Final Background Document
on the sector

Off Road
LAND-BASED DIESEL ENGINES
18-560 kW

Prepared by CITEPA, Paris

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Sector : LAND-BASED OFFROAD DIESEL ENGINES Agriculture, Forestry, Construction & Industry, Others (Household and gardening, military…)

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.

Five engine sizes are considered :

- Category one (18-37 kW) gathers engines like Commercial Turfs, Refrigeration/AC, Generators Sets, Skid-Steer Loaders, Pumps, Welders, Lawn and Garden Tractors, Agricultural Tractors…
- Category two (37-75 kW) gathers engines like Skid-Steer Loaders, Refrigeration/AC, Tractors/Loaders/Backhoes, Generator Sets, Welders, Ag Tractors, Pumps, Forklifts…
- Category three (75-130 kW) gathers engines like Generator Sets, Tractors/Loaders/Backhoes, Ag Tractors, Graders, Forklifts, Forest Equipments, Air Compressors, Irrigation Sets, hydraulic excavators, wheel-loaders…
- Category four (130-450 kW) gathers engines like Agricultural Tractors, Generator Sets, Combines, Rubber-Tired Loaders, Graders, Crawlers, Air Compressors, Off-Highway Trucks, Forest Equipments, hydraulic excavators …
- Category five (450–560 kW) gathers engines like Generator Sets, Off-Highway Trucks, Crawlers, Off-Highway Tractors…

Three domains of activity are treated :

- Agriculture and forestry : tractors, balers, combine, sprayers, skidders…
- Industry and construction : backhoes, cement mixers, paving equipments…
- Others (household and gardening, military…) : garden tractors, mowers, chippers, military equipments…

Two different types of data are used :

- For costs and emission levels, sub-sectors are not differentiated since these data are only dependant of engine's sizes.
- For country specific data, sub-sectors such as forestry and agriculture, industry and others are considered separately.

ACTIVITY : fuel consumption (GJ/year)
POLLUTANT CONSIDERED : NOx, HC, PM and SO_2

1 Data currently used in the RAINS model

Following data are just displayed for comparison reasons

Data are derived from reference [14].

- Activity

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

➢ Emission factors

Table 1.1 : Unabated emission factors used in the RAINS PM module for diesel off-road sources

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]	TSP [g/kWh] *
Agriculture	141	149	157	1,41
Construction	134	141	149	1,34
Other land-based machinery	0,112	127	133	1,2

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

➢ Engines considered

Table 1.2 : Sectors considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_CNS	Other transport : Construction machinery (exhaust)
TRA_OT_AGR	Other transport : Agriculture (exhaust)
TRA_OT_LB	Other transport : Other off-road; 4-stroke (military, household…)

➢ Techniques and associated costs

Table 1.3 : Cost parameters for control technologies used for construction and agriculture off-road

Technology	Unit investment [€/vehicle]	Fixed O+M [%]
1998, as EURO I for HDV	660	7,9
2000/02, as EURO II for HDV	1 980	4,0
As EURO III for HDV	4452	2,9
As EURO IV for HDV	7 967	2,5
As EURO V for HDV	8 852	2,4
As Euro VI for HDV	9 452	2,4

2 Short technology description

The typical diesel engine used in off-road applications operates on a four-stroke cycle. Near the end of the piston compression stroke, fuel is injected into the cylinder at high pressure and mixes with the cylinder content (air + residual combustion gases + Exhaust Gas Recirculation if EGR-equipped). The period of premixing is referred to as ignition delay. Ignition delay ends when the premixed cylinder content self-ignites due to the high temperature and pressure produced by the compression stroke in a relatively short, homogenous, premixed combustion event.

Two types of injection systems can be observed :

- Direct Injection (DI) : in diesel engines the liquid fuel is injected into the combustion chamber after the air has been heated by compression.
- Indirect Injection (IDI) : the fuel can also be injected in a pre-chamber where the combustion initiates before spreading to the rest of the combustion chamber. This technique has lower NOx emissions. It is however less and less used because specific fuel consumption is higher.

When the fuel mixes with the oxygen of the compressed air, the fuel auto-ignites and the multiple flame fronts spread through the combustion chamber.

3 EU regulations

3.1 EU current regulation

Two Directives (97/68/EC and 2000/25/EC) regulate land-based diesel engines.

Table 3.1.1 : Scopes of the Directives

Directive References	Scope	Exemptions
*97/68/EC [2] **	Internal Combustion (IC) engines rated between 18 and 560 kW (i.e. industry and construction, household and gardening…)	- Ship engines - Railway locomotive engines - Aircraft engines - On-road vehicles - Agricultural and forestry tractor engines
2000/25/EC [3]	Agricultural and forestry tractor engines rated between 18 and 560 kW	-

* This Directive is under revision [19] : power categories may be modified to be in phase with the American regulation.
Spark ignition (SI) engines are also regulated as described in the Directive 2002/88/EC [4].

3.2 Emission limit values

Two phases have been set up to implement the standards.
Emission standards implemented by Directive 97/68/EC and Directive 2000/25/EC are similar. Only dates of entering into force of emission limit values for new engines are different.

