Final Background Document
on the sector

Off Road
RECRATIONAL CRAFT
(2-stroke, 4-stroke and compression ignition engines)

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Recreational craft

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 [1].
Three types of engines are studied in this report:

- 2-stoke spark ignition (SI) engines (outboard engines + personal water crafts),
- 4-stoke spark ignition (SI) engines (majority of outboard engines + inboard motors),
- Compression ignition engines (CI) (inboard motors).

Market shares of the different types of engines sold in Europe are presented in table 1.

According to [3], outboards recreational marine engines represent around 70% of the market. The shares of 2 and 4-stroke outboards are derived from the figures provided in reference [3]. Other shares come from the treatment of figures provided in reference [1].

Tableau 1: Market shares (% of total number of engines in use)

Types of engine	European market share [%]
Outboard engines (2 stroke)	40
Outboard engines (4 stroke)	30
Inboard CI engines	20
Inboard SI engines (4-stroke)	3
Personal watercraft (2-stroke)	7

Tableau 2: Shares of 2- and 4-stroke engines for the different categories of engine's sizes as considered in this report (% of total number of engines in use)

Engine categories	Type of engine	Shares as a % of number of engines in use
1,5-11 kW	2-stroke	62
	4-stroke	38
14,7-73,6 kW	2-stroke	49
	4-stroke	51
85-220 kW	2-stroke	84
	4-stroke	16

ACTIVITY: consumption of fuel (PJ / year)
POLLUTANTS CONSIDERED: VOC, NOx, SO_2, PM

1. Data from the bibliography

1.1 Data currently used in the RAINS model [11]

In the current version of RAINS, recreational engines are not considered separately.
Hereafter, data corresponding to Inland navigation are presented.

These data are just presented for comparison reasons.

Data are derived from reference [11].

- Activity

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

Ø Emission factors

Table 1.1.1: Unabated emission factors used in the RAINS PM module for inland navigation

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]	TSP [g/kWh] *
Inland navigation	0,105	111	117	1,05

* Coefficient expressed in g/kWh was calculated from the coefficient in g/GJ assuming 40% efficiency of diesel engine.

Ø Engine considered

Table 1.1.2: Sector considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_INW	Inland navigation

Ø Techniques and associated costs

Rail and inland waterways are studied together in the current stage of development of RAINS.

Table 1.1.3: Cost parameters for control technologies used in rail and inland waterways

Technology	Unit investment [€/vehicle]	Fixed O+M [%]
1998, as EURO I for HDV	1 716	7,8
2000/02, as EURO II for HDV	5 148	3,9
As EURO III for HDV	11 575	2,9
As EURO IV for HDV	20 714	2,5
As EURO V for HDV	23 015	2,4
As Euro VI for HDV	24 575	2,4

1.2 Situation in Norway [12]

According to reference [12], the NMVOC emissions from outboards boat motors were about 2% of the total NMVOC emissions in Norway. One of the measures presented in the report is to introduce exhaust requirements for outboard boats motors.
It was assumed that these requirements could take effect in Norway in 1998, the full impact of this measure being achieved by 2018. CO and CO_2 will also be reduced, whereas the NOx emissions will increase.
The operating expenditures will be reduced as a result of reduced petrol expenses.

2. Short technology description

The exhaust emissions from recreational crafts depend on the types of engine and their rated power.
The proposal [1] distinguishes between the following three groups: each group has been split into sub-categories according to the engine rated power.

2.1 2-stroke engines

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 VOC-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.

2.2 4-stroke engines

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 VOC emissions represent about 5 to 10% of 2-stroke engines VOC emissions.

2.3 Compression ignition engines

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.
VOC emissions are of lower concern for compression ignition engines.

3. European regulation

3.1 Emission levels

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 3.1.1:

Table 3.1.1: 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 3.1.1, P_N is the rate engine power in kW and the emissions are measured in accordance with the harmonised standards.

3.2 Further reduction of exhaust limit values

The current EU emissions 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 [3].

3.3 Sulphur content of fuels

Two types of fuels can be used: diesel and petrol.

