SMALL NON-HANDHELD 4-STROKE ENGINES

SYNOPSIS SHEET

Prepared in the framework of EGTEI

1. Activity description and EGTEI contribution - summary

4-stroke engines considered in [2] are very common in off-road applications such as lawn mowers, lawn and garden tractors and generators for example.

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).

4-stroke engines have considerably lower VOC 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 fuel combustion within the cylinder of a 4-stroke engine is more efficient than in 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 gasoline sulphur content. TSP emissions are not a big issue for these types of engines. They are not considered in this document as no data has been found.

In RAINS [1], off-road 4-stroke engines are considered either separately or with on-road engines when no country specific data are available. NOx emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 2.9 kt representing only 0.04% of transport emissions. VOC emissions are only 2.3 kt being about 0.05% of transport emissions. These figures do not take into account emissions from all countries as some are considered with on-road emissions.

These engines are addressed by the European Directive 2002/88/EC [3]. Fuels used are also regulated by the Directives 98/70/EC [4] and 2003/17/EC [5]. Only engines rated below 18kW are considered in the Directive because they emit 80% of VOC emissions from small off-road engines (according to an inventory from the European Commission). In order to be able to better represent the impact of these Directives in term of emission reductions and costs, this sector **has been considered as an individual activity by EGTEI [1]**.

The representative unit used is the amount of fuel consumed annually (PJ/year). Four engine sizes are considered as defined in the Directive 2002/88/EC. Two reduction stages per engine type are taken into account as in the regulation.

EGTEI provides default emission factors (EF) with abatement efficiencies, investments as well as unit costs (€/t pollutant abated) for each engine's category. No information has been found concerning variable costs (corresponding to maintenance and repair and defined as a percentage (%) of the investment in RAINS).

National experts have to collect engine specific parameters (either load factor, yearly operating hours and lifetime for each category of engines or annual consumption in GJ/engine) and fuel parameters (annual fuel consumption from 2000 to 2020, types of fuel used according to the year and costs of the fuels used).

In the future, any new stages of the regulation or new technical improvements should be defined with corresponding emission factors and costs. Moreover, national data should be improved so this sector can be specifically represented in terms of emissions and costs.

2. European regulation

Directive 2002/88/EC implements two stages for 4 engine classes according to their size.

Stage I: dates of entering into force of emission limit values for new engines:
- 01-08-2004 for classes SN1 and SN2,
- 11-08-2004 for classes SN3 and SN4.

Table 2.1: Stage I emission limit values

Engine class	HC + NOx [g/kWh]
Class SN 1	50
Class SN 2	40
Class SN 3	16.1
Class SN 4	13.4

Stage II: dates of entering into force of emission limit values for new engines:
- 01-08-2004 for classes SN1 and SN2,
- 01-08-2006 for class SN4,
- 01-08-2008 for SN3.

Table 2.2: Stage II emission limit values (deterioration factor are included)

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 are regulated separately),
- Recreational vehicles as snowmobiles (a majority of these engines are rated above 19 kW).

It is assumed that gasoline used in small SI engines is the same as gasoline 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 [5] relating to the quality of gasoline and diesel fuels.

Table 2.3: Sulphur content of gasoline: standards (ppm) implemented by the Directives

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

3. Methodology developed within EGTEI to represent the sector

3.1 Definition of reference engines for each type of engines

Four engine classes are considered as reference engines. An average nominal output power of 6 kW is taken into account [6] for each of them.

Table 3.1.1: 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

3.2 Definition of emission abatement techniques

According to reference [7], the American market mix is represented as follows:

- Class SN1, SN2, SN3: the majority of engines is produced for the low cost consumer market and is 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.

The regulation on 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 reduction durability will be achieved by refinement of piston profile and improved piston ring.

The use of catalysts is not required for any reference engine. For the time being, detailed data being lacking, only two aggregated measures have been considered to reach the different stages of the EC regulation (see table 3.2.1).

Table 3.2.1: Technology improvements to reach stage I and stage II emission limit values

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

4. Country specific data to be collected

National experts do not have to calculate emissions per vehicle category. Calculations will be done in RAINS. However, experts are requested to provide country-specific data for calculations. The formulas used and the appropriate coefficients are presented below (2 options are available):

- Option I: annual NOx, VOC and TSP emissions per engine can be calculated with the following equation:

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

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).

