OTHER MOBILE SOURCES AND MACHINERY

SNAP CODES :	**080100**
	080200
	080300
	080600
	080700
	080800
	080900
	08100
SOURCE SECTOR TITLES :	**Military**
	Railways
	Inland Waterways
	Agriculture
	Forestry
	Industry
	Household and Gardening
	Other off-road

1 ACTIVITIES INCLUDED

The aim of this chapter is to provide a common tool concerning the estimation of emissions of several sub-sectors of SNAP sector 8, including remarks concerning the collection, evaluation and assessment of relevant information, of other mobile sources and machinery:

- Off-Road Vehicles and Machines (SNAP 0806, 0807, 0808, 0809)
- Railways (SNAP 0802)
- Inland Waterways (SNAP 0803) only.

Apart from the 'on-road' vehicles (passenger cars, light duty vehicles, heavy duty vehicles, buses, two wheelers), which are covered by SNAP sector 7, internal combustion engines are used in many other modes of application. In the light of the large number of machinery types to be considered, the work to be carried out requires definition of the source category in more detail.

Several source category sub-splits have been proposed and used elsewhere and provided the starting point for the category split (e.g. Achten 1990, US-EPA 1991). The sub-split needs to be well-balanced since, due to the large number of other mobile sources and machinery, there is a risk of going into too great a detail. On the other hand, all main activities and consequently all major sources need to be well covered. Therefore, a compromise has to be found.

Table 1-1 provides an overview of the proposed sub-split of the source categories to be considered, which has been based on the experiences so far.

In some cases, there is a risk of overlapping with other SNAP sectors, e.g. fire trucks, refuse collectors, sewage trucks, road tankers, etc. because it is not always clear whether or not these utility vehicles are part of national on-road vehicle inventories. It is proposed to count these as on-road vehicles. In addition, some of the vehicles have a second combustion engine in order to operate their special equipment. These additional machines should fall under 'Off-Road' machinery. In some other cases, machinery is mobile in principle, but actually stays at the same site for long periods, or only is mobile within a small radius, e.g., some excavators and cranes. In this case, it is proposed to consider these machines here as 'Other Mobile Sources and Machinery'. Moreover, there are large mobile generator sets, e.g. above 1 MW, which are mobile but quite often not moved in reality. With regard to this equipment, there is a real risk of misallocation, because in many inventories such generator sets most likely fall into the categories of SNAP sectors 1, 2 or 3 under the item 'Stationary Engines'. A further risk of misallocation occurs in the sector 'Airports', because many of the ground activities covered there are carried out by 'off-road' machines and equipment which fall into the category 0801. Therefore, there is a risk of double counting.

Table 1-1: Proposal for a Reference List of 'Off-road' machinery which should be covered under SNAP codes 0801 to 0803 and 0806 to 0809

080100	Military		
080200	Railways:	01	Shunting locs
		02	Rail-cars
		03	Locomotives
080300	Inland Waterways:	01	Sailing Boats with auxiliary engines
		02	Motorboats / Workboats
		03	Personal Watercraft
		04	Inland Goods Carrying Vessels
080600	Agriculture:	01	2-wheel tractors
		02	Agricultural tractors
		03	Harvesters / Combines
		04	Others (sprayers, manure distributors, agriculture mowers, balers, tillers, swatchers)
080700	Forestry:	01	Professional Chain Saws / Clearing Saws
		02	Forest tractors / harvesters / skidders
		03	Others (tree processors, haulers, forestry cultivators, fellers/bunchers, shredders, log loaders, pilling machines)
080800	Industry:	01	Asphalt/Concrete Pavers
		02	Plate compactors / Tampers / Rammers
		03	Rollers
		04	Trenchers / Mini Excavators
		05	Excavators (wheel/crowler type)
		06	Cement and Mortar Mixers
		07	Cranes
		08	Graders / Scrapers
		09	Off-Highway Trucks
		10	Bull Dosers (wheel/crowler type)
		11	Tractors/Loaders/Backhoes
		12	Skid Steer Tractors
		13	Dumper/Tenders
		14	Aerial Lifts
		15	Forklifts
		16	Generator Sets
		17	Pumps
		18	Air/Gas Compressors
		19	Welders
		20	Refrigerating Units

		21	Other general industrial equipment (broomers, sweepers/ scrubbers, slope and brush cutters, pressure washers, pist machines, ice rink machines, scrapers, blowers, vacuums)
		22	Other material handling equipment (conveyors, tunnel locs, snow clearing machines, industrial tractors, pushing tractors)
		23	Other construction work equipment (paving/surfacing equipment, bore/drill rigs, crushing equipment, concrete breakers/saws, peat breaking machines, pipe layers, rod benchers/cutters)
080900	Household and Gardening:	01	Trimmers/Edgers/Bush Cutters
		02	Lawn Mowers
		03	Hobby Chain Saws
		04	Snowmobiles/Skidoos
		05	Other household and gardening equipment (wood splitters, snowblowers, chippers/stump grinders, gardening tillers, leaf blowers/vacuums)
		06	Other household and gardening vehicles (lawn and garden tractors, all terrain vehicles, minibikes, off-road motorcycles, golfcarts)

2 CONTRIBUTION TO TOTAL EMISSIONS

There are indications that the activities covered by this note consume a significant proportion of diesel fuel (Table 2-1).

Table 2-1: Consumption of diesel/gas-oil and motor spirit by selected source categories in EC 12 in 1000 tonnes in 1990 (EUROSTAT 1992)

Source Category	diesel/gas-oil [kt]	motor spirit [kt]
[1] Road Transport	79.620	103.226
[2] Industry	9.620	82
[3] Agriculture	9.763	222
[4] Inland navigation	5.061	387
[5] Railways	2.144	-
[1]-ä[2]..[5]*100 [1]	67	99.3

Remark: The figures given should be considered as an indication of the potential consumption of fuels in the sectors listed only, because it is unclear whether the full amount given for sectors [2] to [4] is actually used in internal combustion engines.

In total, and looking at the pollutants covered by the UN-ECE protocols only, it can be assumed that the sectors covered by this guidebook contribute significantly to total NOx and VOC emissions in most countries.

However, figures are only available for some countries. Moreover, due to the lack of a common systematic approach, these figures are not fully comparable among each other, because the machinery covered still differs somewhat among countries. Table 2-2 shows some of the data for VOC, NOx and SO_2 currently available. In some countries, the sector might also be a major source of some of the other pollutants covered by CORINAIR, e.g. CO, and of some pollutants currently not covered by international emission inventory activities, e.g. diesel particulates, heavy metals and persistent organic compounds (UNECE 1994,a,b). Further details on the CORINAIR90 results are presented in chapter ACOR.

An indication of groups of major sub-sources, at least for Western European countries, can currently be obtained by analyzing the EPA data. Table 2-3 shows a first broad evaluation. In the light of these results, the following sectors seem of greatest importance for the different pollutants:

For VOC:	Recreational marine (Subpart of 'Inland Waterways') Lawn and Garden (Subpart of 'Household and Gardening')
For NO_X:	Agriculture Construction (Subpart of 'Industry')
For CO:	Light Commercial (Subpart of 'Industry') Lawn and Garden (Subpart of 'Household and Gardening')
For PM:	Construction (Subpart of 'Industry')

Table 2-2: Estimates of national emissions of VOC, NOx and SO_2 from parts of the CORINAIR sector 08 'Other Mobile Sources and Machinery' in selected countries (Please note: the figures are not fully comparable among each other because the individual subsectors covered by the estimates differ)

Country	Off - road source categories covered	Annual emissions of source category in kt (and % of total national emissions for the pollutants)		
		VOC	NO_x	SO_2
Norway	Agriculture Forestry Industry Military Railways	1.5 (1.0)	12.8 (5.8)	0.7 (0.7)
Denmark	Agriculture Forestry Industry Airport machinery	5.5 (2.6)	36.5 (11.9)	2.5 (0.9)
Finland	Agriculture Forestry Industry Household and Gardening	11.0 (5)	41.0 (15)	2.7 (n.a.)
Sweden	Agriculture Forestry Industry Household and Gardening	7.3 (1.6)	70.5 (6.5)	5.1 (2.6)
Switzerland	Industry	1.1 (0.4)	6.8 (4.2)	0.3 (0.5)
Netherlands	Industry	22..56 (5..12)	53..125 (9..19)	4..10 (1..3)

This means that data collection for the sectors forestry and recreation (activity 080105 'Household and Gardening') are of lower relevance for these pollutants. However, these sectors are of some relevance for emissions of heavy metals, in particular lead, due to the consumption of gasoline (see Table 2-4). In any case, this assessment does not need to be true for all European countries.

Table 2-3: Contribution of 'Off-road' machinery to total emission [in percent], as estimated by US-EPA for different non-attainment areas

Pollutant	**VOC**	**NOx**	**CO**	**PM**
*Total over all areas*1)	10.9	15.9	7.3	1.4
Total by areas	4 - 19	8 - 29	3 - 14	0.3 - 5.2
by category				
Agriculture	0.1 - 1.2	0.5 - 11	0.02 - 0.6	0.02 - 0.8
Airport Service	0 - 0.25	0 - 3.5	0 - 0.8	0 - 0.2
Recreational Marine	0 - 6.5	0 - 1.5	0 - 0.8	0 - 0.3
Construction	0.5 - 1.8	3 - 23	0.2 - 1.8	0.1 - 2.1
Industry	0.1 - 0.8	0.3 - 3.0	0.3 - 2.9	0.02 - 0.4
Lawn and Garden	1.9 - 10.5	0.1 - 0.5	0.02 - 4.5	0.02 - 0.2
Light Commercial	0.3 - 2.3	0.1 - 0.5	1.0- 7.5	0.01 - 0.15
Forestry	0.02 - 0.16	0 - 0.1	0.02 - 0.35	0 - 0.3
Recreation	0.2 - 2.1	0 - 0.1	0.2 - 3.9	0 - 0.1

1) Average of two different industries

Table 2-4: Trace element emissions in Europe in [tonnes/year] (UNECE 1994b)

No.	Category	As (1982)	Cd (1982)1)	Hg (1987)	Pb (1985)2)	Zn (1982)
1	Fuel combustion in utility boilers	330	125	189	1300	1510
2	Fuel combustion in industrial,	380	145	216	1600	1780
3	Gasoline combustion	-	-	-	64000	-
4	Non-ferrous metal industry	3660	730	29	13040	26700
5	Iron and steel production	230	53	2	3900	9410
6	Waste incineration	10	37	35	540	650
7	Other sources	360	30	255	112	4540
	Total	4970	1120	726	85500	44590

1) The 1990 emissions of Cd in Europe was estimated between 270 and 1950 tonnes (678 tonnes as average value)

2) The 1990 emissions of Pb in Europe was estimated between 32200 and 54150 tonnes.

Industrial associations also published some emission data. EUROMOT has provided emission estimates for the sector off-road machinery using a somewhat different methodology than that proposed in this guidebook in order to overcome the problem of estimating the equipment population and the annual hours of equipment use (EUROMOT 1992). The EUROMOT methodology assumes that the 'annual sales' times the 'equipment life time' is equal to the 'number of equipment in use' times the 'annual hour of equipment usage'. This assumption is valid only if there is no growth in engine population over the lifetime. Moreover, the estimate is not made for a specific year but for a period corresponding to the lifetime of equipment (which may vary from about 5 to 15 years). In the light of the uncertainties associated with the equipment population and the usage, the EUROMOT method seems to be a good way to overcome the problem.1) Moreover, ICOMIA very recently provided emission data for the sector 'Inland Waterways'. Table 2-5 shows some of the results of these two publications, related to the estimated 1985 emissions of the European Union.

Table 2-5: Emission estimates of EUROMOT and ICOMIA

Country	Off - road source categories covered	Annual emissions of source category in kt (and % of total national emissions for the pollutants)		
		VOC	NO_x	SO_2
EUROMOT	Agriculture Forestry Inland Waterways	500 (4.8)	2450 (23.5)	650 (-)
ICOMIA	Inland Waterways (Inland goods carrying vessels most likely not fully covered)	41.8 (0.004)	12.4 (0.001)	112 (-)

It is, therefore, proposed to aim at estimating emissions of all pollutants covered by CORINAIR 90, except NH_3 if too difficult, and to add diesel particulates and other relevant pollutants which are of priority for the PARCOM/ATMOS work, in particular Cd, Cu, Pb and Zn as far as heavy metals are concerned, and polyaromatic hydrocarbons (benzo(a)anthracene, benzo(b)fluoranthene, diebenzo(a,h)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthene) as far as persistent organic compounds are concerned.

3 GENERAL

3.1 Brief description of machinery

In order to identify the vehicles and machinery dealt with, it is helpful to provide a brief description (see also Table 3-1).

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1) However, it needs to be checked whether the inherent assumption made that the lifetime of equipment depends on its power output and not on its purpose is correct, e.g., is the lifetime of a 20 kW engine used for marine propulsion equal to a 20 kW engine used in a trencher?

3.1.1 SNAP 080100 Military

There is no further split provided. It is assumed that all equipment is diesel engine powered.

3.1.2 SNAP 0802xx Railways

01 Shunting Locomotives

These locomotives are used for shunting wagons. They are equipped with diesel engines having a power output of about 200 to 2000 kW.

02 Railcars

Railcars are mainly used for short distance rail traction, e.g., urban/suburban traffic. They are equipped with diesel engines having a power output of about 150 to 1000 kW.

03 Locomotives

Diesel locomotives are used for long distance rail traction. They are equipped with diesel engines having a power output of about 400 to 4000 kW.

3.1.3 SNAP 0803xx Inland Waterways

01 Sailing Boats with auxiliary engines

One can distinguish small sailing boats with a length of up to about 6 metres which are partly equipped with outboard engines and larger sailing ships which, in general, have inboard engines. The small engines used for small sailing boats have a power output between about 2 and 8 kW and are all 2 stroke petrol engines. For larger sailing boats mainly diesel engines are used having a power output between 5 and about 500 kW. Four-stroke petrol engines with a power output between about 100 and 200 kW are also on offer but rarely used. The average 8 to 10 metre sailing boat is equipped with an engine of 10 to 40 kW power output.

02 Motor Boats / Workboats

A large number of 2-stroke petrol engines is on offer for recreational motor boats with a length of about 3 to 15 metres. They have a power output between 1 and 200 kW. There are also 4-stroke engines on offer having a power output between 5 to 400 kW. For larger motor boats generally diesel engines are used which are identical to those used for large sailing boats. There is a large number of different workboats in use, e.g., for inland passenger transport, in harbours for ship towing and other commercial purposes (e.g., swimming cranes and excavators), for police and custom purposes. These boats have a power output of about 20 to 400 kW and are all diesel engine equipped.

