Transportation and Air Quality. EPA420-F-99-008. March 1999.

[7] 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.
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[9] Common meeting. Euromot-CITEPA. March 2003.

[10] http://www.gpec.org/InfoCenter/Topics/Economy/USInflation.html

[11] ECB monthly bulletin.

[12] Exhaust Emission Factors for Nonroad Engine Modeling – Spark ignition. EPA420-R-99-009. Revised March 30, 1999.

[13] Directive 2003/88/EC of the European Parliament and of the Council of 3 March 2003 relating to the quality of petrol and diesel fuels and amending Council Directive 98/70/EC [Official Journal L 76, 27.03.2003].

[14] 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.

[15] Entwicklung eines Modells zur Berechnung der Luftschadstoffemissionen und des Kraftstoffverbrauchs von Verbrennungsmotoren in mobilen Geraten und Maschinen. IFEU. January 2004.

9 Modification compared to the previous document

9.1 Modification in paragraph 5

NMVOC and NOx emission factors have been modified in tables 5.2.1.
Investments have been corrected in table 5.2.2. They are now considered compared to the unabated measure MC00.

9.2 Modifications in paragraph 7

Emission factors have been reviewed on the base of a new report [15] released in 2004 defining specific emission factors for each type of off-road engines. Uncertainties have been reduced.