3.2.1 Stage I

Table 3.2.1.1 : Emission limit values (g/kWh) according to the engine power rate (kW)

Power range (kW)	18-37	37-75	75-130	130-560
Compliance dates for 97/68/CE	-	01-03-1999	31-12-1998	31-12-1998
Compliance dates for 2000/25/CE	-	30-06-2001		
CO (g/kWh)	-	6,5	5,0	5,0
HC (g/kWh)	-	1,3	1,3	1,3
NOx (g/kWh)	-	9,2	9,2	9,2
PM (g/kWh)	-	0,85	0,7	0,54

3.2.2 Stage II

Table 3.2.2.1 : Emission limit values (g/kWh) according to the engine power rate (kW)

Power range (kW)	18-37	37-75	75-130	130-560
Compliance dates for 97/68/EC	31-12-2000	31-12-2003	31-12-2002	31-12-2001
Compliance dates for 2000/25/EC	31-12-2001	31-12-2003	30-06-2003	30-06-2002
CO (g/kWh)	5,5	5,0	5,0	3,5
HC (g/kWh)	1,5	1,3	1,0	1,0
NOx (g/kWh)	8,0	7,0	6,0	6,0
PM (g/kWh)	0,8	0,4	0,3	0,2

3.3 Future development of the regulation

Two further stages will be implemented : Stage III A and Stage III B as presented in [19].

Table 3.3.1 : Stage III A emission limit values

Power range (kW)	18-37	37-75	75-130	130-560
Dates of entering into force of standards for new engines	31-12-2006	31-12-2007	31-12-2006	31-12-2005
CO (g/kWh)	5,5	5,0	5,0	3,5
HC + NOx (g/kWh)	7,5	4,7	4,0	4,0
PM (g/kWh)	0,6	0,4	0,3	0,2

Table 3.3.2 : Stage III B emission limit values

Power range (kW)	18-37	37-75	75-130	130-560
Dates of entering into force of standards for new engines	-	31-12-2011	31-12-2010	31-12-2010
CO (g/kWh)	-	5,0	5,0	3,5
HC + NOx (g/kWh)	-	4,7	4,0	4,0
PM * (g/kWh)	-	0,025	0,025	0,025

* The standards for particulate matter are subject to a technical review by the 31st of December 2006.

3.4 Quality of fuels used for off-road engines

3.4.1 Sulphur content of fuels

Off-road fuels are most commonly supplied as heating oil quality with dye/marker, at a lower duty rate than road fuels. In some countries, road fuel quality is supplied to part or all of the non-road mobile machinery fuel market [5].

Table 3.4.1.1 : Regulations on sulphur content of fuels

Directive References	Scope	Exemptions
98/70/EC [7] *2003/17/EC [17]*	Quality of petrol and diesel fuels	-
99/32/EC [6]	Sulphur content of fuels : gas-oil and heavy fuel	Diesel and petrol as defined in Directive 98/70/CE

Table 3.4.1.2 : Sulphur content of fuels : standards (ppm) implemented by the Directives

Fuels	2000	2005	2008
Diesel	350	50	10
Gas-oil and heavy fuels	2 000	2 000	1 000

Some Member States have national standards [5]. This is a country specific information which has to be provided by national experts (chapter 6).

3.4.2 Biofuels

A proposal of Directive [8] on the promotion of biofuel use is currently under discussion. In a near future, a minimum share of biofuels sold should be mandatory.

Time being short, it has been decided during the EGTEI steering group held on April 4th in Paris to keep the list of fuels currently used in the RAINS model. Biofuels are then not developed in this document.

4 Definition of Reference Engines

As explained above, Directives 97/68/EC and 2000/25/EC implement different emission limit values according to engine's powers. Each power range is represented in this study by one Reference Engine characterized by a nominal power situated in the middle of the range. These definitions have been reported from [1].
Engine category 130-560 kW is split into two sub-categories for cost assessment purposes.

Table 4.1 : Reference engines

Reference engine code (REC)	Power range	Average rated power of reference engines
01	18-37 kW	27,5 kW
02	37-75 kW	56 kW
03	75-130 kW	102,5 kW
04	130-450 kW	290 kW
05	450-560 kW	505 kW

5 Emission abatement techniques and costs

NOx, PM and SO_2 are the main pollutants from diesel engines.
Due to an excess of oxygen, HC evaporating in the combustion chamber tend to be completely burned. Incomplete evaporation and burning of the fine droplets result in emissions of the very small particles of PM. Small amounts of lubricating oil can also participate in PM emissions.
High NOx emissions are due to high temperatures in the combustion chamber.
Controlling both PM and NOx requires different and sometimes opposing strategies. NOx can be reduced by reducing the combustion temperatures when PM can be reduced by higher temperatures in the combustion chamber or faster burning. To control both NOx and PM, manufacturers need to combine approaches using the many variables to achieve optimum performance.
SO_2 emission levels are proportional to the sulphur content of the fuel used. Lowering sulphur content of the fuel is necessary to implement technologies reducing PM emissions. The only way to reduce SO_2 emissions is to reduce the sulphur content of fuels.

Technologies to reduce pollutant emissions from compression ignition engines are described below.

5.1 Definition of primary measures

5.1.1 Combustion optimisation

Numerous optimisations can be done to reduce pollutant emissions : engines parameters include charge air temperature and pressure, peak cylinder temperature and pressure, turbulence, valve and injection timing, injection pressure, fuel spray geometry and rate, combustion chamber geometry and compression ratio.

- Injection timing retard

This technique should enable engines rated under 37 kW manufacturers to meet stage I emission limit values. NOx emissions are reduced because the premixed burning phase is shortened reducing cylinder temperature and pressure.