03 Personal Watercrafts

These are 'moped' type crafts, all equipped with two-stroke engines.

04 Inland Goods Carrying Vessels

They are all equipped with slow diesel engines having a power output between 200 and 800 kW with an average of about 500 kW. Since not all vehicles/machinery listed above make use of all types of engines, the methodology can be concentrated on those engines mainly used. Table 3-1 provides an overview on the engine types taken into account.

3.1.4 SNAP 0806xx Agriculture

01 Two-Wheel Tractors

Tractors are used in agriculture (and forestry) as universal working machines. Very small one axle/two wheels tractors only have a few kW power output (about 5 to 15 kW) and are equipped with two-stroke or four-stroke petrol or with diesel engines.

02 Agricultural Tractors

Two axles/four wheel tractors (there are also some articulated wheel and crawler type tractors which fall under this category) are nearly exclusively diesel engine powered and have a power output of between 20 and about 250 kW. The main power range used for agricultural purposes is 100 to 130 kW for the first tractor and 20 to 60 kW for the second one. For vineyards, somewhat smaller tractors are used having a typical power output of 30 to 50 kW. (In forestry, the same tractors are used as in agriculture, having a power range of about 60 to 120 kW.) In general, over the last 30 years there has been a clear tendency towards higher power outputs and towards four wheel drive. Larger 4- and 6 cylinder diesel engines are equipped with turbo charger.

03 Harvesters/Combiners

These machines are used mainly for harvesting grain (chaff, beet etc.). They have a power output between 50 and 150 kW, all are diesel engine equipped.

04 Others

Under this heading falls all other agricultural equipment, e.g. sprayers, manure distributors, mowers, balers, tillers, swatchers. Mainly diesel engines, but also 2- and 4-stroke gasoline engines are used in these machines. The power output is in the range of 5 to 50 kW.

3.1.5 SNAP 0807xx Forestry

01 Professional Chain Saws / Clearing Saws

These are chains saws for professional use, all are 2-stroke petrol engine driven with a power output of about 2 to 6 kW.

02 Forest Tractors / Harvesters / Skidders

These are vehicles (e.g. wheel forwarder, crawler forwarder, grapple skidder, cable skidder etc.) used for general transport and harvesting work in forests. They are all diesel engine equipment with a power output of about 25 to 75 kW.

03 Others

Under this heading are covered machines such as tree processors, haulers, fellers, forestry cultivators, shredders, and log cultivators. They are mainly diesel engine equipment; some use 2-stroke engines.

3.1.6 SNAP 0808xx Industry

01 Asphalt Pavers / Concrete Pavers

These wheeler crawler type machines (road pavers, slurry seal pavers, chip spreaders, large pavement profilers, pavement recyclers) are street finishers which use asphalt or concrete as paving material. They are equipped with 3- to 6-cylinder diesel engines with a power output between 15 and 160 kW. Larger engines are turbo charged.

02 Plate Compactor / Tampers / Rammers

Small compaction equipment is powered by 2-stroke gasoline engines having about 1 to 3 kW output; medium size and large size compaction equipment are equipped either with 4-stroke gasoline engines or with diesel engines of 2 to 21 kW. Tampers and rammers are tools for surface treatment operated by 2-stroke petrol engines of about 1 - 3 kW power output. Large rammers fall under 'Other Construction Equipment'.

03 Rollers

These machines (e.g. smooth drum rollers, single drum rollers, tandem rollers, padfoot rollers), used for earth compaction, are all diesel engine equipped having a power output in the range of 2 to 390 kW.

04 Trenchers / Mini Excavators

These crawler or wheel type machines can be considered as a special type of a mini-excavator used for digging trenches. Some are equipped with special tools, e.g. cable plows. They are diesel engines equipped with a power output of 10 to 40 kW.

05 Excavators (wheel / crawler type)

Excavators are mainly used for earth movement and loading work. Hydraulic and cable models are covered by this category. Some have special tools like fork arms, telescopic booms, rammers etc. Excavators can be distinguished into three classes. Small ones used for digging work to put pipes or cables into the earth have a power output of about 10 to 40 kW. They are equipped with 2- to 4-cylinder diesel engines and fall under the sub-category 'Trenchers'. Medium size hydraulic and dragline ones used for general earth moving work have a power output of about 50 to 500 kW. The engines have 4 to 12 cylinders. Many of the engines are turbo charged. Above 500 kW starts the group of large excavators and crawler tractors used for heavy earthwork and raw material extraction. The power output can be as high as several thousand kW, having 8 to 16 cylinders. All engines are turbo charged.

06 Cement and Mortar Mixers

Small concrete mixers run on electric power or 4-stroke petrol engines of about 1 to 7.5 kW power output. Larger mixers run on diesel engines having a power output of 5 to 40 kW.

07 Cranes

Cranes (e.g. crawler mobile cranes, carry cranes, tower cranes) are all either electricity (if they operate quasi-stationary) or diesel engine powered, having an output of about 100 to 250 kW.

Models with a special design can have a significantly higher power output. (Note: Tower cranes are mainly driven by electrical engines.)

08 Graders / Scrapers

Graders (e.g. articulated steered or wheel steered ones) are used to level surfaces. They have a power output of about 50 to 190 kW. Scrapers (e.g. wheel steered tractor scrapers, articulated steered tractor scrapers) are used for earthwork. They have a power output of about 130 - 700 kW and are all diesel engine powered.

09 Off-Highway Trucks

These are large trucks (e.g. rigid frame dumpers, wheel steered mine dumpers, articulated steered mine dumpers etc.) used for heavy goods transport on construction sites and quarries (but not on public roads), e.g., to transport sand, rocks, etc. They run on diesel engines of 300 to 500 kW power output, nearly all turbo charged.

10 Bulldozers

This category includes wheel dozers, articulated steered dozers, crawler dozers, crawler loaders etc. They are mainly used for demolishing and earth moving work and are all diesel engine equipped with a power output of about 30 to 250 kW. Large engines are turbo charged. (Some might have a significantly larger power output.)

11 Tractors / Loaders / Backhoes

Tractors are used for general transport word. They are all diesel engine equipped with a power output of 25 to 150 kW. Loaders (e.g. wheel loaders, articulated steered wheel loaders, landfill compactors) are used for earth work or can be equipped with special tools (e.g. with brush cutters, forearms, handling operation devices, snowthawers etc.). Crawler loaders should be treated under 'Bulldozers'. They are all diesel engine equipped. As it is the case for excavators, loaders fall into three classes: 'Minis' have about 15 to 40 kW and are equipped with 3 or 4 cylinder diesel engines, with normal aspiration; medium size loaders have a power output between 40 to 120 kW; large loaders go up to about 250 kW. The medium and large size engines are, in general, turbo charged. Backhoes are combinations of a wheel loader and a hydraulic excavator. They run on diesel engines with a power output of about 10 to 130 kW.

12 Skid Steer Loaders

These are small wheel loaders which have appeared on the market very successfully only a few years ago. Some of them also have independent steering. They run on diesel engines having a power output between 15 to 60 kW.

13 Dumpers / Tenders

Small dumpers and tenders (e.g. wheel steered site dumpers, articulated steered site dumpers, crawler dumpers etc.) are used for transport of goods at construction sites. Most of them run with diesel engines with a power output of about 5 to 50 kW, some have 4-stroke petrol engines with a power output between 5 to 10 kW.

14 Aerial Lifts

Small aerial lifts (< 2 kW) run mainly on electrical engines, only some on small mainly 2-stroke petrol engines with a power output of 3 to 10 kW. Large aerial lifts and work platforms are mounted on truck chassis and are operated by separate engines with a power output of 5 to 25 kW or by the vehicle engine utilizing a pneumatic system. Attention must be paid to avoid double counting with the category 'On road vehicles'.

15 Fork Lifts

Forklift trucks, from small ones like pallet stacking trucks to large ones like stacking straddle carriers, are equipped with electrical or internal combustion engines. Electrical engines are mostly used for indoor material handling. The internal combustion engines run with petrol or LPG and/or diesel fuel. In general, they have a power output between 20 and 100 kW. The engine displacement is between 1.5 to 4 litres for 4-stroke petrol/LPG engines and 2.5 to 6 litres for diesel engines.

16 Generator Sets

There are three main groups of power packs used. Small ones which can be carried by 1 or 2 persons. They have an output of 0.5 to 5 kW and are powered by 4-stroke engines. Some of the very small sets still run with 2-stroke engines. Medium ones which can be put on small one axle / two or four wheel trailer. They are 3 or 4 cylinder diesel engine powered and have an output of about 5 to 100 kW. Larger engines are turbo charged. Larger power packs are actually 'small mobile power plants', put into a container and having a power output of 100 to about 1000 kW. Nearly all engines are turbo charged. Generator sets above 1000 kW are not considered as mobile machinery.

17 Pumps

Mobile pumps are offered with a power range between 0.5 to 70 kW. Many of the pumps in use are operated with electric engines. If not, all types of fuels are used except LPG. However, above about 10 kW power output 2-stroke and above 20 kW power output 4-stroke petrol engines are not readily need anymore.

18 Air / Gas Compressors

Nearly all of the small compressors used for handicraft purposes run with electric engines. Large compressors used for construction works, are equipped with diesel engines with a power output between 10 and 120 kW.

19 Welders

Small mobile welders (< 10 kW) are also offered with 4-stroke petrol engines, all larger ones are diesel engine equipped and go up to about 40 kW.

20 Refrigerating Units

Diesel engines are used to operate refrigerators which are mounted on trucks and train wagons for cooling purposes. The power output of such units is in the range of 10 to 20 kW.

21 Other General Industrial Equipment

These are sweepers, scrubbers, broomers, pressure washers, slope and brush cutters, swappers, piste machines, ice rink machines, blowers, vacuums etc. not belonging to on-road vehicles. Petrol and diesel engines are used.

22 Other Material Handling Equipment

These are for example conveyors, tunnel locomotives, snow clearing machines, industrial tractors, pushing tractors. Mainly diesel engines are used.

23 Other Construction Equipment

Under this heading falls paving and surfacing equipment, bore / drill rigs, crushing equipment, peat break machines, concrete breakers / saws, pipe layers etc. Mainly diesel and 2-stroke gasoline engines are used.

3.1.7 SNAP 0809xx Household and Gardening

01 Trimmers / Edgers / Brush Cutters

This equipment is mainly 2-stroke petrol engine equipped and has about 0.25 to 1.4 kW power output.

02 Lawn Mowers

Mowers are either 2-stroke or 4-stroke petrol engine powered, having a power output between 0.5 and 5 kW. Some rear engine riding mowers are relatively powerful, used to treat large lawn surfaces. Mainly 1- or 2-cylinder diesel engines and 4-stroke petrol engines are used, having a power output of about 5 to 15 kW. Front mowers are professional like equipment for lawn cutting and mainly diesel or 4-stroke petrol engine powered. The power output ranges from 1,5 to 5 kW, displacements between 100 and 250 ccm.

03 Hobby Chain Saws

Do-it-yourself motorsaws are mainly equipped with 2-stroke petrol engines (some have electric engines). Small (hobby) motorsaws have a power output of about 1 to 2 kW (professionally used motorsaws of about 2 to 6 kW, cf. sector 'Forestry').

04 Snow Mobiles / Skidoos

These are small 'moped-like' snow vehicles, equipped with 2- and 4-stroke gasoline engines with a power output of 10 to 50 kW.

05 Other Household and Gardening Equipment

Under this heading lawn and garden tractors, wood splitters, snow blowers, tillers etc. are covered.

06 Other Household and Gardening Vehicles

This heading covers non-road vehicles like all terrain vehicles, off-road motor cycles, golfcarts etc.

Table 3-1: Engine-types of 'Off-road' machinery which should be covered under the CORINAIR 1990 SNAP codes 0801 to 0803

			Engine Type			
SNAP	**Code**	**Vehicle / Machinery Type**	**D**	**2SG**	**4SG**	**LPG**
08 02	01	Shunting locs	x			
	02	Rail-cars	x			
	03	Locomotives	x			
08 03	01	Sailing Boats with auxiliary engines	x	x		
	02	Motorboats / Workboats	x	x	x	
	03	Personal Watercraft		x		
	04	Inland Goods Carrying Vessels	x			
08 06	01	2-wheel tractors	x	x	x	
	02	Agricultural tractors	x			
	03	Harvesters / Combiners	x			
	04	Others (sprayers, manure distributors, etc.)	x	x	x	
08 07	01	Professional Chain Saws / Clearing Saws		x		
	02	Forest tractors / harvesters / skidders	x			
	03	Others (tree processors, haulers, forestry cultivators etc.)	x	x		
08 08	01	Asphalt/Concrete Pavers	x			
	02	Plate compactors / Tampers / Rammers	x	x	x	
	03	Rollers	x			
	04	Trenchers / Mini Excavators	x			
	05	Excavators (wheel/crowler type)	x			
	06	Cement and Mortar Mixers	x		x	
	07	Cranes	x			
	08	Graders / Scrapers	x			
	09	Off-Highway Trucks	x			
	10	Bull Dosers (wheel/crowler type)	x			
	11	Tractors/Loaders/Backhoes	x			
	12	Skid Steer Tractors	x			
	13	Dumper/Tenders	x		x	
	14	Aerial Lifts	x	x		
	15	Forklifts	x		x	x
	16	Generator Sets	x	x	x	
	17	Pumps	x	x	x	
	18	Air/Gas Compressors	x			
	19	Welders	x			
	20	Refrigerating Units	x			
	21	Other general industrial equipment (broomers, sweepers etc.)	x	x	x	
	22	Other material handling equipment (conveyors etc.)	x			
	23	Other construction work equipment (paving/surfacing etc.)	x	x		
08 09	01	Trimmers/Edgers/Bush Cutters		x		
	02	Lawn Mowers	x	x	x	
	03	Hobby Chain Saws		x		
	04	Snowmobiles/Skidoos		x	x	
	05	Other household and gardening equipment	x	x	x	
	06	Other household and gardening vehicles	x	x	x	

<u>Legend:</u>

Legend:	D:	diesel (fuel used: diesel oil for road transport)
	2SG:	2-stroke gasoline (fuel used: motor gasoline)
	4SG:	4-stroke gasoline (fuel used: mixture of motor gasoline and lubrication oil)
	LPG:	LPG (fuel used: liquefied petroleum gases)

4 SIMPLER METHODOLOGY

Several methods to calculate emissions can be foreseen. In all cases, emission estimates have to be based on a mixture of (some) hard facts and a (large) number of assumptions. It is, therefore, important to define a method to be used for the estimation work which builds upon as many hard facts as possible, reducing at the same time the number of assumptions. However, when searching for such a compromise method, one always has to keep in mind the objective of the work, i.e. the final data usage which determines to a large extent the source category split requirements.