Option II (consumption method): emission factors are expressed in g of pollutant/GJ using the engine's efficiency. This method is used to estimate emissions in RAINS because it is a simplified approach.

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

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

In this case, only the total fuel consumption and the operating lifetime per size of engines have to be provided.

5. Default emission factors and cost data defined with the EGTEI methodology

Tables 5.1.1 and 5.1.2 give an overview of all data provided by EGTEI: default emission factors (EF), investments and unit costs.

5.1 Reduction of VOC, NOx

To calculate unit costs, annual emissions per engine are first calculated with the equation given in paragraph 4. Then, total investments are annualised (taking into account the engine's lifetimes and an interest rate of 4%). Unit costs for NOx are not calculated because big uncertainties remain on emission factors and investments are incurred to reduce VOC emissions.

Examples of unit costs (only for REC 03 and 04) are given in table 5.1.2 according to different engine characteristics [8].

Table 5.1.1: Emission factors (EF) and investments for each combination

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	Invest. [€/engine]
01 00	26.9	1.8	0
01 01	16.1	4.3	6
01 02	16.1	4.3	6
02 00	8.7	3.5	0
02 01	7	4.7	6
02 02	7	4.7	6
03 00	15.9	3.8	0
03 01	11.6	5.1	6
03 02	9.4	5.1	27.8
04 00	11.1	1.3	0
04 01	9.3	2.6	6
04 02	7.4	2.6	20

* Only investments are taken into account in the calculations

Table 5.1.2: Emission factors (EF), investments and abatement costs for each combination

REC MC	Engine's use	Power rate (kW)	Load factor	Hours in use (h/y)	Unit costs [€/t VOC]*
03 00	Lawn mower/household and gardening	4	0.4	50	0
03 01					1,569
03 02					4,808
03 00	Cement mixer/industry	1.5	0.5	200	0
03 01					837
03 02					2,564
04 00	Other household and gardening	5	0.45	25	0
04 01					5,330
04 02					8,643
04 00	2-wheel tractor	10	0.5	50	0
04 01					1,199
04 02					1,945

5.2 Sulphur content of fuels

Gasoline used in small SI engines is assumed to be the same as the one used in on-road vehicles. Sulphur content of fuel is regulated by Directives 98/70/EC [4] and 2003/17/EC [5] related to the quality of gasoline and diesel fuels.

The different fuel type costs have to be entered only once in ECODAT in the 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. EGTEI proposes two sets of default costs for EU North and EU South. According to reference [9], the main driver of cost difference between north and south EU is the crude oil quality (in particular the sulphur content) handheld in refineries.

Table 5.2.1: Costs of lowering the sulphur content of gasoline [9]

	Min. (€/l)	Max. (€/l)	Average (€/l)
EU. North	0.001	0.003	0.002
EU. South	0.002	0.003	0.0025

6. Relevance of EGTEI information for Integrated Assessment Modelling (IAM)

In RAINS, off-road 4-stroke engines are considered either separately or with on-road engines when no country specific data are available. EGTEI data have not been used and will not be used for the moment.

It would be interesting to distinguish between off-road and on-road engines like it is the case for 2-stroke engines because emission factors, control strategies and costs are very different.

7. Perspective for the future

In the future, any new regulation should be considered by EGTEI in the background document to continuously improve the representation of the sector. This is crucial to well represent this sector in RAINS.

8. Bibliography

[1] Review of data used in RAINS model http://www.iiasa.ac.at/web-apps/tap/RainsWeb/
[2] EGEI background document. http://citepa.org/forums/egtei/small_SI_nonhandheld_engines_4_stroke_final_200803.pdf This background document has been updated and a new version from 01/04/05 will be released.
[3] 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.
[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] 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.
[6] Common meeting. Euromot-CITEPA. March 2003.
[7] 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.
[8] Z. SAMARAS, K.-H. ZIEROCK. Guidebook on the Estimation of the Emissions of “Other Mobile Sources and Machinery. Final Report. September 1994.
[9] 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.
[10] OFEFP- Report n° 136 - p.103

ANNEXE: Example of data collection and use of EGTEI data – Case of France

A. Country specific data collection and scenarios developed

2 and 4-stroke engines are studied together in the following example as they are considered together in the French inventory. It is assumed that all handheld engines are 2-stroke and all non-handheld engines are 4-stroke.

Activity levels are derived from the French national statistics on fuel consumption per sector (after a pre-treatment of the data). Fuel consumption is defined for 2 sub-sectors: agriculture and household applications.

