RECREATIONAL CRAFTS

SYNOPSIS SHEET

Prepared in the framework of EGTEI

1. Activity description and EGTEI contribution - summary

According to ICOMIA (International Council of Marine Industries Association) Statistics, 1997, the European Union with non-EU member's countries accounts for 36% of the world output of pleasure boats. The exhaust emissions from recreational crafts depend on the engine types and their rated power.

Three types of engines are studied in the EGTEI background document [1]:

2-stoke spark ignition (SI) engines (outboard engines + personal water crafts):

2-stroke SI engines are normally used as outboard engines in power ratings from 1.5 up to 200 kW. The advantages of this type of engines are the good relation between engine weight and power output combined with low price. Petrol 2-stroke engines in general suffer from high unburned NMVOC-emissions because of high scavenge losses: between 25 to 40% of petrol input. CO emissions are also very high. On the other hand, NOx emissions are relatively low because of the rich mixture and of the natural exhaust gas recirculation which lowers combustion peak temperature.

4-stoke spark ignition (SI) engines (majority of outboard engines + inboard motors):

4-stroke engines are used as outboard engines as well as inboard engines. They typically have higher cost and weight as 2-stroke engines for the same rated power. Outboard engines are usually rated between 2 to 75 kW (can be up to 200 kW for some engines) and inboard engines are rated up to 400 kW. Their NMVOC emissions represent about 5 to 10% of 2-stroke engine emissions.

Compression ignition engines (CI) (inboard motors):

These engines are normally used as inboard engines rated between 5 to 500 kW. NOx emissions are high because of high combustion temperatures. PM emissions are also higher than those of SI engines. NMVOC emissions are of lower concern for compression ignition engines.

In RAINS, recreational watercrafts and inland waterways are considered together. Emissions given hereafter are then total emissions for both sub-sectors. At a EU25 level for the year 2000 (according to the RAINS model: version CP_CLE_Aug04(Nov04)), NOx emissions for diesel engines were 96.6 kt representing 1.4% of NOx emissions from mobile sources and 13.2 kt of NMVOC being about 0.3% of NMVOC emissions from mobile sources. For gasoline engines, NOx emissions were about 10 kt and NMVOC emissions 9 kt.

Recreational crafts are addressed by the European Directive 2003/44/EC [2]. Fuels used are also regulated by the Directives 98/70/EC [3] and 2003/17/EC [4]. In order to be able to better represent the impact of these Directives in terms of emission reductions and costs, this sector **has been considered as an individual activity by EGTEI [1]**. It was and is still considered together with inland waterways in RAINS [5], [6] though. No modification has been made (even if a specific **methodology was defined by EGTEI) because of a lack of detail information at the European level.** In RAINS, emission factors (expressed in g/GJ) are the same than for other engines.

The representative unit used is the amount of fuel consumed annually (GJ/year). For each of the three engine types defined above, different sizes are considered when it is necessary to properly represent the costs.

One stage per engine type is taken into account as in the regulation. For 2-stroke engines, an additional abatement measure has been defined to study further emission reductions.

EGTEI provides default emission factors (EF) with abatement efficiencies, investments as well as unit costs (€/t pollutant abated) for each engine 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).

EGTEI data have not been introduced in RAINS and this will be the case as long as no detail country specific data will be provided by national experts.

In the future, any new stage 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

The European Directive 2003/44/EC regulates exhaust emissions from recreational crafts [2]. Engines have to comply from 2006 onwards with the following emission levels presented in 2.1:

Table 2.1: Emission limit values (g/kWh)

Engine type	CO (g/kWh) CO = A +B/P^n_N			VOC (g/kWh) VOC = A +B/P^n_N			NOx [g/kWh]	PM [g/kWh]
	A	B	n	A	B	n		
2-stroke	150	600	1	30	100	0.75	10	Not Appl.
4-stroke	150	600	1	6	50	0.75	15	Not Appl.
CI	5	0	0	1,5	2	0.5	9.8	1

Not Appl.: Not Applicable

Where A, B and n are constants in accordance with table 2.1, P_N is the rate engine power in kW and the emissions are measured in accordance with the harmonised standards.

The current EU Directive 2003/44/EC requires the European Commission to submit a report by 2007 to the EU Parliament and Council on the possibilities to further reduce the limit values. For CI engines, the future emission limits are likely to be aligned with the US EPA Recreational Marine Rule and the amendment to 97/68/EC (inland waterway vessels). For SI engines the emission reduction will depend on the future development in the US. The US South West Research Institute is currently undertaking catalyst test on petrol stern drive engines. However, the potential emission reduction for SI engines is not yet known.