A simple methodology for estimating emissions is based on total fuel consumption data which then have to be multiplied by appropriate bulk emission factors (Eggleston et al. 1993). Therefore, the formula to be applied in this case is:

$$E_i = FC \cdot Ef_i \qquad (1)$$

with

E_i = mass of emissions of pollutant i during inventory period

FC = fuel consumption

EF_i = average emissions of pollutant i per unit of fuel used

With regard to emissions of CO_2, SO_2 and emissions of lead, it is proposed to use the following equations:

Ultimate CO_2 emissions are estimated on the basis of fuel consumption only, assuming that the carbon content of the fuel is fully oxidised to CO_2**.** The following formula is applied:

$$\text{mass of } CO_2 = 44.011 \text{ (mass of fuel}/(12.011 + 1.008 \cdot r_{H/C})) \qquad (2)$$

with

$r_{H/C}$ = the ratio of hydrogen to carbon atoms in the fuel (~1.8 for gasoline and ~2.0 for diesel)

If **end-of-pipe CO_2** emissions are to be calculated, then other emissions of C atoms in the form of CO, VOC and particulate emissions have to be taken into account. Then the following formula is applied :

$$\begin{aligned}\text{mass of } CO_2 = 44.011 \text{ (mass of fuel}/(12.011 + 1.008 \cdot r_{H/C}))\\ - \text{mass of CO}/28.011 - \text{mass of VOC}/13.85\\ - \text{mass of particulates}/12.011) \qquad (2a)\end{aligned}$$

The emissions of SO_2 are estimated by assuming that all sulphur in the fuel is transformed completely into SO_2 using the formula:

$$E_{SO2} = 2 \sum_j \sum_l k_{S,l}\, b_{j,l} \qquad (3)$$

with

$k_{S,l}$ = weight related sulphur content of fuel of type l [kg/kg]

$b_{j,l}$ = total annual consumption of fuel of type l in [kg] by source category j

For the actual figure of $b_{j,l}$ the statistical fuel consumption should be taken, if available.

Emissions of lead are estimated by assuming that 75% of lead contained in the fuel is emitted into air. The formula used is:

$$E_{Pb} = 0.75 \sum_j \sum_l k_{Pb,l}\, b_{j,l} \tag{4}$$

with

$k_{Pb,l}$ = weight related lead content of fuel of type l in [kg/kg]

Since the simple methodology outlined above averages over different types of engines, using different types of fuels, it can provide only broad estimates at its best.

5 DETAILED METHODOLOGY

The simple methodology outlined under section 4 makes use of fuel statistics, to be multiplied with bulk emission factors accordingly expressed. In fact, at first glance it seems to be an easy way to estimate (by order of magnitude) the emissions of off-road machinery and equipment taking estimated average emission factors (see, for example, OECD 1991) and to multiply them by the statistical fuel consumption. Unfortunately, this is quite often not feasible, because the statistical fuel consumption data are not available in the required detail. For most countries, only for the sector 'Railways' and the sub-part 'Goods Carrying Vessels', which is part of the sector 'Inland Waterways', fuel consumption data seem to be specific enough to be used for an order of magnitude estimate.

Therefore, in the following, a more detailed methodology is described, which is mainly based on the US-EPA method for estimating off-road emissions (US-EPA 1991).
The following basic formula is used to calculate emissions:

$$E = N \times HRS \times HP \times LF \times EF_i \tag{5}$$

where:

E = mass of emissions of pollutant i during inventory period
N = source population (units)
HRS = annual hours of use
HP = average rated horsepower
LF = typical load factor
EF_i = average emissions of pollutant i per unit of use (e.g. [g/kWh])

This approach has been complemented based on a recently published report on emissions of construction work machinery in Switzerland (Infras 1993). In a first step, the methodology applied there has been somewhat simplified in order to reduce the data input requirements and then, in a second step, it has been extended to other types of machinery and, more importantly, engine types.

In this methodology, the parameters N, HRS, HP, LF, EF_i of the basic formula (5) mentioned above are split further by classification systems as follows:

N: the machinery/vehicle population is split into different age and power ranges.

HRS: the annual working hour is a function of the age of the equipment/vehicles; therefore, for each sub category, individual age dependent usage patterns can be defined.

HP: the mean horse power is a function of the power distribution of the vehicles/machinery; therefore, for each sub category an individual power distribution can be defined within given power ranges.

EF_i: the emission factor is, for each pollutant, a function of age and power output, and, for diesel engines, engine type mix; therefore, the emission factors are modified taking into account these dependencies.

Many of the input data required for the application of this approach (e.g. the usage and the population data) are not part of general statistical year-books. Therefore, special investigations have to be carried out and reasonable estimates can be made, based on general technical experiences.

With regard to the typical load factor, it is proposed to apply, as far as possible, the weighting factors laid down in ISO DP 8178. Tables 5.2-1 and 5.2-2 provide examples of the kind of vehicles and mobile machinery which fall under the different test cycles.

In this advanced approach, in addition to exhaust emissions, evaporative emissions of gasoline engines are taken into account. In reality evaporative emissions occur under all conditions, e.g. while the machine/vehicle is in operation or not in operation. However, the emissions of off road machines and vehicles are not very well known. Therefore, only diurnal losses, based on US-EPA's methodology, are taken into account. That means that hot soak, resting and running losses are not included.

The emissions are estimated using the formula:

$$E = N \text{ x } HRS \text{ x } EF_{eva} \qquad (6)$$

The parameters N and HRS are identical to those used for the estimation of exhaust emissions. The emission factor EF_{eva} needs to be tabled.

In principle, elements of the above described approach are used in many national studies and by industry (Utredning 1989, Achten 1990, Barry 1993, Puranen et al. 1992, Danish Environmental Protection Agency 1992, Caterpillar 1992, ICOMIA 1993).

Table 5.2-1: Test points and weighting factors of ISO DP 8178 test cycles

B-type mode number	1	2	3	4	5	6	7	8	9	10	11
Torque	100	75	50	25	10	100	75	50	25	10	0
Speed	rated speed					intermediate speed					low idle
Off-road vehicles											
Type C1	0.15	0.15	0.15		0.1	0.1	0.1	0.1			
Type C2				0.06		0.02	0.05	0.32	0.30	0.10	
Constant speed											
Type D1	0.3	0.5	0.2								
Type D2	0.05	0.25	0.3	0.3	0.1						
Locomotives											
Type F	0.25							0.15			0.6
Utility, lawn and garden											
Type G1						0.09	0.2	0.29	0.3	0.07	0.05
Type G2	0.09	0.2	0.29	0.3	0.07						0.05
Type G3	0.9										0.1
Marine application											
Type E1	0.06	0.11					0.19	0.32			0.3
Type E2	0.2	0.5	0.15	0.15							
Marine application											
Mode number E3	1					2		3		4	
Power % of rated power	100					75		50		25	
Speed % of rated speed	100					91		80		63	
Weighting factor	0.2					0.5		0.15		0.15	
Mode number E4	1					2		3		4	5
Speed % of rated speed	100					80		60		40	idle
Torque % of rated torque	100					71.6		46.5		25.3	0
Weighting factor	0.06					0.14		0.15		0.25	0.4
Mode number E5	1					2		3		4	5
Power % of rated p.	100					75		50		25	0
Speed % of rated speed	100					91		80		63	idle
Weighting factor	0.08					0.13		0.17		0.32	0.3

Test cycle **A** (13 - mode cycle)

Mode number cycle A	1	2	3	4	5	6	7	8	9	10	11	12	13
Speed	Low idle speed	Intermediate speed					Low idle speed	Rated speed					Low idle speed
% Torque	0	10	25	50	75	100	0	100	75	50	25	10	0
Weighting factor	0.25/3	0.08	0.08	0.08	0.08	0.25	0.25/3	0.1	0.02	0.02	0.02	0.02	0.25/3

Table 5.2-2: Test cycles of ISO DP 8178 for industrial engine applications with typical examples

Cycle A	**Automotive, Vehicle Applications**	
	Examples:	forestry and agricultural tractors, diesel and gas engines for on-road applications
Cycle B	**Universal**	
Cycle C	**Off-Road Vehicles and Industrial Equipment**	
	C1:	Diesel powered off-road industrial equipment
	Examples:	industrial drilling rigs, compressors etc.; construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, off-highway trucks, etc.; agricultural equipment, rotary tillers; forestry equipment; self propelled agricultural vehicles; material handling equipment; fork lift trucks; hydraulic excavators; road maintenance equipment (motor graders, road rollers, asphalt finishers); snow plow equipment; airport supporting equipment; aerial lifts
	C2:	off-road vehicles with spark ignited industrial engines > 20 kW
	Examples:	fork lift trucks; airport supporting equipment; material handling equipment; road maintenance equipment; agricultural equipment
Cycle D	**Constant Speed**	
	D1:	power plants
	D2:	generating sets with intermittent load
	Examples:	gas compressors, refrigerating units, welding sets, generating sets on board of ships and trains, chippers, sweepers
	D3:	generating sets onboard ships (not for propulsion)
Cycle E	**Marine Application**	
	E1:	Diesel engines for craft less than 24 m length (derived from test cycle B)
	E2:	heavy duty constant speed engines for ship propulsion
	E3:	heavy duty marine engines
	E4:	pleasure craft spark-ignited engines for craft less than 24 m length
	E5:	Diesel engines for craft less than 24 m length (propeller law)
Cycle F	**Rail Traction**	
	Examples:	locomotive, rail cars
Cycle G	**Utility, Lawn and Garden, typically < 20 kW**	
	G1:	non hand held intermediate speed application
	Examples:	walk behind rotary or cylinder lawn mowers, front or rear engine riding lawn mowers, rotary tillers, edge trimmers, lawn sweepers, waste disposers, sprayers, snow removal equipment, golf carts
	G2:	non hand held rated speed application
	Examples:	portable generators, pumps, welders, air compressors; rated speed application may also include lawn and garden equipment which operates at engine rated speed
	G3:	hand held rated speed applications
	Examples:	edge trimmers, string trimmers, blowers, vacuums, chain saws, portable saw mills

6 RELEVANT ACTIVITY STATISTICS

The following types of fuels are used in the sectors:

• for diesel engines:	Diesel oil for road transport (NAPFUE code 205),
• for 2-stroke gasoline engines:	Mixture of motor gasoline (NAPFUE code 208) and lubrication oil, mixing rate is about 25:1,
• for 4-stroke gasoline engines:	Motor gasoline (NAPFUE code 208),
• for LPG engines:	Liquefied petroleum gas (NAPFUE code 303).

7 POINT SOURCE CRITERIA

There are no relevant point sources which fall under the source categories dealt with in this chapter.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

With regard to the simple methodology, Table 8-1 shows the emission factors proposed for diesel engines and Table 8-2 shows the bulk emission factors for gasoline engines. No emission factors for CO_2, SO_2 and lead are given because these emissions depend fully on actual fuel composition and fuel consumption. For heavy metals and persistent organic compounds, the emission factors given in Tables 8-1 and 8-2 should be applied.

With regard to the advanced approach, Tables 8-3 to 8-8 provide the baseline emission factors. For diesel engines, these baseline emission factors are modified depending on the engine design parameters in accordance with Table 8-9. Moreover, in order to take into account the change of emissions with the age, degradation factors as shown in Tables 8-10 to 8-12 are defined. It should be noted that the emission factors calculated by the advanced approach differ somewhat from those proposed to be used in the basic approach. Emission factors for SO_2, CO_2, heavy metals and persistent organic pollutants have to be taken from Tables 8-1 and 8-2, or have to be calculated based on fuel composition and fuel consumption data. Emission factors for persistent organic pollutants for LPG powered engines are not available. However, this source can be considered as irrelevant compared to other sources. Finally, Table 8-13 presents a set of emission factors for the calculation of evaporative losses from the gasoline powered engines.

The advanced approach can be considered as the one providing emission estimates of significantly better quality than the simple approach. It is also more transparent, because all major parameters influencing emissions are covered, e.g. the user of this approach has to report the assumptions made for selecting emission factors. Moreover, this approach allows one to take into account the legislative steps which are currently in preparation at EU level. It can be assumed that the emission factors for persistent organic pollutants will not be affected by these measures.

It should be mentioned that, apart from smoke emission of agricultural tractors (CEC 1977) there are no emission limiting regulations in force in Europe for the sectors covered by this note. However, currently there is legislation in preparation for parts of the sector, e.g. diesel engines used in construction works (European Commission 1993).

Table 8-1: Bulk emission factors for 'Other Mobile Sources and Machinery', part 1: Diesel engines

Diesel Engines [g/kg fuel]	NOx	NM-VOC	CH_4	CO	NH_3	N_2O	PM
Agriculture	50.3	7.27	0.17	16.0	0.007	1.29	5.87
Forestry	50.3	6.50	0.17	14.5	0.007	1.32	5.31
Industry	48.8	7.08	0.17	15.8	0.007	1.30	5.73
Household	48.2	10.4	0.17	22.9	0.007	1.23	7.65
Railways	39.6	4.65	0.18	10.7	0.007	1.24	4.58
Inland waterways	42.5	4.72	0.18	10.9	0.007	1.29	4.48

Heavy Metal Emission Factors for all Categories in mg/kg fuel

Cadmium	Copper	Chromium	Nickel	Selenium	Zinc
0.01	1.7	0.05	0.07	0.01	1

Persistent Organic Pollutants Emission Factors for all Categories in mg/kg fuel

Diesel engines	[µg/kg fuel] irrespective of sector
Benz(a)anthracene	80
Benzo(b)fluoranthene	50
Dibenzo(a,h)anthracene	10
Benzo(a)pyrene	30
Chrysene	200
Fluoranthene	450
Phenanthene	2500

Remark: Emission factors are still quite uncertain and may need revision as soon as more information becomes available

Table 8-2: Bulk emission factors for 'Other Mobile Sources and Machinery', part 2: gasoline engines

Gasoline 4-stroke [g/kg fuel]	NOx	NMVOC	CH_4	CO	NH_3	N_2O
Agriculture	7.56	73.6	3.68	1486	0.005	0.07
Forestry	-	-	-	-	-	-
Industry	9.61	43.4	2.17	1193	0.005	0.08
Household	8.00	110	5.50	2193	0.005	0.07
Railways	-	-	-	-	-	-
Inland waterways	9.70	34.4	1.72	1022	0.005	0.08

Persistent Organic Pollutants Emission Factors for all Categories in mg/kg fuel

Gasoline 4-stroke	[µg/kg fuel] irrespective of sector
Benz(a)anthracene	75
Benzo(b)fluoranthene	40
Dibenzo(a,h)anthracene	10
Benzo(a)pyrene	40
Chrysene	150
Fluoranthene	450
Phenanthene	1200