- Combustion chamber geometry

Parameters like the shape of the chamber and the location of emission, reduced crevice volumes and compression ratio can be studied to reduce emissions.

- Swirl

Increasing the turbulence of the intake air can improve the mixing of air and fuel in the combustion chamber. Thus, at low load, increased swirl reduces HC, PM, and smoke emissions and lowers fuel consumption. At high loads, swirl causes slight decreases in PM emissions and fuel consumption but NOx may increase because of the higher temperature. A higher pressure fuel system can offset this drawback.

5.1.2 Advanced fuel injection control

The following parameters can be taken into account : injection pressure, nozzle geometry, timing of the start of injection, rate of injection throughout the combustion process.

- Increasing injection pressure enhances mixing of the fuel with the intake air to achieve more complete combustion. HC and PM are reduced but NOx emissions increase. The combination with injection retard makes it possible to reduce NOx emissions.

- Multiple injection limits NOx emissions without increasing PM emissions. For electronically controlled engines, the use of high pressure multiple injections allows to reduce NOx emissions by 50%.

5.1.3 Exhaust Gas Recirculation (EGR)

EGR reduces peak combustion chamber temperature by slowing reaction rates and absorbing some of the heat generated by combustion. PM emissions and fuel consumption can increase especially at high loads. PM formation can be lowered by reducing the flow of recirculated gases during high load operation.

5.1.4 Improving charge air characteristics

Turbochargers increase the amount of air entering the cylinder by compressing the charge air. Charge air compression is primarily used to increase power output and reduce fuel consumption. To prevent NOx formation, an after cooler is typically installed to reduce the temperature of the charge air after it has been heated during compression.

After coolers can be of two types :

- Air-to-water after coolers use the engine’s main cooling system to cool the air approximately to the engine operating temperature.
- Air-to-air after coolers use fan-driven ambient air to more effectively cool the charge air.

5.2 Definition of secondary measures

Techniques as oxidation catalysts and particulate traps can be used to reduce pollutant emissions [9].

5.2.1 Catalytic converters

Catalytic converters are add-on devices used to lower exhaust emissions from engines. Typically, a catalytic converter consists of a ceramic or metallic support coated with a wash-coat which contains catalytic material (like rare-earth element or noble metals). The catalytic element initiates a chemical reaction which can, depending on the catalyst material, oxidize hydrocarbons and carbon monoxide, and/or reduce nitrogen oxides.

5.2.2 PM filters

The system consists of a filter and the means to allow filter regeneration (disposal of the accumulated soot). This device will be required to reach Stage IIIB standards.
PM filters need low sulphur fuel to operate safely.

5.2.3 Selective Catalytic Reduction (SCR)

SCR systems are currently being developed for NOx control for mobile sources.

5.3 Definitions of aggregated reduction measures

Measures are defined as a mix of techniques to reach the different emission limit values.

PM emissions from diesel engines are highly dependant on the sulphur content of the fuel. PM emissions from diesel engines are generally comprised of unburned or partially burned fuel, engine oil, and sulphur compounds. When the engine burns fuel, the fuel sulphur is oxidized to both sulphur dioxide and sulphur trioxide. The sulphur trioxide rapidly absorbs water to form hydrated sulphuric acid which condenses and is collected on filters as PM [10].

Table 5.3.1 : Abatement measure definitions

Measure codes MC	Description
00	None
01	Mix of technologies to reach Stage I emission limit values
02	Mix of technologies to reach Stage II emission limit values
03	Mix of technologies to reach Stage III A emission limit values
04	Mix of technologies to reach Stage III B emission limit values

For a question of time, retrofit is not studied in this report.

5.4 Emission factors and cost data for the different measures

The analysis develops emission factors and cost estimates for a single "typical" engine per category.

Table 5.4.1 : Emission factors for each combination code

REC MC	EF HC [g/output kWh]	Q	CI %	EF NOx [g/output kWh]	Q	CI %	EF PM [g/output kWh]	Q	CI %
01 00	2,91	4	30	14,36	4	30	1,80	4	30
01 02	1,50	3	30	8,00	3	30	0,80	3	30
01 03	1,00	3	40	6,50	3	40	0,60	3	40
02 00	2,28	4	30	14,36	4	30	1,51	4	30
02 01	1,30	3	30	9,20	3	30	0,85	3	30
02 02	1,30	3	30	7,00	3	30	0,40	3	30
02 03	1,00	3	40	3,70	3	40	0,40	3	40
02 04	1,00	2	40	3,70	2	40	0,02	2	40
03 00	1,67	4	30	14,36	4	30	1,23	4	30
03 01	1,30	3	30	9,20	3	30	0,70	3	30
03 02	1,00	3	40	6,00	3	40	0,30	3	40
03 03	0,50	3	40	3,50	3	40	0,30	3	40
03 04	0,50	3	40	3,50	3	40	0,02	2	40
04 00	1,30	4	30	14,36	4	30	1,10	4	30
04 01	1,30	3	40	9,20	3	40	0,54	3	40
04 02	1,00	3	40	6,00	3	40	0,20	3	40
04 03	0,50	3	30	3,50	3	30	0,20	3	30
04 04	0,50	3	30	3,50	3	30	0,02	2	40
05 00	1,30	4	30	14,36	4	30	1,10	4	30
05 01	1,30	3	40	9,20	3	40	0,54	3	40
05 02	1,00	3	30	6,00	3	30	0,20	3	30
05 03	0,50	3	40	3,50	3	40	0,20	3	40
05 04	0,50	3	40	3,50	3	40	0,02	2	40

EF : Emission Factor
Q : Quality of data
CI % : Coefficient of variation

Table 5.4.2 : Investments and operating costs

Investments are given compared to the unabated (MC 00) case.