Two fuel types can be used: diesel and gasoline.

Table 2.2: Regulations on sulphur content of fuels

Directives	Scope	Exemptions
98/70/EC [3] *2003/17/EC [4]*	Quality of petrol and diesel fuels	-

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

Fuels	2000	2005	2008
Diesel	350	50	10
Gasoline	150	50	10

3. Methodology developed within EGTEI to represent the sector

3.1 Definition of reference engines for each type of engines

3.1.1 2-stroke SI engines

Four engine categories are defined in reference [7] for the cost calculation. These definitions are presented in table 3.1.1.1: three categories are defined for outboard motors and one for Personal Water Crafts (PWC).

Table 3.1.1.1: Reference engines for 2-stroke SI engines

Reference Engine Code (REC)	Nominal engine power [kW]
01	6 representing the range 1.5-11 kW outboard
02	44 representing the range 14.7-73.6 kW outboard
03	122 representing the range 85-220 kW outboard
04	88 representing the range 59-118 kW for PWC

3.1.2 4-stroke SI engines

The same ranges as for 2-stroke engines are considered in table 3.1.2.1. Outboard 4-stroke engines represent the big majority of this category. As 4-stroke inboards motors are very few, they are not considered hereafter.

Table 3.1.2.1: Reference engine for 4-stroke SI engines

Reference Engine Code (REC)	Nominal engine power [kW]
01	6 representing the range 1.5-11 kW outboard
02	44 representing the range 14.7-73.6 kW outboard
03	122 representing the range 85-220 kW outboard

3.1.3 CI engines

Three engine ranges are defined in reference [7] for the cost calculation. These definitions are used in table 3.1.3.1.

Table 3.1.3.1: Reference engines for CI engines

Reference Engine Code (REC)	Nominal engine power [kW]
01	35 kW representing the range 5-70 kW
02	160 kW representing the range 70-250 kW
03	375 kW representing the range 250-500 kW

3.2 Definition of emission abatement techniques

3.2.1 2-stroke SI engines

Abatement techniques correspond to the conversion of “old-technology” 2-stroke engines to DI 2-stroke engines. As the use of catalytic converters has to be studied by the European Commission (c.f. chapter 2), this technique is presented in this document. It is added on top of measure 01.

Table 3.2.1.1: Abatement measure definition

Measure codes (MC)	Description
00	None
01	Conversion to DI 2-stroke engine
02	01 + use of a catalytic converter

3.2.2 4-stroke SI engines

Abatement techniques correspond to the conversion of “old-technology” 4-stroke engines to cleaner 4-stroke engines.

Table 3.2.2.1: Abatement measure definitions

Measure codes (MC)	Description
00	None
01	Conversion to cleaner 4-stroke engines

3.2.3 CI engines

A mix of techniques allowing reaching stage I requirements is defined for CI engines.

Table 3.2.3.1: Abatement measure definitions

Measure codes (MC)	Description
00	None
01	Mix of techniques to reach the Directive requirements

4. Country specific data to be collected

National experts do not have to calculate emissions per engine 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 [6], engine's efficiency is considered to be about 40% for diesel engines and 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.

Default values for all types of use according to references [7] and [8] are presented hereafter.

Table 4.1: Default values provided for gasoline engines

Parameters	Default values
Load factor	0.2144
Annual usage of outboard [h/y]	35
Operating lifetime [years]	10

Table 4.2: Default values provided for CI engines

Parameters	Default values
Load factor	0.3425
Annual usage of outboard [h/y]	48
Operating lifetime [years]	10

These data have been used to calculate annual emissions per engine and then unit costs presented in paragraph 5.

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

Tables below give an overview of all data provided by EGTEI: default emission factors (EF), investments as well as unit costs per t pollutant abated.

5.1 Reduction of VOC, NOx and TSP

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 engine lifetimes and an interest rate of 4%) to calculate abatement costs for the three pollutants.

When the technique does not reduce a pollutant, no abatement cost is calculated.

5.1.1 2-stroke engines

No information is given for combinations 0101 and 0102 because small 2-stroke engines will be replaced by 4-stroke engines to comply with the Directive's requirements [8]. Uncontrolled emission factors come directly from reference [9] as they were given in g of VOC/GJ in the EGTEI document [1]. All EF are given in the same unit g/kWh (EGTI background document has been updated).