Gasoline 2-stroke [g/kg fuel]	NOx	NMVOC	CH_4	CO	NH_3	N_2O
Agriculture	1.70	617	6.17	1070	0.004	0.02
Forestry	1.55	762	7.67	1407	0.004	0.02
Industry	2.10	602	6.00	1103	0.004	0.02
Household	1.77	813	8.13	1572	0.004	0.02
Railways	-	-	-	-	-	-
Inland waterways	2.67	505	5.06	892	0.004	0.02

Heavy Metal Emission Factors for all Categories in mg/kg fuel

Cadmium	Copper	Chromium	Nickel	Selenium	Zinc
0.01	1.7	0.05	0.07	0.01	1

Remark:
- POP emission factors for gasoline 2-stroke engines are not available
- Emission factors are still quite uncertain and may need revision as soon as more information becomes available

Table 8-3: Baseline emission factors for uncontrolled diesel engines in [g/kWh]

POLLUTANT	**Power Range in kW**							
[g/kWh]	**0-20**	**20-37**	**37-75**	**75-130**	**130-300**	**300-560**	**560-1000**	**>1000**
NO_x	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
N_2O	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CH_4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CO	8.38	6.43	5.06	3.76	3.00	3.00	3.00	3.00
NMVOC	3.82	2.91	2.28	1.67	1.30	1.30	1.30	1.30
PM	2.22	1.81	1.51	1.23	1.10	1.10	1.10	1.10
NH_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
FC	271	269	265	260	254	254	254	254

Equations used:

NOx: 14.36, irrespective of power output
NMVOC: for P ó 130 kW: $12.0 - 6.5 \cdot P^{0,1}$; for P > 130 kW: 1.3
CO: for P ó 130 kW: $26.0 - 14 \cdot P^{0,1}$; for P > 130 kW: 3.0
PM: for P ó 130 kW: $6.0 - 3.0 \cdot P^{0,1}$; for P > 130 kW: 1.1
N_20: 0.35, irrespective of power output and engine type
CH_4: 0.05, irrespective of power output and engine type
NH_3: 0.002, irrespective of power output and engine type
FC: for P ó 130 kW: $272 - 0.12 \cdot P$; for P > 130 kW: 254

P = Max. Power output

Table 8-4: Baseline emission factors for stage I (for 37 ó P < 560 kW) controlled diesel engines in [g/kWh], irrespective of engine type

POLLUTANT	**Power Range in kW**							
[g/kWh]	**0-20**	**20-37**	**37-75**	**75-130**	**130-300**	**300-560**	**560-1000**	**>1000**
NO_x	14.4	14.4	*9.20*	*9.20*	*9.20*	*9.20*	14.4	14.4
N_2O	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CH_4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CO	8.38	6.43	*6.50*	*5.00*	*5.00*	*5.00*	3.00	3.00
NMVOC	3.82	2.91	*1.30*	*1.30*	*1.30*	*1.30*	1.30	1.30
PM	2.22	1.81	*0.85*	*0.70*	*0.54*	*0.54*	1.10	1.10
NH_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
FC	271	269	265	260	254	254	254	254

Note: The above table is produced on the basis of the emission factors for the uncontrolled case and replacing the emission standards proposed by the EC (European Commission 1993) in the appropriate categories (numbers in italics). For CO, the emission standards proposed are in some cases higher than the emission factors of the uncontrolled engines. In this cases it is proposed to use the “uncontrolled” values.

Table 8-5: Baseline emission factors for stage II (for 20 ó P < 560 kW) controlled diesel engines in [g/kWh], irrespective of engine type

POLLUTANT	**Power Range in kW**							
[g/kWh]	**0-20**	**20-37**	**37-75**	**75-130**	**130-300**	**300-560**	**560-1000**	**>1000**
NO_x	14.4	*8.50*	*8.00*	*7.00*	*7.00*	*7.00*	14.4	14.4
N_2O	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
CH_4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CO	8.38	*5.50*	*5.00*	*5.00*	*3.50*	*3.50*	3.00	3.00
NMVOC	3.82	*1.50*	*1.30*	*1.00*	*1.00*	*1.00*	1.30	1.30
PM	2.22	*0.80*	*0.40*	*0.30*	*0.20*	*0.20*	1.10	1.10
NH_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
FC	271	269	265	260	254	254	254	254

Note: The above table is produced on the basis of the emission factors for the uncontrolled case and replacing the emission standards proposed by the EC (European Commission 1993) in the appropriate categories (numbers in italics). For CO, the emission standards proposed are in some cases higher than the emission factors of the uncontrolled engines. In this cases it is proposed to use the “uncontrolled” values.

Table 8-6: Baseline emission factors for uncontrolled 2-stroke gasoline engines in [g/kWh]

POLLUTANT	Power Range in kW							
[g/kWh]	0-2	2-5	5-10	10-18	18-37	37-75	75-130	130-300
NO_x	1.00	1.02	1.05	1.10	1.19	1.38	1.69	2.45
N_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CH_4	6.60	3.55	2.70	2.26	2.01	1.84	1.76	1.69
CO	1500	643	460	380	342	321	312	306
NMVOC	660	355	270	226	200	184	175	169
NH_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
FC	500	476	462	449	438	427	417	406

Equations used:

CO: $300 + 1200/P$
NMVOC: $160 + 500/P^{0.75}$
NOx: $6{,}73 \cdot 10^{-3} * P + 1$
CH_4: $1{,}6 + 5/P^{0.75}$ (1 % of VOC)
N_2O: 0.01
NH_3: 0.002
FC: $100 + 400/P^{0.05}$

P = Max. Power output

Table 8-7: Baseline emission factors for uncontrolled 4-stroke gasoline engines in [g/kWh]

POLLUTANT [g/kWh]								
	0-2	**2-5**	**5-10**	**10-18**	**18-37**	**37-75**	**75-130**	**130-300**
NO_x	4.00	4.00	4.02	4.04	4.08	4.15	4.28	4.58
N_2O	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
CH4	5.30	2.25	1.40	0.96	0.71	0.54	0.46	0.39
CO	2300	871	567	433	370	336	320	309
NMVOC	106	45.1	28.7	19.1	14.1	10.9	9.10	7.78
NH_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
FC	430	409	396	386	376	366	358	348

Equations used:

CO: $300 + 2000/P$
NMVOC: $6 + 100/P^{0.75}$
NOx: $2{,}7 \cdot 10^{-3} * P + 4.0$
CH_4: $0{,}3 + 5/P^{0.75}$ (5% of VOC)
N_2O: 0.03
NH_3: 0.003
FC: $80 + 350/P^{0.05}$

P = Max. Power output

Table 8-8: Baseline emission factors for uncontrolled 4-stroke LPG engines in [g/kWh]

NOx:	10, irrespective of power output
NMVOC:	13.5, irrespective of power output
CO:	15, irrespective of power output
NH_3:	0.003, irrespective of power output
N_20:	0.05, irrespective of power output
CH_4:	1.0, irrespective of power output
FC:	350, irrespective of power output

Table 8-9: Pollutant weighing factors as a function of engine design parameters for uncontrolled diesel engines

Engine type	NO_x	$NMVOC/CH_4$	CO	PM	$FC/SO_2/CO_2$	N_2O/NH_3
NADI	1.0	0.8	0.8	0.9	0.95	1.0
TCDI/ITCDI	0.8	0.8	0.8	0.8	0.95	1.0
NAPC	0.8	1.0	1.0	1.2	1.1	1.0
TCPC	0.75	0.95	0.95	1.1	1.05	1.0
ITCPC	0.7	0.9	0.9	1.0	1.05	1.0

NADI: Naturally Aspirated Direct Injection
TCDI: Turbo-Charged Direct Injection
ITCDI: Intercooled Turbo-Charged Direct Injection
ITCPC: Intercooled Turbo-Charged Prechamber Injection
NAPC: Naturally Aspirated Prechamber Injection
TCPC: Turbo-Charged Prechamber Injection

Table 8-10: Degradation factors of diesel engines for the different pollutants and fuel consumption

$CH_4/NMVOC$:	1.5% per year
CO:	1.5% per year
NOx:	0% per year
$FC/SO_2/CO_2$:	1% per year
N_2O/NH_3:	0% per year
PM:	3% per year

Table 8-11: Degradation factors of 2-stroke gasoline engines

$CH_4/NMVOC$:	1.4% per year
CO:	1.5% per year
NOx:	- 2.2% per year
$FC/SO_2/CO_2$:	1% per year
N_2O/NH_3:	0% per year

Table 8-12: Degradation factor of 4-stroke gasoline and 4-stroke LPG engines

$CH_4/NMVOC$:	1.4% per year
CO:	1.5% per year
NOx:	- 2.2% per year
$FC/SO_2/CO_2$:	1% per year
N_2O/NH_3:	0% per year

Table 8-13: Proposed emission factors for evaporative losses in g/h

SNAP	Code	Vehicle / Machinery Type	2SG	4SG
0802	01	Shunting locs		
	02	Rail-cars		
	03	Locomotives		
0803	01	Sailing Boats with auxiliary engines	0.75	
	02	Motorboats / Workboats	11.0	11.0
	03	Personal Watercraft	0.75	
	04	Inland Goods Carrying Vessels		
0806	01	2-wheel tractors	0.30	0.30
	02	Agricultural tractors		
	03	Harvesters / Combiners		
	04	Others (sprayers, manure distributors, etc.)	0.3	0.30
0807	01	Professional Chain Saws / Clearing Saws	0.03	
	02	Forest tractors / harvesters / skidders		
	03	Others (tree processors, haulers, forestry cultivators etc.)	0.07	
0808	01	Asphalt/Concrete Pavers		
	02	Plate compactors / Tampers / Rammers	0.11	0.12
	03	Rollers		
	04	Trenchers / Mini Excavators		
	05	Excavators (wheel/crowler type)		
	06	Cement and Mortar Mixers		1.20
	07	Cranes		
	08	Graders / Scrapers		
	09	Off-Highway Trucks		
	10	Bull Dosers (wheel/crowler type)		
	11	Tractors/Loaders/Backhoes		
	12	Skid Steer Tractors		
	13	Dumper/Tenders		0.40
	14	Aerial Lifts	2.30	
	15	Forklifts		2.25
	16	Generator Sets	0.13	0.12
	17	Pumps	0.10	0.09
	18	Air/Gas Compressors		
	19	Welders		
	20	Refrigerating Units		
	21	Other general industrial equipment (broomers, sweepers etc.)	1.20	1.20
	22	Other material handling equipment (conveyors etc.)		
	23	Other construction work equipment (paving/surfacing etc.)	1.20	
0809	01	Trimmers/Edgers/Bush Cutters	0.02	
	02	Lawn Mowers	0.05	0.05
	03	Hobby Chain Saws	0.01	
	04	Snowmobiles/Skidoos	1.00	1.00
	05	Other household and gardening equipment	0.05	0.05
	06	Other household and gardening vehicles	0.10	0.10

Legend:
2SG: 2-stroke gasoline (fuel used: motor gasoline)
4SG: 4-stroke gasoline (fuel used: mixture of motor gasoline and lubrication oil)

9 SPECIES PROFILES

There is still no systematic approach concerning the evaluation and the reporting of species profiles, e.g. it is not clear whether individual compounds, chemical groups or reactivity classes should be reported.

With regard to VOC profiles, Tables 9-1, 9-2 and 9-3 provide information as used by Veldt, Derwent and Loibl et al. in their work on emission estimates for the road transport sector. In principle, the composition given there can also be used for the sectors covered by this guidebook.

10 UNCERTAINTY ESTIMATES

For many sub-sectors, the estimation of emissions is still associated with quite large uncertainties due to the lack of information on vehicle and machinery population, emission factors, and conditions of use. Table 10-1 provides broad qualitative uncertainty estimates.

11 WEAKEST ASPECTS AND PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The detailed methodologies proposed in this chapter need no improvements in the short term because already they require more input than is statistically available. Therefore, efforts should concentrate on data collection (actual fuel use in sectors and subsectors, machinery population, conditions of use) and on emission factors for N_2O in general, and all pollutants as far as two-stroke gasoline powered machinery is concerned.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

The source categories covered by this chapter require to make use of somewhat different spatial allocation procedures:

- Agricultural, forestry and military emissions should be disaggregated using land use data
- Railway emissions should be disaggregated as a line source along tracks, in the way it will be done for on road emissions, or they could be treated as area source taking into account the railway track distribution
- Industrial and Household and Gardening emissions should be disaggregated using general population density data
- Inland waterways should be allocated to the appropriate inland water surfaces

Within each of the sectors further refinement is possible. However, since total emissions decrease with every further split it is questionable whether the additional efforts are justified.

Table 9-1: Composition of VOC emission of motor vehicles (data as provided by Veldt et al.)