REC MC	Investment [€$_{2000}$ / engine]	Q	CI %	Operating Costs [€$_{2000}$/y] *
01 00	0	-	-	-
01 02	77	4	20	-
01 03	220	4	20	-
02 00	0	-	-	-
02 01	95	2	30	-
02 02	480	4	20	
02 03	1 035	4	20	-
02 04	4 285	3	25	-
03 00	0	-	-	-
03 01	185	2	30	-
03 02	1 520	4	20	
03 03	2 450	4	20	-
03 04	6 950	3	25	-
04 00	0	-	-	-
04 01	510	3	25	-
04 02	1 725	4	20	-
04 03	2 905	4	20	-
04 04	9 905	3	25	-
05 00	0	-	-	-
05 01	890	3	25	-
05 02	4 585	4	20	-
05 03	7 600	4	20	-
05 04	14 600	3	25	-

* Operating costs are a mix of different components. See chapter 7.2.5 for further explanations

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

The following tasks are required :

6.1 Validation work

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

- Validation of investments provided,

Or

- Provide other costs for the same combination of techniques and justify them.

6.2 Provision of specific data

Tables to be filled in by national experts

➢ Fuel parameters

Table 6.2.1 : Fuel parameters

	2000	2005	2008	2010	2015	2020
Heat value of diesel [GJ/t]						
Heat value of gas-oil [GJ/t]						

Table 6.2.2 : Fuel prices (net of taxes)

	Fuel prices [(€$_{2000}$ / l]
Diesel 350 ppm sulphur (€$_{2000}$/l)	
Diesel 50 ppm sulphur (€$_{2000}$/l)	
Diesel 10 ppm sulphur (€$_{2000}$/l)	
Gas-oil 2 000 ppm sulphur (€$_{2000}$/l)	
Gas-oil 1 000 ppm sulphur (€$_{2000}$/l)	

➢ Activity level

IIASA uses international fuel statistics to define fuel consumptions 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 in each sub-sector 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 the three categories of vehicles for 2000 up to 2020 in 5-years intervals.

Table 6.2.3 : Fuel consumption for Agriculture and Forestry engines [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										
Gasoil 2000 ppm sulphur										
Gasoil 1000 ppm sulphur										
Default values proposed for CI		10		20		50		100		100

Table 6.2.4 : Fuel consumption for Industry and Construction engines [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										
Gasoil 2000 ppm sulphur										
Gasoil 1000 ppm sulphur										
Default values proposed for CI		10		20		50		100		100

Table 6.2.5 : Fuel consumption for Others engines [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										
Gasoil 2000 ppm sulphur										
Gasoil 1000 ppm sulphur										
Default values proposed for CI		10		20		50		100		100

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

- 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, HC and PM can be calculated with the following equation :

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

Country specific data (engine characteristics) are required for each Reference Engines <u>for each sub-sector</u> (agriculture, industry and others) :

- 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 [14], <u>engine's efficiency</u> is considered to be about <u>40%</u> for diesel engines. Currently, no better data have been provided.

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

This method is used in the RAINS model.

The following data are required :

- Distribution of engine's sizes

- For each sub-sector (agriculture, industry and others), the 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 6.2.6 : Distribution of the different engine sizes (% of total activity (fuel use)) for agriculture and forestry

REC	Proportion [%] 2000	Proportion [%] 2005	Proportion [%] 2010	Proportion [%] 2015	Proportion [%] 2020
01					
02					
03					
04					
05					
Total	**100**	**100**	**100**	**100**	**100**

Table 6.2.7 : Distribution of the different engine sizes (% of total activity (fuel use)) for construction and industry

REC	Proportion [%] 2000	Proportion [%] 2005	Proportion [%] 2010	Proportion [%] 2015	Proportion [%] 2020
01					
02					
03					
04					
05					
Total	**100**	**100**	**100**	**100**	**100**

Table 6.2.8 : Distribution of the different engine sizes (% of total activity (fuel use)) for others (household, military….)

REC	Proportion [%] 2000	Proportion [%] 2005	Proportion [%] 2010	Proportion [%] 2015	Proportion [%] 2020
01					
02					
03					
04					
05					
Total	**100**	**100**	**100**	**100**	**100**

- Number of engines

For cost calculations, number of engines in each of the three sub sectors in the base year (2000) is necessary. If this information is available, this should be specified in column 2 of tables 6.2.9 to 6.2.11. 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 6.2.9 : Engine characteristics for Agriculture and forestry 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				
05				

Table 6.2.10 : Engine characteristics for Construction and Industry machinery 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				
05				

Table 6.2.11 : Engine characteristics for Others (household, military…) 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				
05				

Default values for all types of use according to reference [12] are displayed hereafter : they do not correspond exactly to what is asked above but they can help to fill in tables 6.2.9 to 6.2.11.

Type of engine REC	**Load factor**	**Estimated average load [kW]**	**Operating lifetime (hours)**
01	0,33	9,2	5 000
02	0,33	18,7	6 700
03	0,33	34,2	8 000
04	0,33	96,7	10 000
05	0,33	168,3	10 000

➢ Other parameters

Engine characteristics given in Tables 6.2.9 to 6.2.11 are valid for the base year 2000. For other years, two additional parameters should be specified :

- fuel efficiency improvement (Tables 6.2.12 to 6.2.14),
- change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.15 to 6.2.17).