Fuel consumption forecasts are based on a scenario developed by France in June 2004. This exercise is under revision for the CAFÉ programme so data presented in table A.1 are provisional. Gasoline consumption is assumed to decrease from 2010 to 2020. This can be explained by the increasing use of electric lawn mowers for example. These figures have not been validated by the French expert yet. For the years 2005 and 2015, average figures are taken into account.

Table A.1: Gasoline consumptions (PJ / y)

Activity	2000	2005	2010	2015	2020
Agriculture [PJ]	1.15	1.21	1.28	1.28	1.28
Household [PJ]	3.75	3.92	4.08	3.76	3.43
Total [PJ]	4.90	5.13	5.36	5.04	4.71

Fuel parameters for 2000 are based on annual data provided by the French Petroleum association (UFIP).

Table A.2: Fuel parameters

	2000	2005	2010	2015	2020
Gasoline sulphur content (%)	0.015	0.005	0.001	0.001	0.001
Heat value of gasoline [GJ/t]	44	44	44	44	44

Fuel costs should be provided by the French Ministry of economy and industry (MINEFI).

French data are available at different level of detail according to the sub-sector:

Types and number of engines are assumed for the 2 sub-sectors (i.e. agricultural and household). Engine characteristics (load factor, operating hours…) are derived from the reference [8]: this makes it possible to estimate the annual fuel consumption per engine and then the total fuel consumption for 2-stroke and 4-stroke engines. The consumption share is assumed to remain the same from 2000 to 2020 as no detailed data are available.

Table A.4: Share of fuel consumption in 2- and 4-stroke engines [% of total fuel consumption]

	2000	2005	2010	2015	2020
2-stroke engines	23.3	23.3	23.3	23.3	23.3
4-stroke engines	76.7	76.7	76.7	76.7	76.7

Emission factors used in the French inventory are given for two types of engines as an example. Chain saws are representative for 2-stroke engines and lawn mowers for 4-stroke engines.

Unabated emission factors are derived from reference [8] where they are provided in g/kWh per type of engines. As all engine characteristics are also given (load factor, annual consumption of fuel, annual use and average power rate), it is possible to calculate annual emissions. Emission factors in g/GJ are then deduced.

Table A.5: VOC emission factors for 2 types of engines (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	11,837	1,039
Stage I	11,411	726
Stage II	2,289	726

Table A.6: NOx emission factors for 2 types of engines (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	48	325
Stage I	71	319
Stage II	78	319

Table A.7: TSP emission factors for 2 types of engines (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	220	30
Stage I	220	30
Stage II	220	30

These emission factors are consistent with data provided in the EGTEI document. They are not exactly the same because EGTEI emission factors are given as average figures for each engine category: in the French inventory, engines are considered separately. TSP emissions are also considered for 4-stroke engines [10] even if these emissions are not taken into account in some references.

The control strategy is defined by considering average lifetime of each engine's category (between 7 and 15 years according to the use) and by considering different dates of entry into force for the two abatement stages as defined in the regulation.

This is not further developed in this synopsis sheet because of the complexity of this exercise and for confidentiality reasons. Average emission factors for the totality of the fleet and corresponding emissions are presented in paragraph B bellow.

B. Trends in emission factors and emissions

Emissions are calculated with a simplified approach by considering average emission factors and control strategies for each type of engine.

Table B.1: Emission factors evolving with the control strategy

REC	2000	2005	2010	2015	2020
NMVOC (g/GJ)	3,620.5	3,576.7	2,837.4	2,125.8	1,452.5
NOX (g/GJ)	241.8	243.2	253.2	252.4	250.1
TSP (g/GJ)	74.6	74.9	75.3	78.0	80.9
SO_2 (g/GJ)	6.8	2.3	0.5	0.5	0.5

Emissions are presented in table B.2.

Table B.2: Emissions from 2000 to 2020 for gasoline engines (2- and 4-stroke)

REC	2000	2005	2010	2015	2020
NMVOC (kt)	17.74	18.35	15.22	10.71	6.84
NOX (kt)	1.18	1.25	1.36	1.27	1.18
TSP (kt)	0.37	0.38	0.40	0.39	0.38
SO_2 (kt)	0.033	0.012	0.003	0.003	0.002

NMVOC and SO_2 emissions will be dramatically reduced. NOx and TSP emissions remain constant but this is not a big issue in this sector.