A) Non-methane VOCs (composition in weight % of exhaust)

Species or group of species	Gasoline			Diesel	LPG
	Exhaust gases		Evaporation		
	4-stroke engine				
	(conventional)	3-way catalyst equipped			
Ethane	1.4	1.8		1	3
Propane	0.1	1	1	1	44
n-Butane	3.1	5.5	20	2	
i-Butane	1.2	1.5	10		
n-Pentane	2.1	3.2	15	2	
i-Pentane	4.3	7	25		
Hexane	7.1	6	15		
Heptane	4.6	5	2		
Octane	7.9	7			
Nonane	2.3	2			
Alkanes C>10	0.9	3		30 (1)	
Ethylene	7.2	7		12	15
Acetylene	4.5	4.5		4	22
Propylene	3.8	2.5		3	10
Propadiene	0.2				
Methylacetylene	0.3	0.2			
1-Butene	1.7	1.5	1	)	
1,3 Butadiene	0.8	0.5		) 2	
2-Butene	0.6	0.5	2	)	
1-Pentene	0.7	0.5	2		
2-Pentene	1.1	1	3	1	
1-Hexene	0.6	0.4	)		
1,3 Hexene	0.6	0.4	) 1.5		
Alkanes C>7	0.3	0.2	)	2 (1)	
Benzene	4.5	3.5	1	2	
Toluene	12.0	7	1	1.5	
o-Xylene	2.5	2		0.5	
m,p-Xylene	5.6	4	0.5	1.5	
Ethylbenzene	2.1	1.5		0.5	
Styrene	0.7	0.5			0.1
1,2,3-Trimethylbenzene	0.5	1			
1,2,4-Trimethylbenzene	2.6	4			
1,3,5-Trimethylbenzene	0.8	2			
Other aromatic compounds C9	3.8	3			
Aromatic compounds C>10	4.5	6		20 (1)	
Formaldehyde	1.7	1.1		6	4
Acetaldehyde	0.3	0.5		2	2
Other Aldehydes C4	0.3	0.2		1.5	
Acrolein	0.2	0.2		1.5	
2-Butenal				1.0	
Benzaldehyde	0.4	0.3		0.5	
Acetone	0.1	1		1.5	
	100	100	100	100	100

(1) C13

Table 9-1: continued

B) Methane (composition in weight % of exhaust)

Gasoline	
- conventional	5
- 3-way catalyst equipped	12
Diesel	4
LPG	3

Table 9-2: Composition of VOC-emissions (data as used by Derwent)

No.	Species	Percentage by mass speciation by source category, w/w %		
		petrol engines exhaust	diesel exhaust	petrol evaporation vehicles
0	methane	8.00	3.7	
1	ethane	1.30	0.5	
2	propane	1.20		
3	n-butane	1.95	2.5	19.990
4	i-butane	0.93	2.5	10.480
5	n-pentane	2.78	2.5	7.220
6	i-pentane	4.45	2.5	10.150
7	n-hexane	1.76	2.5	2.020
8	2-methylpentane	2.14	2.5	3.020
9	3-methylpentane	1.49	2.5	2.010
10	2,2-dimethylbutane	0.28	2.5	0.600
11	2,3-dimethylbutane	0.54	2.5	0.740
12	n-heptane	0.74	2.5	0.703
13	2-methylhexane	1.39	2.5	0.924
14	3-methylhexane	1.11	2.5	0.932
15	n-octane	0.37	2.5	0.270
16	methylheptanes	3.90	2.5	0.674
17	n-nonane	0.18	2.5	
18	methyloctanes	1.58	2.5	
19	n-decane	0.37	2.5	
20	methylnonanes	0.84	2.5	
21	n-undecane	2.75	2.5	
22	n-duodecane	2.75	2.5	
23	ethylene	7.90	11.0	
24	propylene	3.60	3.4	
25	1-butene	1.40	0.5	1.490
26	2-butene	0.50		2.550
27	2-pentene	0.90		2.350
28	1-pentene	0.70	0.7	0.490
29	2-methyl-1-butene	0.70		0.670
30	3-methyl-1-butene	0.70	0.5	0.670
31	2-methyl-2-butene	1.40	0.5	1.310
32	butylene	0.50		
33	acetylene	6.30	3.2	
34	benzene	3.20	2.6	2.340
35	toluene	7.20	0.8	5.660
36	o-xylene	1.58	0.8	1.590
37	a-xylene	2.06	0.8	1.880
38	p-xylene	2.06	0.8	1.880
39	ethylbenzene	1.20	0.8	1.320
40	n-propylbenzene	0.16	0.5	0.410
41	i-propylbenzene	0.13	0.5	0.120
42	1,2,3-trimethylbenzene	0.40	0.5	0.310
43	1,2,4-trimethylbenzene	1.60	0.5	1.600
44	1,3,5-trimethylbenzene	0.50	0.5	0.390
45	o-ethyltoluene	0.38	0.5	0.370
46	a-ethyltoluene	0.63	0.5	0.640
47	p-ethyltoluene	0.63	0.5	0.640
48	formaldehyde	1.60	5.9	
49	acetaldehyde	0.35	1.0	
50	proprionaldehyde	0.57	1.0	
51	butyraldehyde	0.07	1.0	
52	i-butyraldehyde		1.0	
53	valeraldehyde	0.03		
54	benzaldehyde	0.39		
55	acetone	0.14	2.0	

Table 9-3: Composition of VOC emissions from traffic and mobile sources (Loibl et al. 1993)

	Exhaust - Conventional Cars	Exhaust - Catalyst Cars	Exhaust - Cold Start (all cars)	2 stroke Engines	Diesel Engines	Evaporation losses
Non reactive						
Ethane	2	3	1	1	-	-
Acetylene	8	3	4	2	-	-
Paraffins						
Propane	-	-	-	1	-	2
Higher Paraffins	32	48	45	72	52	85
Olefins						
Ethene	11	7	6	3	6	-
Propene	5	4	2	1	3	-
Higher Olefins (C4+)	6	9	7	9	3	10
Aromatics						
Benzene	5	1	4	2	-	1
Toluene	10	11	140	3	-	1
Higher Aromatics (C8+)	21	6	21	6	12	1
Carbonyls						
Formaldehyde	-	8	-	-	13	-
Acetaldehyde	-	-	-	-	3	-
Higher Aldehydes (C3+)					4	
Cetones					1	
Other NMVOC						
Alcohols, esters, ethers						
Acids						
Halogenated Compounds						
Other/undefined					3	

Table 10-1: Uncertainty estimates for input data required to apply the proposed methodologies

Sector	Subsector	Total Fuel Consumption	Parameter Unit Fuel Consumption	Population	Load Factor	Annual Hours of use	Power Range	Emission factor for the pollutants [1]									Age Distri-bution	Engine Design Distributio
								CO_2	CO	NMVOC	CH_4	NO_x	N_2O	NH_3	SO_2	PM		
Agriculture	02 Tractors	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	03 Harvesters	D	B	C	D	C	B	B	B	B	C	B	E	E	B	B	D	D
	01/04 All others	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Forestry	02 Tractors	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	01/03 All others	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Industry	01, 04, 05, 07 to 13, 15 (all types of con- struction equipment)	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D
	02, 03, 06, 14, 16 to 22	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Military	(all)	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Household & Gardening	all subsectors	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
Railways	all subsectors	B	B	A	B	B	B	B	B	B	C	B	E	E	B	B	B	B
Inland Waterways	01 Sailing boats, Motor boats, Personal watercraft	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
	04 Inland Goods Carrying Vessels	D	B	A	C	D	C	B	B	B	C	B	E	E	B	B	D	D

[1] As a rule, the emission factors to be used in the “simple methodology” are one quality class worse.

Table 10-1: Legend

Emitting activity rates

Data Quality A:	very precise value, specifically known.
Data Quality B:	precise specific value.
Data Quality C:	approximate value, but sufficiently well estimated to be considered correctly representative.
Data Quality D:	approximate value, indicating good order of magnitude.
Data Quality E:	very approximate value, estimation of a possible order of magnitude.

Emission factors

Data Quality A:	Data set based on a composite of several tests using analytical techniques and can be considered representative of the total population.
Data Quality B:	Data set based on a composite of several tests using analytical techniques and can be considered representative of a large percentage of the total population.
Data Quality C:	Data set based on a small number of tests using analytical techniques and can be considered reasonably representative of the total population.
Data Quality D:	Data set based on a single source using analytical techniques or data set from a number of sources where data are based on engineering.
Data Quality E:	Data set based on engineering calculations from one source; data set(s) based on engineering judgment; data set(s) with no documentation provided; may not be considered representative of the total population.

13 TEMPORAL DISAGGREGATION CRITERIA

There are no relevant reports available about the temporal disaggregation of emissions from the source categories covered. Therefore, only 'common sense criteria' can be applied. Table 13-1 provides a proposal for the 'average' European disaggregation of emissions. In practice, the temporal disaggregation might differ considerably among countries.

Table 13-1: Proposal of the average European temporal disaggregation of emissions. The figures indicate percentages of the disaggregation of total seasonal, weekly, and hourly emissions to seasons, days, and hours.

		Seasonal Disaggregation (in %)			
Sector	Subsector	Winter	Spring	Summer	Fall
Inland Waterways	all but 04	5	10	75	10
	04, Inland Goods Carrying Vessels	20	30	30	20
Agriculture	all	10	20	50	20
Forestry	all	10	20	50	20
Industry	all	20	30	30	20
Military		20	30	30	20
Household & Gardening	all but 04	10	40	30	20
	04, Snowmobiles	90	5	0	5
Railways	all	25	25	25	25

		Seasonal Disaggregation (in %)							Hourly Disaggregation (in			
Sector	Subsector	M	T	W	T	F	S	S	6-12	12-18	18-24	24-6
Inland Waterways	all but 04	5	5	5	5	10	35	35	35	35	4	1
	04, Inland Goods Carrying Vessels	18	18	18	18	18	5	5	35	35	4	1
Agriculture	all	18	18	18	18	18	5	5	45	45	8	2
Forestry	all	18	18	18	18	18	5	5	45	45	8	2
Industry	all	19	19	19	19	19	2.5	2.5	50	45	4	1
Military		19	19	19	19	19	2.5	2.5	35	35	15	15
Household & Gardening	all but 04	5	5	5	5	10	35	35	35	35	4	1
	04, Snowmobiles	10	10	10	10	10	25	25	35	35	4	1
Railways	all	15	15	15	15	20	10	10	35	25	35	5

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

National experts should check the overall fuel balance, e.g. whether the calculated fuel consumption corresponds to the statistical fuel consumption if such statistical information is available. Moreover, they should carefully evaluate whether there are good reasons to deviate from the default values given in this note and the computer programme.

A central team should compare the main input parameters used by countries in order to identify major deviations. In cases where the following boundaries are exceeded the national experts should be contacted in order to check the correctness of the values and to learn about the reasons for their choice.

A) Simple methodology

- The applied bulk emission factors for diesel, two-stroke gasoline, four-stroke gasoline, and LPG engines should not differ by more than 30% for NO_X and fuel consumption, more than 50% for CO and NMVOC, and more than a factor of 2 for N_2O, NH_3, CH_4 and diesel particulates from the all-country mean.

B) Advanced methodology

- The applied emission factors for the individual sub-categories should not differ by more than 30% for NO_X and fuel consumption, more than 50% for CO and NMVOC, and more than a factor of 2 for N_2O, NH_3, CH_4 and diesel particulates from the all-country mean.
- The applied average annual working hours should not differ by more than 50% from the all-country mean.
- The applied average load factors should not differ by more than 25% from the all-country mean.
- The applied average power output should not differ by more than 25% from the all-country mean.

The national statistical offices should check the calculated energy consumption data in the greatest possible detail, or make available appropriate data for cross-checking. The (calculated) fuel consumed by the categories should be incorporated into or cross-checked with the total national fuel balance.

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LIST OF ABBREVIATIONS USED

CH_4 : Methane
CO : Carbon monoxide
CO_2 : Carbon dioxide
Cd : Cadmium
Cu : Copper
FC : Fuel Consumption
HM : Heavy Metals
NH_3 : Ammonia
NMVOC : Non-methane volatile organic compounds
NO_x : Nitrogen oxides
NO_2 : Nitrogen
N_2O : Nitrous oxide
Pb : Lead
PM : Particulate matter
POP : Persistent organic pollutants
SO_2 : Sulphur dioxide
VOC : Volatile organic compounds
Zn : Zinc
CC : Cylinder Capacity of the Engine
CORINE : COoRdination INformation Environmentale
CORINAIR : CORINeAIR emission inventory
COPERT : COmputer Programme to calculate Emissions from Road Transport
EIG : Emission Inventory Guidebook
IPCC : Intergovernmental Panel on Climate Change
NAPFUE : Nomenclature of Fuels
NUTS : Nomenclature of Territorial Units for Statistics (0 to III). According to the EC definition, NUTS level 0 is the complete territory of the individual Member States
SNAP : Selected Nomenclature for Air Pollution
TU : Territorial Unit

SNAP CODES:	**080402** **080403** **080404**
SOURCE ACTIVITY TITLE:	**Shipping Activities**
NOSE CODES:	**202.04.01** **202.04.02** **202.04.03**

1 ACTIVITIES INCLUDED

Shipping activities include all ship activities, whether at sea, in port or on inland waterways.

All ships, including fishing vessels, of more than 100 gross tonnes are covered. Military vessels should also be included if data are available.

The emissions should be split as follows:
Shipping Activities (SNAP sub-sector 0804):

- National sea traffic within EMEP area (SNAP 080402);
- National Fishing within EMEP area (SNAP 080403);
- International sea traffic (SNAP 080404).

Smaller boats and leisure craft are included under SNAP 080301-03.

SNAP 080402 and 080403 are reported to ECE and IPCC as part of national totals and are subject to reductions in accordance with the protocols. SNAP 080404 is reported to IPCC for information only. The latter category includes emissions from all bunker fuel sold to international sea traffic in the reporting country, regardless of the flag of the ships consuming it.

On board incineration of waste is to be included in SNAP 090201. Evaporation of NMVOC is to be included in SNAP 050401 or if gasoline in SNAP 050502.

2 CONTRIBUTION TO TOTAL EMISSIONS

Table 2.1 Ranges of contribution of national shipping to total emissions of the CORINAIR-94 inventory

	Contribution to total emissions [%]
SO_2	0-80
NOx	0-30
NMVOC	0-5
CH_4	0-2
CO	0-18
CO_2	0-40
N_2O	0-1
NH_3	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions have been reported

On an European scale, SO_2 and NO_x emissions from national shipping can be important with respect to total national emissions (Table 2.1). However, emissions from *national shipping* generally only represent a few percent of the emissions from *shipping* operating *internationally*. Globally, shipping is estimated to be responsible for around 5-12 % and 3-4% respectively of anthropogenic NO_x and SO_2 emissions (extrapolations from Marintek (1990) and Lloyd’s Register (1995)). Estimated total NO_x attributable to shipping in the North-eastern Atlantic is approximately equivalent to the national total for France and Denmark combined, and slightly greater than the emissions attributed to road transport in Germany in 1990. Total SO_2 emissions are estimated to be equivalent to the total emission from France and half that emitted by UK power stations in 1990. Shipping generated exhaust emissions of hydrocarbons (VOC) and CO are relatively insignificant in comparison to national land based sources (Lloyd’s Register (1995)).

3 GENERAL

3.1 Description

Exhaust emissions arise from:

- marine diesel engines used as main propulsion engines or auxiliary engines;
- boilers used for steam turbine propulsion or other purposes;
- gas turbines.

The majority of emissions will derive from combustion in diesel engines and are well defined. Emission factors for steam turbine propulsion and gas turbines are available, but these are less well defined. Should other fuel or engine types become available, the same general methodology can be adopted, substituting the emission factors, where appropriate.

3.2 Definitions

Ship Types
The ship types are defined in the World fleet statistics and are summarised in Table 4.1.

EMEP area
The EMEP area is defined in a polar conical projection and is approximately the area East of 40 deg W, West of 60 deg E and North of 30 deg N.

National Sea Traffic
This activity includes all national ship transport including ferries, irrespective of flag, between ports in the same country, within the EMEP area. This means that Danish traffic to the Faeroe Islands and east Greenland is included but traffic to west Greenland is excluded. Norwegian traffic to Svalbard is included, but the Russian traffic is excluded. All Mediterranean national traffic of the ECE countries is included. Russian traffic between the White Sea, the Baltic Sea and the Black Sea is included. French traffic between Atlantic and Mediterranean ports is included. Portuguese traffic to the Azores and Madeira and Spanish traffic to the Canary Islands are excluded.