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

Table 6.2.12 : Fuel efficiency improvement for individual engine sizes relative to the base year for agriculture and forestry (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	
05	100	98		96		94		92	

Table 6.2.13 : Fuel efficiency improvement for individual engine sizes relative to the base year) for construction and industry (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	
05	100	98		96		94		92	

Table 6.2.14 : Fuel efficiency improvement relative to the base year for other off-road vehicles and machines (household, military etc.) (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	
05	100	98		96		94		92	

Table 6.2.15 : Change in activity per engine relative to the base year for agriculture and forestry (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	
05	100	100		100		100		100	

Table 6.2.16 : Change in activity per engine relative to the base year for construction and industry (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	
05	100	100		100		100		100	

Table 6.2.17 : Change in activity per engine relative to the base year for other off-road vehicles and machines (household, military etc.) (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	
05	100	100		100		100		100	

- Application rate and applicability

IIASA experts assume a certain lifetime of vehicles 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 6.2.18 : Application rate and Applicability (% of total activity (fuel use)) for agriculture and forestry engines

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 02									
01 03									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
02 03									
02 04									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
03 03									
03 04									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
04 02									
04 03									
04 04									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00									
05 01									
05 02									
05 03									
05 04									
Total REC 05	**100**	**100**		**100**		**100**		**100**	

Table 6.2.19 : Application rate and Applicability (% of total activity (fuel use)) construction and industry engines

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 02									
01 03									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
02 03									
02 04									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
03 03									
03 04									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
04 02									
04 03									
04 04									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00									
05 01									
05 02									
05 03									
05 04									
Total REC 05	**100**	**100**		**100**		**100**		**100**	

Table 6.2.20 : Application rate and Applicability (% of total activity (fuel use)) for other off-road vehicles and machines (household, military etc.)

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 02									
01 03									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
02 03									
02 04									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
03 03									
03 04									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
04 02									
04 03									
04 04									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00									
05 01									
05 02									
05 03									
05 04									
Total REC 05	**100**	**100**		**100**		**100**		**100**	**100**

7 Explanatory notes

7.1 Emission factors

Engines of different power output produce different amounts of pollutants. Emission factors in g/kWh reported from [11] are presented in table 7.1.1.

Table 7.1.1 : Pre-control (MC 00) emission factors (g/kWh) according to the engine power rate (kW)

REC	01	02	03	04	05	Q	CI %
NOx	14,36	14,36	14,36	14,36	14,36	4	30
HC	2,91	2,28	1,67	1,30	1,30	4	30
PM	1,80	1,51	1,23	1,10	1,10	4	30

Emission limit values are used as emission factors for MC 01 and MC 02 as shown in [11].

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

REC	01	Q	CI %	02	03	04	05	Q	CI %
NOx	14,36	4	30	9,20	9,20	9,20	9,20	3	30
HC	2,91	4	30	1,30	1,30	1,30	1,30	3	30
PM	1,80	4	30	0,85	0,70	0,54	0,54	3	30

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

REC	01	02	03	04	05	Q	CI %
NOx	8,00	7,00	6,00	6,00	6,00	3	30
HC	1,50	1,30	1,00	1,00	1,00	3	30
PM	0,80	0,40	0,30	0,20	0,20	3	30

For MC 03 and MC 04 for which NOx and HC emission limit values are given as the sum of the pollutants, values are derived from [12].

Table 7.1.4 : MC 03 emission factors (g/kWh)

REC	01	02	03	04	05	Q	CI %
NOx	6,50	3,70	3,50	3,50	3,50	3	40
HC	1,00	1,00	0,50	0,50	0,50	3	40
PM	0,60	0,40	0,30	0,20	0,20	3	40

Table 7.1.5 : MC 04 emission factors (g/kWh)

REC	01	02	03	04	05	Q	CI %
NOx	6,50	3,70	3,50	3,50	3,50	3	40
HC	1,00	1,00	0,50	0,50	0,50	3	40
PM	0,6	0,025	0,02	0,02	0,02	2	40

7.2 Derivation of Cost Data

In [15], costs are given in $\$_{1992}$. $\$_{2000}$ are calculated from the inflation rate [20]. The following equivalence is used : 1 US$\$_{1992}$ = 1,22 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$. 1 US$\$_{1992}$ = 1,32 €$_{2000}$

In [1], costs are given in $\$_{1998}$. $\$_{2000}$ are calculated from the inflation rate [20]. The following equivalence is used : 1 US$\$_{1998}$ = 1,06 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$. 1 US$\$_{1998}$ = 1,15 €$_{2000}$

Reference [15] provides aggregated costs for MC 01 costs. These data are used hereafter. For MC 02 and MC 03, costs are derived from reference [1]. MC 04 costs come from reference [12].

7.2.1 Investment costs

- MC 01 technologies [15]

Technologies include fuel injection base timing changes, fuel injection pump improvements such as variable injection timing and increased injection pressures, fuel injection nozzle modification, combustion chamber modification, air to water aftercooler improvements, turbocharger improvements, and increased application and optimisation of smoke control systems [16].

For engines greater than 130 kW, the disaggregated data generally indicate that an engine purchaser can expect a price increase of approximately €132 per 75 kW, which represents less than one percent of the equipment price in most cases [15].