Table 3.3.1: Regulations on sulphur content of fuels

Directives	Scope	Exemptions
98/70/EC [5] *2003/17/EC [6]*	Quality of petrol and diesel fuels	-

Table 3.3.2: Sulphur content of fuels: standards (ppm) implemented by the Directives

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

4. 2 stroke spark ignition (SI) engines

4.1 Definition of Reference engines and techniques

Four categories of engines are defined in reference [1] for the cost calculation. These definitions are used in table 4.1.1: three categories are defined for outboard motors and one for Personal Water Crafts (PWC).

Table 4.1.1: 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

Abatement techniques correspond to the conversion of “old-technology” 2-stroke engines to DI 2-stroke engines as defined in table 4.1.2.
As the use of catalytic converters has to be studied by the European Commission (see chapter 3.2), this technique is presented in this document. It is added on top of measure 01.

Table 4.1.2: Abatement measure definition

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

4.2 Data to be provided by national experts for the completion of the data basis for their own country

The following tasks are required:

4.2.1 Validation work

Tables to be filled in by national experts

Ø Fuel parameters

Table 4.2.1.1: Fuel parameters

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

Table 4.2.1.2: Fuel prices (net of taxes)

	Fuel prices [(€$_{2000}$ / l]
Petrol 150 ppm sulphur (€$_{2000}$/l)	
Petrol 50 ppm sulphur (€$_{2000}$/l)	
Petrol 10 ppm sulphur (€$_{2000}$/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 intervals.

Table 4.2.1.3 : Fuel consumption [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 document 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:

Emissions [t/y] = 2 × Fuel Consumption (t/y) × S content (%) / 100

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

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

E [t/y]=Load Factor × Power [kW] × Annual use [h/y] × Emission Factor [g/kWh]/10^6

Country specific data (engine characteristics) are required for each type of engines:
- 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 [11], engine's efficiency is considered to be about 35% for petrol engines. Currently, no better data have been provided.

E [t/y]= Fuel consumption [GJ/y] × Emission Factor [g/GJ] / 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.

Table 4.2.1.4: 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 4.2.1.5. 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 4.2.1.5: 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				

Table 4.2.1.6: Default values provided in references [1] and [3]

Parameter	**Default value**
Load factor	0,2144 [3]
Annual usage of outboard [h/y]	35 [3]
Operating lifetime [years]	10 [1]

Ø Other parameters

Engine characteristics given in Table 4.2.1.5 are valid for the base year 2000. For other years, two additional parameters should be specified:

- Fuel efficiency improvement (Table 4.2.1.7),
- Change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 4.2.1.8).

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

Table 4.2.1.7: 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 4.2.1.8: 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	

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 4.2.1.9: 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**	

4.3 Explanatory notes

4.3.1 Emission abattement technique [7]

Ø Current technology
The current technology for outboard and personal watercraft engines is predominantly crankcase fuel/air/oil scavenged two-stroke. After combustion of the air/fuel/oil mixture, the resulting exhaust gases are “pushed” or “scavenged” from the cylinder by the crankcase air/fuel/oil charge.
Thus a portion of the air/fuel/oil charge exits the cylinder along with the exhaust gases resulting in extremely high hydrocarbon emission levels. Up to 25-30 percent of the fuel consumed by such engines can exit the cylinder unburned.

Ø Potential emission technology
Direct injection 2-stroke technology reduces significantly hydrocarbons emissions. Fuel is injected directly into the combustion chamber, thus avoiding the air/fuel/oil scavenging losses inherent with current 2-stroke engines. Fuel economies are also achieved.

EPA [7] estimates that the two primary technologies which will be used to meet the emission reductions required by the regulation (i.e. conversion to 4-stroke and DI 2-stroke) will both result in an increase in the level of NOx produced by outboard and PWC engines.

Ø Catalytic converters
The use of catalytic converters on new motorised equipments is presented in [12]. They are assumed to reduce VOC emissions by 50%.