N.B. This definition is considered by some to be somewhat unworkable, since a proportion of emissions from ships on international voyages, and using international bunkers, will have to be included in the national emission total if the ship travels between two ports in the same country.

Statistical data for fuel use is generally split between national and international bunkers. This does not readily allow for the splitting of emissions into both national and international elements on the same voyage.

The IPCC definition for national emissions from shipping is somewhat more workable and is as follows: “Emissions from fuel used for navigation of all vessels not engaged in international transport except fishing. This may include journeys of considerable length between two ports in the same country, e.g. Bordeaux to Marseilles.” However, this definition is not to be used and is included for information purposes only.

National fishing
Emissions from all national fishing within the EMEP area. The fuel may have been bought in a country other than the one reporting.

International sea traffic
Emissions from bunkers sold to international sea traffic in the reporting country. The emissions are to be reported to IPCC for information only.

3.3 Techniques

Marine diesel engines are the predominant form of power unit within the marine industry for both propulsion and auxiliary power generation. In 1991 motorships accounted for around 98% by number of the world merchant fleet, the remaining 2% of vessels were powered by steam plant. Marine diesel engines are generally categorised into two distinct groups (Lloyd’s Register (1993)):

Slow speed engines, operating on the two stroke cycle at speeds between 80-140 rpm, are normally crosshead engines of 4-12 cylinders. Some current designs are capable of developing in excess of 4000 kW/cylinder and with brake mean effective pressures of the order of 17 bar. Within the marine industry such engines are exclusively used for main propulsion purposes and comprise the greater proportion of installed power and hence fuel consumption within the industry.

Medium speed engines, generally operating on the four stroke cycle at speeds ranging from 400-1000 rpm, are normally trunk piston engines of up to 12 cylinders in line or 20 cylinders in vee formation. Current designs develop powers between 100-2000 kW/cylinder and with brake mean effective pressures in the range 10-25 bar. Engines of this type may be used for both main propulsion and auxiliary purposes in the marine industry. For propulsion purposes such engines may be used in multi-engined installations and will normally be coupled to the propeller via a gearbox. Engines of this type will also be used in diesel electric installations.

Exhaust emissions from marine diesel engines comprise nitrogen, oxygen, carbon dioxide and water vapour, with smaller quantities of carbon monoxide, oxides of sulphur and nitrogen, partially reacted and non-combusted hydrocarbons and particulate material. Metals and organic micropollutants are emitted in very small quantities.

3.4 Controls

The simplest technical way to reduce SO_2 emissions is reducing the sulphur content of the bunker oil. SO_2 can also be removed (> 90%) by seawater scrubbing (CONCAWE, 1994). Regulations on SO_2 limitation are presently being prepared by The European Commission and by the International Maritime Organization (IMO).

NO_x emissions from marine engines are to be controlled by new regulations developed by IMO. The following limits are likely to be applied to new diesel engines above 130 kW. The limits may become effective from the year 2000.

17 g/kWh when $n < 130$,
$45 * n^{-0.2}$ g/kWh when $130 < n < 2000$
9.84 g/kWh when $n > 2000$

where n is the rated engine speed in rpm.

There are a number of technological options for reducing NO_x from ships. Use of these technologies may be dependent upon whether residual fuel oil or distillate fuel is being burnt. Three options are mentioned here (based on Klokk, 1995):

- Exhaust Gas Recirculation (EGR) where a portion of the exhaust gas is routed back to the engine charge air whereby the physical properties of the charge air is changed. For marine diesel engines, a typical NO_x emission reduction of 10-30% can be found. This technique has not yet been in regular service for ships;
- Selective Catalytic Reduction (SCR) where a reducing agent is introduced to the exhaust gas across a catalyst. Hereby NO_x is reduced to N_2 and H_2O. However this technology imposes severe constraints on the ship design and operation to be efficient. A reduction of 85-95% can be expected applying this technology. The technology is in use in a few ships and is still being developed;
- Selective Non Catalytic Reduction (SNCR) where the exhaust gas is treated as for the SCR exhaust gas treatment technique, except the catalyst is omitted. The process employs a reducing agent, supplied to the exhaust gas at a prescribed rate and temperature upstream of a reduction chamber. Installation is simpler than the exhaust gas treatment, but needs a very high temperature to be efficient. Reductions of 75-95% can be expected. However, no installations have been applied yet on ships.

3.5 Projections

Future emissions from shipping will be governed by future change in activity, new engine technologies and penetration of new technologies. SO_2 emissions will depend on future sulphur content of fuel as well as the changes in activity rates.

Information about future change in activity of domestic shipping may be available in national transport plans. Economic development tends to increase the demand for freight transport. On the other hand changes in infrastructure (e.g. building of bridge connections) may lead to decrease in the demand for passenger transport by ferries.

Regulations may put a ceiling on sulphur content of fuel. IMO has agreed on a cap of 4.5 % sulphur content of fuel, this is, however, higher than the average used in Europe. There may also be restrictions on sulphur content of fuel used in certain areas, this should be checked by the national authorities.

As mentioned above (3.4) will there be regulations of NO_x emissions from year 2000. The effect of this on the national total emissions from shipping is dependent of the penetration of new technologies. In a baseline scenario is it recommended to assume an average 10 % reduction in the NO_x emission factors for diesel engines if better information not is available (MEET 1998). Emissions factors for other engines (steam and gas turbines) should be kept constant.

Emission factors for other pollutants than SO_2 and NO_x should be kept constant in a baseline analysis.

There is research going on to test alternative fuels on ships. Although such fuels are phased in at a small scale, e.g. use of natural gas in ferries, is large-scale use not expected in the near future. Consequently, should alternative fuels not be incorporated into a baseline scenario.

4 SIMPLE METHODOLOGY

Emissions should be estimated as follows

Emission = Fuel sold x Emission factor (eq. 1)

Fuel sold should be divided into Residual Bunker Fuel Oil (heavy fuel oil) and Distillate fuel (gas oil and marine diesel oil), although in some countries other fuel qualities may also be in use. This is important since fuel type significantly influences SO_2 and heavy metal emissions.

Relevant emission factors are given in Table 8.1, 8.2 and 8.3.

The simple methodology should always be used for estimating the CO_2 emissions, even if the detailed methodology is used for other pollutants.

Table 4.1 Estimated speed factors, main engine power and auxiliary engine power by ship type and gross tonnage

Ship Type	**Speed Factor** *Knots*	**Estimated Main Engine Power kW (total power of all engines)**							**Estimated Auxiliary Power kW (medium speed)**					
		<500 GRT	500-999 GRT	1000-4999 GRT	5000-9999 GRT	10000-49999 GRT	>=50000 GRT	All	<500 GRT	500-999 GRT	1000-4999 GRT	5000-9999 GRT	10000-49999 GRT	>=50000 GRT
Liquified Gas Tanker	16	650 (m)	700 (m)	2250 (m)	5350 (#)	11600 (s)	15200 (s)	5900	75	100	125	300	400	1000
Chemical Tanker	15	1000 (m)	-	2000 (m)	5000 (#)	10250 (s)	-	5700	40	50	165	300	435	-
Other Tanker	14	600 (m)	950 (m)	2200 (m)	4300 (#)	9600 (s)	17200 (s)	7900	40	50	165	300	435	530
Bulk Dry Cargo	14	550 (m)	750 (m)	2700 (m)	5000 (#)	8800 (s)	17000 (s)	9100	20	40	175	300	380	500
General Cargo	14	550 (m)	950 (m)	1800 (m)	5500 (#)	8500 (s)	-	3300	20	40	175	300	380	-
Passenger/General Cargo	18	450 (m)	900 (m)	2850 (m)	6450 (#)	12600 (s)	-	4900	20	40	175	300	380	-
Container	20	1000 (m)	1750 (m)	2950 (m)	6000 (#)	17200 (s)	35000 (s)	16300	40	60	160	500	1400	1400
Refrigerated Cargo	20	900 (m)	900 (m)	3100 (m)	8850 (#)	10000 (s)	-	6700	40	140	180	455	580	-
Ro-Ro Cargo	18	1500 (m)	1900 (m)	4300 (m)	7200 (#)	11600 (#)	12550 (s)	7700	100	150	350	1000	2500	4000
Passenger/Ro-Ro	20	600 (m)	-	6500 (m)	12300 (#)	16650 (#)	-	12800	100	150	350	1000	2500	-
Passenger	20	550 (m)	-	3350 (m)	7800 (#)	16800 (#)	50000 (m)	14400	100	150	350	1000	2500	4000
Other Dry Cargo	15	900 (m)	-	2050 (m)	4450 (#)	17600 (#)	-	5900	20	40	175	300	380	500
Fish Catching	11	-	1050 (m)	2500 (m)	-	-	-	2200	-	80	200	-	-	-
Other Fishing	15	650 (m)	800 (m)	2300 (m)	5300 (m)	5400 (s)	-	2600	40	105	180	550	550	-
Offshore	14	1800 (m)	2150 (m)	3800 (m)	7450 (#)	11800 (#)	-	4000	40	60	150	350	450	-
Research	14	900 (m)	1300 (m)	3250 (m)	5300 (#)	8950 (s)	-	2900	40	60	150	400	400	-
Tug	11	3000 (m)	4050 (m)	6450 (m)	-	-	-	4400	40	60	150	-	-	-
Dredger	9	400 (m)	550 (m)	2400 (m)	7350 (#)	9250 (#)	-	4500	40	50	60	130	770	-
Cable	7	1100 (m)	-	3850 (m)	5950 (m)	13400 (s)	-	5300	80	-	200	300	-	-
Other Activities	-	500 (m)	900 (m)	3300 (m)	7650 (#)	8500 (#)	-	3700	40	60	150	300	500	-
Non-propelled	2	-	400 (m)	2750 (m)	-	-	-	2200	-	-	-	-	-	-
All		900 (m)	1200 (m)	2400 (m)	6200 (#)	9900 (#)	18700 (s)		50	80	200	450	900	1750

m = predominantly medium speed
s = predominantly slow speed
# = both medium and slow speed

5 DETAILED METHODOLOGY

The data sources available for performing a detailed methodology may vary between countries. Also the scope of such a study may vary. We will present here two detailed methodologies for shipping, one based on ship movement data and one based on fuel statistics. In addition, we will sketch how to perform a port inventory e.g. for inclusion in an urban emission inventory. The methodologies may of course also be combined, either for cross checking or for using one for a particular category of vessels and the other for a different category.

The *fuel consumption* methodology is recommended when statistics on fuel use for vessel categories or individual ships are available. It is particularly suited for estimating national emissions. The emission estimate can be directly compared with fuel sales figures. The spatial information may be less accurate than when using the ship movement methodology. The fuel consumption methodology is suited to show trends in emissions.

The *ship movement* methodology is recommended when detailed ship movement data as well as technical information on the ships are available. It is suited for estimating national and international emissions. The methodology may be quite time consuming to perform. The output is difficult to compare with the fuel statistics. The methodology is not very well suited to show annual trends in emissions.

The methodologies may be used to calculate the emissions following the UNECE/EMEP definition of national shipping, as well as other definitions (flag, ownership, geographical area etc.).

5.1 Fuel Consumption Methodology

The methodology is based on annual fuel consumption data for vessel categories or individual ships (see section 6). This methodology indirectly includes emissions from ships alongside or at anchor.

1. Compile information on fuel consumption by individual ships or vessel categories. For estimating the emissions of SO_2 and heavy metals, residual fuel oil and distillate fuel should be distinguished.
2. If data for individual ships are available, use Table 8.2 to determine a NO_x emission factor based on the ship engine type. If data for individual ships are not available, use Table 4.1 to determine the proportion of slow speed to medium speed engines for each vessel category and use Table 8.2 to determine a weighted emission factor. For the other pollutants a single emission factor is applicable (Table 8.1, 8.2 and 8.3).
3. Multiply the fuel consumption data in tonnes by the fuel based emission factors to obtain an annual emission estimate.
4. If a spatial disaggregation is required, use information on routes and ship movements to distribute the emissions.

5.2 Ship Movement Methodology

The methodology is based on ship movement information for individual ships (see section 6). Using the ship movement methodology, emissions from ships hotelling in port, or at anchor awaiting a berth or awaiting orders, are excluded - and must be estimated using port statistics. Previous studies have indicated that «in port» and harbour traffic emissions are significant sources of emissions (up to 26% of the overall total in the English Channel area). However, routine quantification of harbour traffic is not considered feasible using the detailed methodology presented here. Only emissions from shipping on passage or arriving or departing from a berth are included.

1. Compile the ship movement data; place of departure, place of arrival, time of departure and time of arrival for each individual ship. This may be done for the whole year or a representative sample of the year, for all ships or for a representative sample of the ships. This choice will depend on the resources available and the required accuracy of the study.
2. Determine the sailing routes and distances between ports. This may be done individually or fitted into the main shipping lanes. A GIS (Geographical Information System) is useful, but not necessary, for this task. If a GIS not is available, there are standard distance tables for distances between main ports (Thomas Reed Publications, 1992).
3. Group the ships into vessel categories (Table 4.1). This step is optional, but will require less work than continuing with the data set containing the individual ships.
4. Determine the sailing time for each ship/vessel category, either based on the distance and speed factors (Table 4.1) or time of departure and arrival. The choice should be based on an assessment of the quality of the data.
5. Determine emission rates in kg/h. The emission rates should be based on the data in Table 8.5 and the engine power of each individual ship or the average for each vessel category (Table 4.1). Both the main and auxiliary engines should be included.
6. Combine the sailing time (in hours) with emission rates in (kg/h) to obtain a total emission estimate of CO, NMVOC and NO_x:

$$\boldsymbol{E = e * t} \qquad \text{(eq 2)}$$

where

E = The emission in the defined area per ship
e = emission rate (kg/h)
t = time in defined area (d/s)
  d = distance travelled within defined area
  s = speed of vessel

If the study is based on samples, scale the result to get an annual total. A GIS can be used to spatially disaggregate the data.

7. To estimate emissions of SO_2 and heavy metals, information about fuel type is needed. Assumptions about the fuel type should be made from the engine type or sale statistics, as this information is not directly available from the ship movement methodology. The fuel

consumption may be estimated from the data in Table 8.6. Estimate the emissions of the remaining pollutants of interest from the estimated fuel consumption and the fuel based emission factors or, if possible, using the simple or fuel based methodology.

5.2.1 Emissions in ports

An emission inventory for ports must be based on local knowledge and is best performed for individual ports. An outline methodology only is sketched here. The methodology is based on port calling statistics showing the exact time of arrival and departure of individual ships. There are four main types of emission sources in a port:

- Ships' hotel loads, alongside or at anchor;
- Cargo working, alongside or at anchor;
- Manoeuvring emissions by ships leaving and arriving in port;
- Emissions from harbour craft.