Table 5.1.1.1: Emission factors (EF), investments and abatement costs for each combination

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	TSP EF [g/outp.kWh]	Invest. [€/engine]	Unit costs [€/t VOC]*	Unit costs [€/t NOx]*	Unit costs [€/t TSP]*
01 00	-	-	-	-	-	-	-
01 01	-	-	-	-	-	-	-
01 02	-	-	-	-	-	-	-
02 00	172	10	5	0	0	-	-
02 01	35.8	10	5	1,060	2,906	-	-
02 02	17.9	10	5	1,295	3,138	-	-
03 00	172	10	5	0	0	-	-
03 01	32.7	10	5	3,355	3,244	-	-
03 02	16.3	10	5	3,945	3,412	-	-
04 00	172	10	5	0	0	-	-
04 01	33.5	10	5	4,990	6,727	-	-
04 02	16.7	10	5	5,430	6,528	-	-

* Only investments are taken into account in the calculations

Unit costs for REC 04 are much higher than for other engines because investments are proportionally higher for a given power rate.

According to reference [9], NOx emission factors seem to be overestimated in the EGTEI background document [1]. NOx EF would be between 2 and 4 g/kWh. This issue needs to be studied in more detail before being validated.

5.1.2 4-stroke engines

Uncontrolled emission factors come directly from reference [9] as they were given in g of VOC/GJ in the EGTEI document [1].

Table 5.1.2.1: Emission factors (EF), investments and abatement costs for each combination

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	TSP EF [g/outp.kWh]	Invest. [€/engine]	Unit costs [€/t VOC]*	Unit costs [€/t NOx]*	Unit costs [€/t TSP]*
01 00	24.0	15	1	0	0	-	-
01 01	19.0	15	1	221	121,035	-	-
02 00	14	15	1	0	0	-	-
02 01	9.0	15	1	1,257	93,875	-	-
03 00	14	15	1	0	0	-	-
03 01	7.4	15	1	3,971	81,028	-	-

* Only investments are taken into account in the calculations

Unit costs are very high because annual VOC emissions from 4-stroke engines are relatively low.

According to reference [9], NOx emission factors seem to be overestimated in the EGTEI background document [1]. NOx EF would be between 5 and 10 g/kWh. These issues need to be studied in more detail before being validated.

5.1.3 CI engines

Uncontrolled emission factors come directly from reference [9] as they were given in g of VOC/GJ in the EGTEI document [1]. NOx EF for stage I come also from reference [9] which seems to be more realistic. TSP EF are very low and are assumed to be reduced by about 30% after compliance with stage I [2].

Table 5.1.2.1: Emission factors (EF), investments and abatement costs for each combination

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	TSP EF [g/outp.kWh]	Invest. [€/engine]	Unit costs [€/t VOC]*	Unit costs [€/t NOx]*	Unit costs [€/t TSP]*
01 00	2.2	18	1	0	0	0	0
01 01	1.8	7.8	0.7	550	12,324	314,263	444,187
02 00	2.0	8.6	1	0	0	0	0
02 01	1.6	7.8	0.7	667	42,309	84,619	119,603
03 00	2.0	8.6	1	0	0	0	0
03 01	1.6	7.8	0.7	1,148	30,611	61,222	86,533

* Only investments are taken into account in the calculations

Unit costs are very high for VOC and TSP because this stage focuses on NOx emission reduction. The other pollutants are reduced because of the combustion improvement.

5.2 Sulphur content of fuels

Fuels used have to be defined with their sulphur content and their cost from 2000 to 2020.

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

In RAINS, recreational crafts are considered together with inland waterways. Diesel and gasoline engines are defined separately.

Data developed in the EGTEI background document [1] have not been introduced because of a lack of country specific detail information. If relevant country data were provided to CIAM, recreational engines could also be studied separately. This does not have a big influence on emissions as abatement efficiencies are pretty similar among sectors but it might have an influence on unit costs (as recreational crafts run very few hours per year) if engine particularities are not considered the RAINS (this could be done by using different annual consumptions per engine for example).

This is then very important for national experts to fill in EGTEI spreadsheet with detail information to facilitate the discussion during the bilateral consultations with CIAM.

7. Perspective for the future

In the future, any new regulation should be taken into account in the RGTEI background document to continuously improve the representation of the sector. The use of catalytic converters is already studied for 2-stroke engines but the costs should be updated when new studies will be released.

Emission factors and country specific parameters should also be reviewed as new reports have been released.

8. Bibliography

[1] EGEI background document. http://citepa.org/forums/egtei/recreational_craft_081203.pdf This background document has been updated and a new version from 01/04/05 will be released.