4.3.2 Emission factors

Emission factors for the baseline are reported from reference [4] for VOC and NOx and from [8] for PM. EF are provided in g/kg of fuel. They have been converted in g/GJ.
They are also given in g/kWh. VOC emission factor comes from an IFEU report from January 2004 [14]. PM emission factor come from reference [8] and NOx emission factor is assumed to remain constant. According to [14], NOX EF vary between 2 and 4 but this has to be checked before taking it into account.
No emission factors are 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 [3].

Table 4.3.2.1: MC 00 (baseline) emission factors (g/GJ) for 2-stroke engines

Pollutants	Emission factors [g/GJ]	Emission factors [g/kWh]	Q	CI %
VOC	10 159	172	3	30
NOx	54,5	10	3	30
PM	227	5	2	40

New emission limits are used as in-use emission factors for controlled engines. They are calculated from the equations given in the Directive [2] with nominal engine power defined in table 4.1.1.

Table 4.3.2.2: MC 01 emission factors (g/kWh)

Pollutants	REC				Q	CI %
	01	02	03	04		
VOC	-	35,8	32,7	33,5	3	30
NOx	-	10	10	10	3	30
PM	-	5	5	5	2	40

Table 4.3.2.3: MC 02 emission factors (g/kWh)

Pollutants	REC				Q	CI %
	01	02	03	04		
VOC	-	17,9	16,3	16,7	3	30
NOx	-	10	10	10	3	30
PM	-	5	5	5	2	40

4.4 Costs

4.4.1 Investments

For 2-stroke manufacturers converting to 4-stroke models, prior investment in new machine tools has to be made since the construction of 4-stroke engines is entirely different from that for 2-strokes. For old-technology 2-stroke engines converting to direct-injected 2-strokes, the previous simple carburettor system has to be changed to high pressure computer controlled fuel/air management systems with newly designed crank cylinder assemblies.

Costs for catalytic converters are derived from reference [13]. They cost about 400 NOK for small engines (about 4 kW). This corresponds to about 50 € for a small engine. For bigger engines, as no data are available, costs are assumed to be proportional to the amount of pollutants released.

Table 4.4.1.1: Investments for catalytic converters

REC	Investment [€]	Q	CI%
01	-	-	
02	235	1	50
03	590	1	50
04	440	1	50

Investments for the different measures are presented in table 4.4.1.2.

Table 4.4.1.2: Cost calculation for Outboard motors and personal Watercraft [1]

REC PM	Investment [€]	Q	CI%
01 00	-	-	-
01 01	-	-	-
01 02	-	-	-
02 00	0	-	-
02 01	1 060	4	20
02 02	1 295	1	40
03 00	0	-	-
03 01	3 355	4	20
03 02	3 945	1	40
04 00	0	-	-
04 01	4 990	4	20
04 02	5 430	1	40

4.4.2 Operating costs

Ø Fuel consumption

New technology will lead to 30% improvement in fuel consumption figures for MC 01.

Ø Maintenance and repair

No data are currently available on the subject.

5. 4 stroke spark ignition (SI) engines

5.1 Definition of Reference engines and techniques

The same ranges as for 2-stroke engines are considered in table 5.1.1. Outboards 4-stroke engines represent the big majority of this category. As 4-stroke inboards motors are very few, they are not considered hereafter.

Table 5.1.1: 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

Abatement techniques correspond to the conversion of “old-technology” 4-stroke engines to cleaner 4-stroke engines as defined in table 5.1.2.

Table 5.1.2: Abatement measure definitions

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

5.2 Data to be provided by national experts for the completion of the data basis for their own country

The following tasks are required:

5.2.1 Validation work

Tables to be filled in by national experts

Ø Activity level

Table 5.2.1.1 : Fuel consumption [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 document Methodology.

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.

Table 5.2.1.2: 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					
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 5.2.1.3. 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 5.2.1.3: 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				

Table 5.2.1.4: Default values provided in references [1] and [3]

Parameter	Default value
Load factor	0,2144 [3]
Annual usage of outboard [h/y]	35 [3]
Operating lifetime [years]	10 [1]

Ø Other parameters

Engine characteristics given in Table 5.2.1.3 are valid for the base year 2000. For other years, two additional parameters should be specified:
- Fuel efficiency improvement (Table 5.2.1.5),
- Change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 5.2.1.6).