5.2.2 Alongside emissions

In dock the main engine is unlikely to be in use. Ships are likely to use shore power or auxiliary engine(s) only. One exception is some types of ferries which will use their main engine whilst in dock. These considerations must be based on local knowledge for each port. The alongside emissions are determined from the time in dock estimated from the time of arrival and departure for each individual ship. The emission factors in Table 8.5 in (kg/h) are applicable for auxiliary (medium speed engines).

5.2.3 Manoeuvring emissions

Different ports will have different sizes, speed limits and other characteristics. Hence, the emission estimate should be based on local knowledge. In principle, once the time spent manoeuvring is known, the emission factors in Table 8.5 are applicable. The engine load will variable when manoeuvring, but the same emission factors may be used as ships at sea.

5.2.4 Emissions from harbour craft

This includes emissions from various vessels and craft operating in the port (tug boats, pilot boats, dredgers etc.). Emissions from shore based equipment are included under SNAP 0810. The emission estimate should be based on a local inventory of such craft, the number, engine type and hours of operation or their annual fuel use. Based on this information and the emission factors in section 8 or chapter 0806-0810 (as some of this craft will be small and consequently covered here) an annual emission estimate can be obtained.

This methodology is also applicable for ships at anchor where these emissions are considered to be significant.

N.B. There may be a double counting of emissions for ports estimated by the fuel based and to a lesser extent the ship movement methodology.

6 RELEVANT ACTIVITY STATISTICS

6.1 Simple methodology

A national statistic for fuel used by ships and split between fisheries, national traffic and international bunker is necessary. The statistics should also be split between residual fuel oil and distillate fuel. All countries report these data annually to IEA (the International Energy Agency) (published in "Energy Statistics of OECD Countries").

6.2 Detailed methodology

The requirements for activity statistics will depend on the methodology chosen.

6.2.1 Ship particulars

A ship register, giving the size and engine type of individual ships, will be useful for either methodology. Such a register of the national fleet will be available in most countries but usually only covering national ships.

Lloyds Register’s Register of Ships will provide details of national and international shipping greater than 100 grt.

6.2.2 Fuel use

Ship or ferry companies: Fuel use data may be recorded by the companies and be available on request.

Statistical offices: Fuel use data may be collected in sample or full surveys. More often data on fuel expenditures will be available. However, the price of fuel for ships is highly variable as large discounts are very common.

Individual ships: Virtually all ships are statutorily required to keep a record of their fuel use. However, such a data collection will probably be very time consuming.

6.2.3 Ship movement

LMIS (Lloyd’s Maritime Information Service): This database records all ship movements world-wide. The database includes ship size, destination, approximate time of arrival and departure, engine type and number etc. The data are available in computerised form. The database covers all ships greater than 250-500 gross tonnes. Ferries and fishing vessels are typically not included. Smaller ports are also excluded. A week or a whole year may be chosen. A selection may also be made on area or ship nationality. The dataset will have to be purchased.

Port calling statistics
Port calling statistics will be available from national sources (statistical offices or the harbour authorities) in all countries, in some countries covering the larger ports only. The information is similar to the LMIS data without engine details. On the other hand it will give more

accurate information about the actual time spent in port. The national port calling statistics may also be useful for validating other sources.

Survey of ship owners
In some countries detailed statistics on individual ships are performed. Such statistics may include a ship movement survey for at least a sample of the fleet.

Ferry timetables
For ferries ship movement data will be available from timetables giving the departures and destinations. “Thomas Cook international rail timetable” includes all main ferry routes in Europe, but more detailed information (covering smaller ferries) will be available from national sources. Such information must be supplemented with engine information. It should be distinguished between summer and winter when applying timetables.

Fishing deliveries
The International Council for the Exploration of the Seas collects information on fishing deliveries (catch area and port of landing) which gives an indication of the vessel movements. The data here are confidential, but is based on national reporting which may be available. The information must be linked to a vessel register. Additional information must be collected on the time spent fishing, as fishing vessels will not move in straight lines when operating. Fishing vessels may also be used for other activities than fishing. Factory ships and trawlers may have significant fuel use connected to trawling, processing and refrigeration, in addition to the vessel movement.

The customs or coast guard authorities may keep records of the international ship traffic in national territorial water.

6.2.4 Ships’ routing

The main shipping routes are given in the IMO publication «Ships’ Routing» (International maritime Organization, 1987).

Distances are given in Reed’s Marine Distance Table (Thomas Reed Publications, 1992).

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS

Emission factors may vary between the simpler and the detailed methodology, in particular for NO_x, where a single emission factor is specified for the simple methodology, but two factors relating to the engine type (slow/medium speed) are specified in the detailed methodology.

8.1 Fuel Based Methodology

Table 8.1 Emission factors - Fuel composition dependent emissions.

	kg/tonne fuel
CO_2	3170
SO_2	20 ∗ %S

S = sulphur content of fuel (% by wt)

Source: Lloyd's Register, 1995

	distillate fuel g/tonne fuel	**residual fuel oil g/tonne fuel**
As	0.05	0.5
Cd	0.01	0.03
Cr	0.04	0.2
Cu	0.05	0.5
Hg	0.05	0.02
Ni	0.07	30
Pb	0.1	0.2
Se	0.2	0.4
Zn	0.5	0.9
PM_{10}	1200	7600

Source: Lloyd's Register, 1995

The average sulphur content of fuel may be obtained from national sources. Values may also be obtained from organisations such as CONCAWE, DNV or Lloyd's Register. In the absence of specific information on fuel sulphur content, default values of:

2.7% (by wt) - residual fuel oil
0.5% (by wt) - distillate fuel

may be used (Lloyd's Register 1995).

Heavy metal emissions will depend on the metal content of the fuel. This will, in turn, depend upon the metal content of the original crude and will vary significantly (by orders of magnitude) between oil fields. Generally, the metal content will be higher in residual fuel oil than in distillate fuel. Heavy metal emission factors are given in Table 8.1. These represent average fuel concentrations but are based on a small sample number, and should be considered to be highly uncertain.

Table 8.2. Engine dependent emission factors

	kg/tonne fuel		
NO_x	87*	72†	57‡
CO	7.4		
NMVOC	2.4		
CH_4	0.3		
N_2O	0.08		

* slow speed † composite factor ‡ medium speed

Source: Lloyd's Register (1995), IPCC (1997)

The emission factors for methane and nitrous oxide (IPCC, 1997) are highly uncertain. NO_x emissions factors for medium and slow speed engines differ significantly; however, a combined factor is provided for use in the simpler methodology.

Table 8.3 Emission factors for POPs

	Unit	Range
HCB	mg/tonne	0.01-0.4
Dioxin	TEQµg /tonne	0.1-8
Total PAH	g/tonne	2.0
PAH*	g/tonne	0.04

Source: Lloyd's Register (1995), * PAHs included in ECE protocol

The emission factors for POPs (Persistent Organic Compounds) are highly uncertain as they are based on a very limited data set. Actual ranges may be greater than indicated.

Table 8.4 Emission factors for steam turbine propulsion and gas turbines, Cruise, kg/tonne fuel

	NO_x	CO	VOC	PM_{10}
Steam turbine propulsion - distillate fuel	3.3	0.6	0.5	2.1
Steam turbine propulsion - residual fuel	7.0	0.4	0.1	2.5
Gas turbines	16	0.5	0.2	1.1

Source: Techne (1997), derived from EPA(1985)

8.2 Ship Movement Methodology

Speed factors are given in Table 4.1 for various vessel categories. The emission rates are shown in Table 8.1.

Table 8.5 Emission rates for medium and slow speed diesel engines (kg/hours)

	Medium speed & auxiliary engines	Slow speed
NO_x	$4.25 \times 10^{-3} \times P^{1.15} \times N$	$17.50 \times 10^{-3} \times P \times N$
CO	$15.32 \times 10^{-3} \times P^{0.68} \times N$	$0.68 \times 10^{-3} \times P^{1.08} \times N$
HC	$4.86 \times 10^{-3} \times P^{0.69} \times N$	$0.28 \times 10^{-3} \times P \times N$
SO_2*	$2.31 \times 10^{-3} \times P \times N$	-
SO_2**	$12.47 \times 10^{-3} \times P \times N$	$11.34 \times 10^{-3} \times P \times N$

P is the engine power (kW) x engine load (85% MCR), N is the number of engines
* is valid for engines < 2000 kW
** is valid for engines ≥ 2000 kW.
Source: Lloyd's Register (1995)

In order to estimate fuel consumption for use with emission factors listed in the fuel use methodology, the default factors given in Table 8.6 are suggested. The consumption at cruise will be about 0.8 of the given figures. Manoeuvring and hotelling will be 0.4 and 0.2, respectively (Techne, 1997). Such average fuel consumption factors should be considered to be highly uncertain.

Table 8.6 Fuel consumption factors, Full power

Ship type	**Average consumption (tonne/day)**	**Consumption at full power (tonne/day) as a function of gross tonnage (GT)**
Solid bulk	33.8	20.186 + 0.00049*GT
Liquid bulk	41.1	14.685 + 0.00079*GT
General cargo	21.3	9.8197 + 0.00143*GT
Container	65.9	8.0552 + 0.00235*GT
Passenger/Ro-Ro/Cargo	32.3	12.834 + 0.00156*GT
Passenger	70.2	16.904 + 0.00198*GT
High speed ferry	80.4	39.483 + 0.00972*GT
Inland cargo	21.3	9.8197 + 0.00143*GT
Sail ships	3.4	0.4268 + 0.00100*GT
Tugs	14.4	5.6511 + 0.01048*GT
Fishing	5.5	1.9387 + 0.00448*GT
Other ships	26.4	9.7126 + 0.00091*GT
All ships	32.8	16.263+ 0.001*GT

Source: Techne (1997)

9 SPECIES PROFILE

The speciation of PAHs as determined by Lloyd's Register (1995) are given here (Table 9.1). Cooper et al, 1996 presents a measurement covering other species.

Cooper et al, (1996) has measured the C_2-C_6 and C_6-C_{12} hydrocarbon concentrations in exhaust from two ferries (Table 19).

Table 9.1 PAH emissions, Distribution by species

	Average (%)	Range (%)
Phenanthrene	37	32-54
Anthracene	1	0-2
Fluoranthene	11	9-15
Pyrene	14	12-20
3,6-dimethylphenanthrene	4	3-5
Triphenylene	12	9
Benxo(b)-fluorene	6	2-19
Benzo(a)anthracene	2	0-2
Chrysene	5	3-9
Benzo(e)-pyrene	2	0
Benzo(j)fluoranthene	0	0
Perylene	0	0-3
Benzo(b)-fluoranthene	1	0-2
Benzo(k)-fluoranthene	0	0
Benzo(a)pyrene	0	0
Dibenzo(a,j)anthracene	0	0-1
Dibenzo(a,l)pyrene	0	0
Benzo(g,h,i)perylene	1	0-2
Dibenzo(a,h)anthracene	1	0-6
Ideno(1,2,3-c,d)pyrene	0	0-1
3-methyl-cholanthrene	0	0
Anthanthrene	0	0

Source: Lloyd's Register, 1995

Table 9.2 Exhaust hydrocarbon concentrations, Percent.

	Ferry 1	Ferry 2
Ethane	0	0
Ethene	5	20
Propane	0	0
Propene	2	6
Ethyne	0	0
Propadiene	0	0
Butane	0	0
trans-2-Butene	0	0
1-Butene	0	1
Isobutene	1	18
cis-2-butene	0	0
Pentane	0	0
Propyne	0	0
3-Methyl-1-butene	0	0
trans-2-Pentene	0	0
1-Pentene	0	1
cis-2-Pentene	0	0
Hexane	0	0
Other C_6 alkenes	0	0
1-Hexene	0	0
Nonane	10	0
Decane	25	0
Undedecane	19	0
Dodecane	14	0
Benzene	4	35
Toluene	5	15
Ethylbenzene	1	0
o-Xylene	2	0
m Plus p-Xylene	4	4
1,3,5-Trimethylbenzene	2	0
1,2,4-Trimethylbenzene	2	0
1,2,3-Trimethylbenzene	3	0

Source: Cooper et.al, 1996

10 UNCERTAINTY ESTIMATES

For the ship movement methodology NO_x emissions are highly dependent upon the type of the ship engines. Lloyd's Register (1995) shows variations in emission profiles for HC and NO_x. In addition the activity data will be uncertain. Uncertainties associated with estimates of HC and NO_x should therefore be considered to be more than ± 20%. The simpler methodology will give higher uncertainties.

Using the fuel consumption methodology, the uncertainty will depend on the quality of the fuel data collected. The NO_x emissions will be more uncertain if information about the engine types not is available.

For SO_2, uncertainty depends on the variation of the sulphur content and fuel consumption which may be estimated to be within ± 5%.

Emissions of heavy metals and POPs are uncertain within an order of magnitude.

11 WEAKEST ASPECTS / PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weaknesses differ with the methodology used.

The estimation of emissions in the *simple methodology* is dependent upon the split of fuel into ship categories. It is uncertain to which extent the assumptions about what fuel is actually used in which ships is true (Rypdal, 1995). Factors are based on assumptions about national and international sea traffic which may not be in accordance with the present guidelines. Furthermore, when emission estimations are based on statistics of fuel sold for various ship categories, there may be divergence from reality. For some vessels the statistics are not necessarily registering all fuel use. Fishing boats may particularly buy fuel abroad and therefore this fuel would not be registered in the national statistics. International fuel use statistics may include fuel burned outside the EMEP area or used during national voyages. The national/fishing split might not be available in some countries. The simple methodology does not give any spatial disaggregation.

When applying the *detailed methodology*, the main assumptions have been made in the text and will vary with quality of the data sources used.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

The ship movement methodology provides a spatial disaggregation of the emissions.

For the simple and fuel based methodology the spatial disaggregation may be determined by ship routing data. Such statistics are described under “relevant activity statistics”, but less detail and accuracy will result than when using in the ship movement methodology.

13 TEMPORAL DISAGGREGATION CRITERIA

Seasonal variation through the year is insignificant (see Lloyd's Register, 1995). However, there may be exceptions in certain areas and for certain vessel types. A greater proportion of fishing and 'other activity vessels' (such as dredgers, tugs and research ships) as well as cruise ships are more active in the late summer months.

14 ADDITIONAL COMMENTS

Military vessels are often omitted from the shipping inventories. They should, however, in principle be included. Often statistics can be found on military fuel data, and the most important ship movements.

15 SUPPLEMENTARY DOCUMENTS

Van der Most, P.F.J. (1990): Calculation and Registration of Emissions from Shipping in the Dutch Emission Inventory. EMEP Workshop on Emissions form Ships, Oslo, 7-8 June.