Price increases for engines between 37 kW and 130 kW will generally increase between zero to two percent of the equipment price [15].

For REC 04 (engines between 130 and 450 kW), investment = 290 kW × 132€ / 75 kW = 510 €
For REC 05, (engines between 450 and 560 kW) investment = 505 kW × 132€ / 75 kW = 890 €
Investments for REC 02 (engines rated between 37 and 75 kW) and REC 03 (engines between 75 and 130 kW) are derived proportionally to the rated power.

Table 7.2.1.1 : Engine modification costs to be in compliance with MC 01 requirements [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
MC 01 technologies	-	95	185	510	890	3	30

- MC 02 & 03 technologies [1]

The following techniques will be used either to reach MC 02 or MC 03 requirements.

- Engine modification

Manufacturers are expected to work on engines design to reduce emissions, improve performance, fuel consumption, durability or serviceability.

Table 7.2.1.2 : Engine modification costs to be in compliance with MC 02 or 03 requirements [$€_{2000}$]

REC	01	02	03	04	05 *	Q	CI %
Total engine costs	105	60	15	30	1385 / 810	4	20

* costs for MC 02 / MC 03 (costs are lowered for MC 03 because more time is given to manufacturers)

- Electronic controls

All direct injection engines are projected to adopt electronic controls.

Table 7.2.1.3 : Electronic controls costs [$€_{2000}$]

REC	02	03	04	05	Q	CI %
Hardware Costs *	440	750	805	1 335	4	20
Fixed Costs	40	65	115	1 200	4	20
Total engine costs	480	815	920	2 535	4	20

* Hardware costs comprise : the Electronic Control Modules, Modified fuel injectors, electronic fuel pump, sensors, wiring harness, assembly, mark-up (29%) and warranty (10%).

- Improved Fuel Injection Hardware

    - Fuel injection

Engines rated under 75 kW, are projected to use upgraded rotary fuel pumps to achieve higher injection pressures.
Incremental fuel pump costs for engines rated between 37 and 75 kW are included as one of the cost elements for incorporating electronic controls.

Table 7.2.1.4 : Injection pumps costs for engines rated between 37 and 75 kW [$€_{2000}$]

REC	01	02	Q	CI %
Total cost per engine	135	130	4	20

Engines rated between 75 and 450 kW are projected to need upgraded unit injection systems.

Table 7.2.1.5 : Injection system costs for engines rated between 75 and 450 kW [$€_{2000}$]

REC	03	04	05	Q	CI %
Hardware costs	110	130	200	4	20
Fixed costs	5	10	520	4	20
Total cost per engine	115	140	720	4	20

- Common rail

This technique is used to provide a constant supply of pressurized fuel at the injectors, which greatly increases control of the injection process.

Table 7.2.1.6 : Common rail costs [$€_{2000}$]

REC	03	04	05	Q	CI %
Hardware costs	130	150	195	4	20
Fixed costs	5	10	480	4	20
Total cost per engine	135	160	675	4	20

- Exhaust Gas Recirculation

Engines rated between 37 and 75 kW are expected to use non-cooled EGR.
All others categories are projected to use cooled EGR.

Table 7.2.1.7 : EGR system costs [$€_{2000}$]

REC	02	03	04	05	Q	CI %
Hardware costs *	70	155	175	260	4	20
Fixed costs	30	30	50	655	4	20
Total cost per engine	100	185	225	915	4	20

* Hardware costs comprise : Electronic EGR, EGR tubing, EGR cooler, assembly, mark-up (29%) and warranty (10%).

Rebuild for engines equipped with EGR is expected to occur after 10 years of operation.

- Turbo charging and after cooling

Turbochargers increase the amount of air entering the cylinder by compressing the charge air.
After coolers extract heat from the compressed charge air, further increasing its density. Air-to-water after coolers use the engine's main cooling system to cool the air approximately to the engine operating temperature.
Air-to-air after coolers use fan-driven ambient air to more effectively cool the charge air.
Engines rated over 75 kW are all projected to use air-to-air after cooling.

Table 7.2.1.8 : Turbo charging costs [€$_{2000}$]

REC	02	03	Q	CI %
Hardware costs	350	630	4	20
Fixed costs	1	3	4	20
Total cost per engine	351	633	4	20

Table 7.2.1.9 : Cost for Air-to-Air After cooling [€$_{2000}$]

REC	03	04	05	Q	CI %
Hardware costs *	390	1 180	4 550	4	20
Fixed costs	10	15	210	4	20
Total cost per engine	400	1 195	4 760	4	20

* Hardware costs comprise : heat exchanger, plumbing, assembly, mark up (29%) and warranty (10%).

Table 7.2.1.10 : Costs to convert Air-to-Water to Air-to Air After cooling [€$_{2000}$]

REC	03	04	05	Q	CI %
Hardware costs	250	790	3 090	4	
Fixed costs	5	10	145	4	
Total cost per engine (AW)	255	800	3 235	4	
Total cost per engine (AA)	400	1200	4755	4	
Net engine cost	145	400	1 520	4	20

* Hardware costs comprise : incremental radiator, supplier's mark-up (29%), plumbing, assembly, mark-up (29%) and warranty (10%).

- MC 04 technologies

According to [12], stage IIIB is essentially the anticipated cost of aftertreatment (i.e. particulate filter). These costs are given in table 7.2.1.11.