[2] Directive 2003/44/EC of the European Parliament and of the Council of 16 June 2003 amending Directive 94/25/EC on the approximation of the laws, regulations and administrative provisions of the Member States relating to recreational craft.

[3] 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].

[4] 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.

[5] 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.

[6] Review of data used in RAINS model http://www.iiasa.ac.at/web-apps/tap/RainsWeb/

[7] Proposal for a Directive of the European Parliament and of the Council modifying Directive 94/25/EC on the approximation of the law, regulations and administrative provisions of the Member States relating to recreational craft. COM(2000)639 final, Brussels, 12.10.2000.

[8] ICOMIA: International Council of Marine Industries Association.

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

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

A. Country specific data collection and scenarios developed

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

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. 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: Fuel consumptions (PJ / y)

Activity	2000	2005	2010	2015	2020
Gasoline [PJ]	6.3	7.4	8.6	9.2	9.9
Diesel [PJ]	11.1	16.0	20.8	22.4	24.1

Fuel parameters for 2000 are based on annual data provided by the French Petroleum association (UFIP). In France, it is assumed that half of the diesel consumed corresponds to road quality diesel and the other half to gas-oil. Diesel sulphur content is an average of these 2 types of fuels.

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
Diesel sulphur content (%)	0.1175	0.1025	0.0505	0.0505	0.0505
Heat value of diesel [GJ/t]	42	42	42	42	42

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:

The number of each engine type of is not known in France. No enquiry has been made on this subject. It is only assumed that half of gasoline engines are 2-stroke and the other half are 4-stroke. Emission factors and emissions are derived from this assumption.

Control strategies shown in the following tables are calculated by considering an average lifetime of 10 years for all engines. 10% of the fleet is replaced each year: 4-stroke and CI engines replaced after the end of 2005 have to comply with the stage I emission limit values. For 2-stroke engines, the date is 2006. This makes it possible to define the control strategy from 2000 to 2020.

Table A.4: Application rates of stages I and II (% of activity) for 2-stroke engines

REC	2000	2005	2010	2015	2020
None	100	100	60	10	0
Stage I	0	0	40	90	100
Stage II	0	0	0	0	0
Total	100	100	100	100	100

Table A.5: Application rates of stage I (% of activity) for 4-stroke engines

REC	2000	2005	2010	2015	2020
None	100	100	50	0	0
Stage I	0	0	50	100	100
Total	100	100	100	100	100

Table A.6: Application rates of stage I (% of activity) for CI engines

REC	2000	2005	2010	2015	2020
None	100	100	50	0	0
Stage I	0	0	50	100	100
Total	100	100	100	100	100

B. Trends in emission factors and emissions

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

Uncontrolled emission factors in g/GJ provided in the EGTEI background document [1] are directly used in the French emission inventory. Emission factors corresponding to stage I requirements are calculated by using abatement efficiencies defined in the Directive proposal [7].

Table B.1: Emission factors evolving with the control strategy for gasoline engines (2 and 4-stroke)

REC	2000	2005	2010	2015	2020
NMVOC (g/GJ)	5,743.2	5,743.2	3,639.5	1,083.8	631.8
NOX (g/GJ)	143.2	143.2	143.2	143.2	143.2
TSP (g/GJ)	146.1	146.1	146.1	146.1	146.1
SO_2 (g/GJ)	6.8	2.3	0.5	0.5	0.5

Table B.2: Emission factors evolving with the control strategy for CI engines

REC	2000	2005	2010	2015	2020
NMVOC (g/GJ)	102	102	90.2	78.4	78.4
NOX (g/GJ)	1,174	1,174	990.9	807.7	807.7
TSP (g/GJ)	107	107	91.3	75.5	75.5
SO_2 (g/GJ)	55.9	48.7	24.2	24.2	24.2

Emissions are presented in tables B.3 and B.4.

Table B.3: Emissions from 2000 to 2020 for gasoline engines (2 and 4-stroke)

REC	2000	2005	2010	2015	2020
NMVOC (kt)	36.2	42.6	31.1	10.1	6.3
NOX (kt)	0.90	1.06	1.22	1.32	1.42
TSP (kt)	0.92	1.08	1.25	1.35	1.45
SO_2 (kt)	0	0	0	0	0

Table B.4: Emissions from 2000 to 2020 for CI engines

REC	2000	2005	2010	2015	2020
NMVOC (kt)	1.1	1.6	1.9	1.8	1.9
NOX (kt)	13.1	18.7	20.6	18.1	19.5
TSP (kt)	1.2	1.7	1.9	1.7	1.8
SO_2 (kt)	0.62	0.78	0.50	0.54	0.58