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

Table 5.2.1.5: 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 5.2.1.6: 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	

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 5.2.1.7: 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									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
Total REC 03	**100**	**100**		**100**		**100**		**100**	

5.3 Explanatory notes

5.3.1 Emission factors

Emission factors for the baseline are reported from reference [4] for VOC and NOx and from [8] for PM. EF are provided in g /kg of fuel. They have been converted in g/GJ.
They are also given in g/kWh. VOC emission factors come from an IFEU report from January 2004 [14]. PM emission factor come from reference [8] and NOx emission factor is assumed to remain constant. According to [14], NOX EF vary between 5 and 10 but this has to be checked before taking it into account.

Table 5.3.1.1: MC 00 (baseline) emission factors (g/GJ) for 4-stroke engines

Pollutant	Emission factor [g/GJ]	Emission factor [g/kWh]	Q	CI %
VOC	1 327	14 to 24 according to the rated power	3	30
NOx	231,8	15	3	30
PM	65	1	2	40

New emission limits are used as in-use emission factors for the three categories of controlled engines.

Table 5.3.1.2: MC 01 emission factors (g/kWh) for 4-stroke engines

Pollutants	REC			Q	CI %
	01	02	03		
VOC	19	9	7,4	3	30
NOx	15	15	15	3	30
PM [8]	1	1	1	2	40

5.4 Costs

5.4.1 Investments

Costs given in table 5.4.1.1 are derived from reference [1].

Table 5.4.1.1: Cost for Outboard motors [1]

REC PM	Investment [€]	Q	CI%
01 00	0	-	-
01 01	221	4	20
02 00	0	-	-
02 01	1 257	4	20
03 00	0	-	-
03 01	3 971	4	20

5.4.2 Operating costs

- Ø Fuel consumption

No fuel saving is considered for this category of engines.

- Ø Maintenance and repair

No data are currently available on the subject.

6. Compression ignition (CI) engines

6.1 Definition of Reference engines and techniques

Three ranges of engines are defined in reference [1] for the cost calculation. These definitions are used in table 6.1.1.

Table 6.1.1: 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

Table 6.1.2: Abatement measure definitions

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

6.2 Data to be provided by national experts for the completion of the data basis for their own country

The following tasks are required:

6.2.1 Validation work

Tables to be filled in by national experts

Ø Activity level

Table 6.2.1.1 : Fuel consumption [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 %
Diesel 350 ppm sulphur										
Diesel 50 ppm sulphur										
Diesel 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 document Methodology.

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 6.2.1.2. 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 6.2.1.2: 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				

Table 6.2.1.3: Default values provided in references [1] and [3]

Parameter	Default values
Load factor	0,3425 [3]
Annual usage of outboard [h/y]	48 [3]
Operating lifetime [years]	10 [1]

Ø Other parameters

Engine characteristics given in Table 6.2.1.2 are valid for the base year 2000. For other years, two additional parameters should be specified:

- Fuel efficiency improvement (Table 6.2.1.4),
- Change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.1.5).

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

Table 6.2.1.4: 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	

Table 6.2.1.5: 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	98		96		94		92	
03	100	98		96		94		92	

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 6.2.1.6: 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									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
Total REC 03	**100**	**100**		**100**		**100**		**100**	

6.3 Explanatory notes

6.3.1 Emission abatement techniques [10]

Ø Potential emission technology

According to [10], recreational marine engines will be able to use technology developed for commercial marine engines.

Timing retard should likely be used in most CI recreational marine applications to gain NOx reductions. The negative impacts of timing retard on VOC, PM and fuel consumption can be offset with advanced fuel injection systems with higher fuel injection pressures, optimised nozzle geometry, and potentially through rate shipping.

Electronic controls should be more used by manufacturers leading to VOC, CO, NOx and PM emission reduction.

Finally, according to [10], all CI recreational engines will be turbocharged and most will be aftercooled to meet proposed emission standards.