Table 7.2.1.11 : Estimated cost of aftertreatment* [€$_{2000}$]

REC	01	02	03	04	05	Q	CI %
Total cost per engine	-	3 250	4 500	7 000	7 000	3	25

* this is assumed filters lifetime to be around 5 000 h; i.e. 10 000 h requires 2 filters.

<u>Complementary information</u> : No emission limit value is given for REC 01 for stage IIIB. However, reference [12] has studied all cases. Investment has been assessed for aftertreatment adapted to REC 01.

Table 7.2.1.12 : Estimated cost of aftertreatment for REC 01 [€$_{2000}$]

REC	01	Q	CI %
Total cost per engine	1 500	3	25

According to [13], experience in the on-road sector shows that generally, real costs are lower than estimations. Moreover, cost estimations are based on the use of two PM filters. EPA's calculations show much lower costs.

7.2.2 Incremental aggregated engine costs

These costs correspond to the costs to reach the more stringent emission limit values.
If the following aggregated costs for individual aggregated measures (MCs) are lower than those given above, this is because all technologies do not have to be installed on the whole fleet to reach the emission limit values.

Table 7.2.2.1 gives total costs per engine category to reach the different emission limit values. "Fraction" data denote the percentage of Reference Engines estimated to require the given technology to comply with emission limit values for individual MCs.

Table 7.2.2.1 : Incremental aggregated engines costs [$€_{2000}$]

	REC	01		02		03		04		05	
		Fraction [%]	Cost [$€_{2000}$]	Fraction [%]	Cost [$€_{2000}$]	Fraction [%]	Cost [$€_{2000}$]	Fraction [%]	Cost [$€_{2000}$]	Fraction [%]	Cost [$€_{2000}$]
Engine modifications	Stage II	33	35	15	10	50	10	50	15	50	690
	Stage III	33	35	85	50	50	10	50	15	50	405
Electronic controls	Stage II	-	-	-		75	610	75	690	15	380
	Stage III	-	-	85	410	25	205	20	185	-	-
Improved injection	Stage II	-	-	-	-	-	-	-	-	-	-
	Stage III	67	90	-	-	-	-	-	-	-	-
Common Rail	Stage II	-	-	-	-	-	-	-	-	50	335
	Stage III	-	-	-	-	100	140	100	160	50	335
EGR	Stage II	-	-	45	45	-	-	-	-	-	-
	Stage III	-	-	40	40	100	185	100	220	100	915
Turbocharger	Stage II	-	-	50	175	50	160	-	-	-	-
	Stage III	-	-	-	-	-	-	-	-	-	-
AA After cooler upgrade	Stage II	-	-	-	-	25	35	25	100	40	610
	Stage III	-	-	-	-	30	40	25	100	45	685
New AA after cooler	Stage II	-	-	-	-	-	-	-	-	-	-
	Stage III	-	-	-	-	45	180	30	360	-	-
Certification	Stage II	100	12	100	7	100	7	100	13	100	170
	Stage III	100	9	100	7	100	7	100	13	100	170
Aggregated costs	MC 00 to MC 01	-	-	-	95	-	185	-	510	-	890
Aggregated costs	MC 01 to MC 02	-	47	-	237	-	822	-	818	-	2 185
Aggregated costs	MC 02 to MC 03	-	134	-	507	-	767	-	1 053	-	2 510
Aggregated costs *	MC 03 to MC 04	-	-	-	3 250	-	4 500	-	7 000	-	7 000

* To reach Stage IIIB standards, after-treatment devices (PM filters) will be necessary.

Reference [1] presents lower costs for certain engine categories because it assumes that manufacturers would have use some of the previous technologies even without the standards implementation.

7.2.3 Equipment change costs

Equipment modifications due to new emission limit values related to packaging (installing engines in equipment engine compartments), power train (torque curve), and heat rejection effects of the newly complying engines.

According to reference [16], engine changes required to meet PMC 01 standards should have a minimal impact on equipment design. Based on input from engine manufacturers, EPA has determined that PMC 01 regulation will have minimal impact on engine packaging since the technologies such as fuel injection retard, fuel upgrades and combustion chamber upgrades do not alter the external dimensions of the engines.

Table 7.2.3.1 : Equipment change costs [$€_{2000}$]

REC	01	02	03	04	05
MC 01 (costs incurred to go from MC 00 to MC 01)					
Total costs	-	0	0	0	0
MC 02 (costs incurred to go from MC 01 to MC 02)					
Fixed costs	10	15	20	30	40
Hardware costs	20	130	490	365	1 470
Total costs	30	145	510	395	1 510
MC 03 (costs incurred to go from MC 02 to MC 03)					
Fixed costs	5	5	5	10	15
Hardware costs	5	45	160	120	490
Total costs	10	50	165	130	505
MC 04 (costs incurred to go from MC 03 to MC 04)					
Total costs	-	0	0	0	0

These costs will decrease with time, firstly because of technology improvements and secondly because fixed costs are amortized with time.

7.2.4 Total costs

Total investment costs correspond to the sum of engine costs and equipment change costs (see table 5.4.2).

7.2.5 Operating costs

Several data are required in the RAINS model.

- Fuel consumption variations

Application of certain technologies leads to a fuel consumption variations.

For example, EPA [1] estimates a fuel consumption reduction of 3% for upgraded after cooling engines and 6% for those engines that currently have no after cooling.
On the other hand, some technologies will lead to fuel consumption increases like EGR application, PM filters and engine modifications for small engines. According to [18], fuel consumptions should increase by 2 to 4 % with the use of a PM filters because of the backpressure induced by the filter.