6.3.2 Emission factors

Emission factors for the baseline are reported from reference [4] for VOC and NOx. The PM emission factor for Inland waterways is used [9]. EF are provided in g/kg of fuel. They have been converted in g/GJ.

They are also given in g/kWh. VOC and NOx emission factors come from an IFEU report from January 2004 [14]. PM emission factor is roughly calculated from the one given in g/GJ taken into account a 40% engine efficiency. However, NOx emissions from CI engines are considered to be very small.

Table 6.3.2.1: MC 00 (baseline) emission factors (g/GJ) for CI engines

Pollutants	Emission factors [g/GJ]	Emission factors [g/kWh]	Q	CI %
VOC	102	2 to 2,2 according to the rated power	3	30
NOx	1 174	8,6 to 18	3	30
PM	107	1	2	40

New VOC emission limits are defined as in-use emission factors for controlled engines. For NOx controlled emission factors, reference [14] is considered because it is more consistent with uncontrolled EF. For PM, an abatement efficiency of 30% is assumed with stage I [1].

Table 6.3.2.2: MC 01 emission factors (g/kWh)

Pollutants	REC			Q	CI %
	01	02	03		
VOC	1,8	1,6	1,6	2	40
NOx	7,8	7,8	7,8	3	30
PM	0,7	0,7	0,7	2	40

6.4 Costs

6.4.1 Investments [1]

Reference [1] presents additional costs for the three reference engine categories.

Table 6.4.1.1: Investments (€)

REC MC	Investments [€]	Q	CI %
01 00	0	-	-
01 01	550	3	30
02 00	0	-	-
02 01	677	3	30
03 00	0	-	-
03 01	1 148	3	30

6.4.2 Operating costs

Ø Fuel consumption
No saving is considered for CI engines.

Ø Maintenance and repair

No data are currently available on the subject.

7 References

[1] 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.

[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] Mr. MATTHIESEN. Personal communication from ICOMIA (International Council of Marine Industry Associations). 09.09.03.
Jan@ICOMIA.com

[4] Manuel. Banque de données offroad. OFEFP. 2000.

[5] 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].

[6] 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.

[7] Regulatory impact analysis. Control of Air pollution Emission Standards for new Nonroad Spark-Ignition Marine Engines. EPA. June 1996.

[8] Z. SAMARAS, K.-H. ZIEROCK. Guidebook on the Estimation of the Emissions of “Other Mobile Sources and machinery”. Final report. Annex II. Data Collection Sheets. September 1994.

[9] Atmospheric emission inventory guidebook. CORINAIR. Volume 3.

[10] Draft regulatory support document: Control of Emissions from unregulated nonroad engines. EPA420-D-01-004. September 2001.

[11] 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

[12] Measures for reducing NMVOC emissions in Norway. Cost estimate. Report 98:07. SFT. 1997.
www.sft.no/skjema.html

[13] Utslipp av NMVOC fra fritidsbåter og bensindrevne motorredskaper”. (Translated into: NMVOC emission from recreational boats and petrol-powered motorised equipment.).
Written by: Jon R. Bang. Department of Transportation Technology, National Institute of Technology. August 1996.

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

8 Modifications compared to the previous version

Modifications made on 31/03/05 concern the definition of emission factors.
In the previous version of the document, uncontrolled emission factors were defined in g of pollutant/GJ and the other ones in g/kWh. It was very difficult to compare them.
When reviewing EGTEI data, it seemed that it would be more appropriate to provide all emission factors in the same unit for consistency reasons.
Since the previous version of the document, IFEU has released a report in 2004 concerning off-road engine emissions [14]. This document has been used to define uncontrolled emission factors in g/kWh and to review, when necessary, abated emission factors (such as NOx EF for CI engines).

Abated PM EF have also been modified for the 3 sub-sectors because they were given in the wrong unit.

Updated data can be found on pages 11, 15-16 and 19-20.
Emission factors given in g/GJ can be used by national experts to calculate emission inventories when emission factors given in g/kWh can be used to calculate unit costs (€/t of pollutant abated).