As variations presented above can be considered in the uncertainty range and, as no more detailed information is available, fuel consumption variations are not considered in this document.

- Sulphur content of fuels

According to [13] low sulphur fuel will be required to meet stage III B limit values on PM. This type of fuel is not required for 18-37 kW engines since no after-treatment device is needed. However in practice, this will be difficult to distribute two types of fuels.
The additional cost of a fuel with 10 ppm sulphur is 0,015 €/liter compared to a fuel with 1000 ppm [13].
Incremental costs to reduce sulphur content of fuels are country specific. An average European value is given as an example in table 7.2.5.1.
According to fuel industry, sulphur removal by itself is not enough. A full fuel modification is also required so a cost range of 0,026 to 0,029 €/litre will be incurred.

Table 7.2.5.1 : Additional costs for the use of low sulphur fuel

Description	Cost (€/l)	Q	CI %
Reduction of S from 1000 ppm to 10 ppm	0,015	4	30
Full fuel modification	0,026-0,029	4	30

- Maintenance and repair

According to EPA [16], effects on operation and maintenance will be minimal for MC 01 engines.

According to IIASA, usually, higher purchase price causes also higher expenditures on maintenance and repairs.
These costs are defined as fixed costs (% of investment) as shown in table 7.2.5.2.

Table 7.2.5.2 : Maintenance and repair expenditures as a percentage of investment [14]

MC	Fixed O+M [%]
00	7,9
01	4,0
02	2,9
03	2,5
04	2,4

8 References

[1] Final Regulatory Impact Analysis : Control of Emissions from Non road Diesel Engines. USEPA, Office of Air and Radiation; Office of Mobile Sources; Engine Programs and Compliance Division. August 1998. EPA420-R-98-016.
http://www.epa.gov/otaq/regs/nonroad/equip-hd/frm1998/nr-ria.pdf.

[2] 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].

[3] Directive 2000/25/EC of the European Parliament and of the Council of 22 May 2000 on action to be taken against the emission of gaseous and particulate pollutants by engines intended to power agricultural or forestry tractors and amending council Directive 74/150/EEC [Official Journal L 173, 12.07.2000].

[4] 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.

[5] Info Concawe. August 2001.

[6] Council Directive 1999/32/EC of 26 April 1999 relating to a reduction in the sulphur content of certain liquid fuels and amending Directive 93/12/EEC [Official Journal L 121, 11.05.1999]

[7] 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]

[8] Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of biofuels for transport [COM (2001) 547 final].

[9] Diesel Emission Control Strategies Available to the Underground Mining Industry. ESI INTERNATIONAL. February 1999. http://www.deep.org/reports/esi_final_report.pdf.

[10] Exhaust Emission Factors for Non road Engine Modelling Compression-Ignition. Report No. NR-009A. USEPA. February 13, 1998.

[11] Software Copert III : http://vergina.eng.auth.gr/mech/lat/copert/copert.htm.

[12] Feasibility study on a third stage of emission limits for compression ignition engines with a power output between 18 and 560 kW. Final report. VTT Processes for the EC DG ENV.5. 17.09.2002.

[13] Rough cost benefit analyses of the implementation of stage III limit values on emissions from Non-road Mobile Machinery (Directive 97/68/CE). Draft 11/10/02.

[14] 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

[15] Control of Air Pollution; Determination of Significance for Nonroad Sources and Emission Standards for New Nonroad Compression Ignition Engines At or Above 37 Kilowatts. EPA. June 1994.
http://www.epa.gov/fedrgstr/EPA-AIR/1996/November/Day-12/pr-23833DIR/Other/a5645-4.html

[16] Final Rule: Determination of Significance for Nonroad Sources and Emission Standards for New Nonroad Compression-Ignition Engines At or Above 37 Kilowatts (published June 17, 1994). Support Documentation 190K ZIP WP5.1
http://www.epa.gov/otaq/equip-hd.htm

[17] 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.

[18] Manuel. Banque de données offroad. OFEFP. 2000. http://www/admi.ch/buwal/publikat/f/

[19] Proposal for a Directive of the European Parliament and of the Council 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/* COM/2002/0765 final - COD 2002/0304.

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

9 Modifications compared to the draft document

9.1 Modifications of Chapter 5

Table 5.4.1 : Some emission factors have been reviewed. This is the case for MCs 01 and 04.

Table 5.4.2 : Investments have been modified. Equivalences between $ and € have been reviewed and in this final document, investments are all compared to the unabated case (MC 00).

9.2 Modifications of Chapter 6

Some tables have been added to be in compliance with IIASA's requirements.

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 for each type of engines (**tables** 6.2.3 to 6.2.5).

Somme parameters are necessary to define the number of engines. National experts have to provide either the number of engines or the load factors and the annual use for each type of engines. Some default values are provided on page 15.

New tables have been added : the fuel efficiency improvement and the change in activity per engine (if no national statistic is available, default values will be used in the model RAINS).

Application rate and applicability (% of total activity (fuel use)) are also requested for each type of engines (**tables** 6.2.18 to 6.2.20).

9.3 Modifications of Chapter 7

Costs have been recalculated with the new equivalence between $ and €.
About operating costs, no variation in fuel consumption is considered in this document because figures found in the literature are not specific enough to give accurate factors.