Flugsrud, K. and Rypdal, K. (1995): Emissions from national sea traffic in Norway. A description of the development of a methodology. Reports 96/17. Statistics Norway. In Norwegian. Summary in English.

16 VERIFICATION PROCEDURES

Comparing emissions estimated by the simple and the two detailed methodologies will be useful. However, such a comparison may not be straight forward due to different scopes.

Comparison with central inventories, like the Lloyd’s Register inventory, should be made if possible.

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18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODES:	**080501** **080502** **080503** **080504**
SOURCE ACTIVITY TITLE:	**Air Traffic**
NOSE CODES:	**202.05.01** **202.05.02** **202.05.03** **202.05.04**

1 ACTIVITIES INCLUDED

This chapter presents common guidelines for estimation of emissions from air traffic. The guideline includes four activities (Table 1.1).

Table 1.1 Overview of the activities included in the present reporting guidelines

Activity	SNAP CODE	NOSE CODE
Domestic airport traffic (LTO-cycles < 1000 m altitude)	080501	202.05.01
International airport traffic (LTO-cycles < 1000 m altitude)	080502	202.05.02
Domestic cruise traffic (> 1000 m altitude)	080503	202.05.03
International cruise traffic (> 1000 m altitude)	080504	202.05.04

LTO is an abbreviation for the Landing and Take-Off cycle.

Domestic aviation is associated with the SNAP codes 080501 + 080503;
International aviation is associated with the SNAP codes 080502 + 080504;
LTO-cycle activities include SNAP codes 080501 + 080502;
Cruise activities include SNAP codes 080503 + 080504.

Emissions associated with domestic and international aviation are to be reported to the UNFCCC. Emissions associated with the LTO-cycle are to be reported to the UNECE[1]. Activities include all use of aeroplanes consisting of scheduled and charter traffic of passengers and freight. This also includes taxiing, helicopter traffic and private aviation. Military aviation is included if it is possible to estimate.

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[1] However, UNECE wants CO_2 emissions and other direct greenhouse gases estimated according to the UNFCCC definition.

2 CONTRIBUTION TO TOTAL EMISSIONS

The total contribution of aircraft emissions to total global anthropogenic CO_2 emissions is considered to be about 2% (IPCC, 1999). This relatively small contribution to global emissions should be seen in relation to the fact that most aircraft emissions are injected almost directly into the upper free troposphere and lower stratosphere. IPCC has estimated that the contribution to radiative forcing is about 3.5 %. The importance of this source is growing as the volume of air traffic is steadily increasing.

The importance of air traffic in Europe for various pollutants is illustrated in Table 2.1. The table reflects the current knowledge. It may be that the ranges actually are different from the figures given in the table. Emissions of H_2O are not covered by Corinair, but can be estimated on the basis of the fuel consumption.

Table 2.1 Emissions from air traffic in Europe. Ranges of contribution to total emissions according to Corinair-94. Per cent of total excluding international cruise.

Category	LTO (%)	Domestic cruise (%)
SO_2	0-0.2	-
NO_x	0-3	0-2
NMVOC	0-0.6	-
CO	0-0.3	-
CO_2	0-2	0-1
CH_4	0	-
N_2O	0	-

3 GENERAL

3.1 Description

In principle the activities include all flights in a country. The traffic is often divided into four categories:

Category 1. Civil IFR (Instrumental Flight Rules) flights
Category 2. Civil VFR (Visual Flight Rules) flights, also called general aviation
Category 3. Civil Helicopters
Category 4. Operational Military flights

Flight data are often recorded for Category 1 only. Most emissions will, however, originate here. Category 2 contains small aircraft, used for leisure, taxi flights etc.

Data are mostly available for turbofans only, but estimates also have to be made from turboprop and piston engine aircraft (which are currently not subject to any emissions regulation).

Aircraft in Category 1 can be classified into types and engines as outlined in Table 3.1. This table presents aircraft and engines most frequently used in European and American aviation, although other engines may be fitted in significant numbers. Also note that some large long distance planes not on this list may be important for fuel consumption (e.g. DC10, A340). More types and engines exist and engines can be seen in ICAO (1995) or at http://www.dera.gov.uk. Also in some countries the aircraft fleet may deviate much from this fleet.

Military aircraft activities (Category 4) are in principle included in the inventory. There may however be some difficulties in estimating these due to scarce and often confidential military data. One should also be aware that some movements of military aircraft might be included in Category 1, for example non-operational activities.

3.2 Definitions

Abbreviations

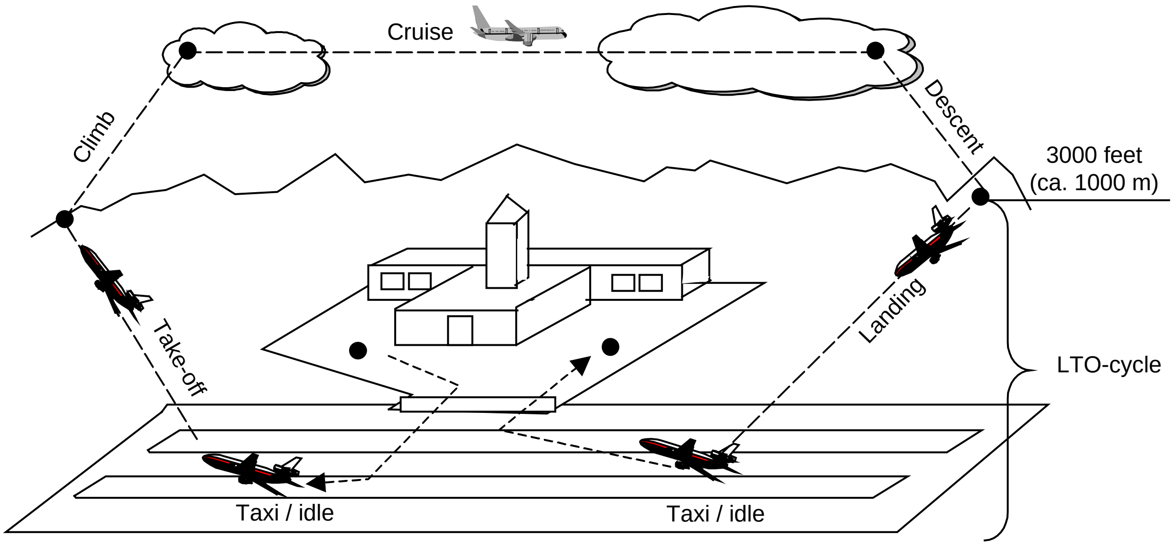
AERONOX: EU-project “The impact of NO_x-emissions from aircraft upon the atmosphere at flight altitudes 8-15 km" (AERONOX, 1995)
ANCAT: Abatement of Nuisance Caused by Air Transport, a technical committee of the European Civil Aviation Conferences (ECAC)
ATC: Air Traffic Control
CAEP: Committee on Aviation Environmental Protection
ICAO: International Civil Aviation Organisation
LTO: Landing/Take-off (see below)

ICAO certification data prepared for the engines of an aircraft takes into account the population of engines fitted to that aircraft according to an aircraft registration database (ANCAT, 1998).

Operations of aircraft are divided into two parts:

- The *Landing/Take-off* (LTO) cycle which includes all activities near the airport that take place below the altitude of 3000 feet (1000 m). This therefore includes taxi-in and out, take-off, climb- out, and approach-landing. The LTO is defined in ICAO (1993).
- *Cruise* which here is defined as all activities that take place at altitudes above 3000 feet (1000 m). No upper limit of altitude is given. Cruise, in this report, includes climb from the end of climb-out in the LTO cycle to cruise altitude, cruise, and descent from cruise altitudes to the start of LTO operations of landing (figure 3.1).

Figure 3.1 Standard flying cycles



Some statistics count either a landing or a take-off as one operation. However it should be noted that *both* one landing and one take-off define a full LTO-cycle in this report.

The emission figures for national and international aviation have to be reported separately. The distinction between national and international aviation is as follows: *All traffic between two airports in one country is considered domestic* no matter the nationality of the carrier. The air traffic is considered international if it takes place between airports in two different countries. If an aircraft goes from one airport in one country to another in the same country and then leaves to a third airport in another country, the first trip is considered a domestic trip, while the second trip is considered an international trip. The only exceptions are technical refuelling stops, or domestic trips that only allow passenger or freight to board for an international trip or leave the aircraft after an international trip. These are not considered domestic but international. Further guidance on the allocation issue is given in the IPCC Good Practice Guidance for Inventory Preparation.

Emissions and fuel from over-flights are excluded from these calculations to avoid double counting of emissions.

Table 3.1 Civil aircraft classification. Movements in Europe per aircraft type*, 1998.

	Movements per aircraft type %	% local (non- trans Atlantic) movements for this type	Number of engines	Type of engine	Most used engine
Boeing B 737, unspecified	14.8	99.6	2	TF	PW JT8D-17, CFMI CFM56-3
Airbus A 320	8.6	99.6	2	TF	CFMI CFM56-5A
McDonnell Douglas MD 80	8.1	100	2	TF	PW JT8D-217
ATR	5.2	100	2	TP	PWC PW120, PW124
BAe 146	4.6	100	4	TF	LY ALF 502R-5
Boeing B 757	3.4	95.3	2	TF	PW 2037
Boeing 737-100	3.3	99.7	2	TF	PW JT8D-17, CFMI CFM56-3
Fokker F-50	3.1	100	2	TP	PW125B
De Havilland DASH-8	2.8	100	2	TP	PW 121/123
Boeing B 767	2.7	46.8	2	TF	GE CF6-80A2, GECF6-80C2B6
Canadair Regional Jet	2.1	100	2	TF	LY ALF 502L-2C
McDonnell Douglas DC 9	1.8	99.8	2	TF	JT8D-15
Boeing B 727	1.7	99.6	3	TF	JT8D-7B
Fokker 100	1.6	100	2	TF	RR TAY 620-15
Boeing B 747 100-300	1.5	43.4	4	TF	PWJT9D-7A, PW4056
SAAB 2000	1.4	100	2	TP	AN GMA2100A
SAAB 340	1.4	100	2	TP	GE CT7-5A2
Airbus A 310	1.3	88.5	2	TF	GE CF6-80C2A5, PW JT9-7R4EI
Airbus A 300	1.0	93.7	2	TF	GE CF6-80C2A5, PW JT9-7R4EI

Data source: Eurocontrol - STATFOR, The Norwegian Civil Aviation Administration (personal comm.)

TJ - turbojet, TF - turbofan, TP - turboprop, R - reciprocating piston, O - opposed piston.
*The number of movements does not necessarily reflect the relative importance with respect to fuel use and emissions, which in addition are mostly determined by aircraft size and flight distances.

3.3 Techniques

In general there are two types of engines; *reciprocating piston* engines, and *gas turbines* (Olivier, 1990). In *piston engines*, energy is extracted from fuel burned in a combustion chamber by means of a piston and crank mechanism, which drives the propellers to give the aircraft momentum. In *gas turbines* air is first compressed and then heated by combustion with fuel in a combustion chamber and the major part of this is used for propulsion of the aircraft. A part of the energy contained in the hot air flow is used to drive the turbine, which in turn drives the compressor. Turbojet engines use only energy from the expanding exhaust stream for propulsion, whereas turbofan and turboprop engines use energy from the turbine to drive a fan or propeller for propulsion.

3.4 Emissions

Air traffic as a source of combustion emissions will depend on the:

- type of aircraft;
- type of engines and fuel used;
- emission characteristics of the engines (emissions per unit of fuel used depending on engine load);
- location (altitude) of operation;
- traffic volume (number of flights and distance travelled).

The effect of engine ageing on emissions is not taken into account. It is, however, generally assumed that this effect is of minor importance compared with the total emissions since aircraft engines are continuously maintained to tighter standards than the engines used in e.g. automotive applications.

Emissions come from use of kerosene and aviation gasoline that are used as fuel for the aircraft. Gasoline is used in small (piston engined) aircraft only.

Other emissions:
Which are related to aircraft, but which are not included under the present SNAP codes. Examples of these are:

- fuelling and fuel handling (SNAP 050402) in general;
- maintenance of aircraft engines (SNAP 060204);
- painting of aircraft (SNAP 060108);
- service vehicles for catering and other services (SNAP 0808);
- anti-icing and de-icing of aircraft (SNAP 060412). Much of the substances used flows off the wings during idle, taxi, and take-off and evaporates.

Emissions from start up of engines:
These are not included in the LTO cycle. There is currently little information available to estimate these. This is not important for total national emissions, but they may have an impact on the air quality in the vicinity of airports.

Auxiliary power operations:
Considerations might be given to allocating a SNAP code to the operation of APUs (Auxiliary Power Unit) (see section 3.4 below). APU is used where no other power source is available for the aircraft and may vary from airport to airport. This is the case, for example, when the aircraft is parked away from the terminal building. The APU fuel use and the related emissions should be allocated on the basis of aircraft operations (number of landings and take-offs). However, currently no methodology has been developed. The use of APU is being severely restricted at some airports to maintain air quality, and therefore this source of fuel use and emissions may be declining.

Fuel dumping in emergencies:
From time to time aircraft will have to dump fuel before landing so that they do not to exceed a certain maximum landing weight. This is done at a location and altitude where there will be no local impact at ground level. Only large (long-range) aircraft will dump fuel. NMVOC emissions might become significant at very large airports with frequent long distance flights. However, since the most probable altitude of these emissions will be above 1000 m, these are currently not relevant for UNECE reporting. The airport authorities and airline companies might give information on the extent (frequency and amount) of dumping and the altitude at particular airports.

The use of energy, and therefore emissions, depends on the aircraft operations and the time spent at each stage. Table 3.2 shows engine power settings and times-in-mode for the LTO-cycle specified by ICAO (ICAO, 1993). The actual operational time-in-mode might vary from airport to airport depending on the traffic, environmental considerations, aircraft types as well as topographical conditions.

Table 3.2. Standard landing and take-off cycles in terms of thrust settings and time spent in the specific mode

Operating mode	Thrust setting (% of maximum sea level static thrust)	Time-In-Mode (min)
Take-off	100%	0.7
Climb-out	85%	2.2
Approach-landing	30%	4.0
Taxi/ground idle	7%	26.0

Source: ICAO, 1993

The proportion of fuel used in a mission which is attributed to LTO decreases as mission distance increases. Thus a substantial part of the fuel consumption takes place outside the LTO-cycle. Studies indicate that the major part of NO_x (60-80%), SO_2 and CO_2 (80-90%) is emitted at altitudes above 1000 m. For CO it is about 50% and for VOC it is about 20-40% (Olivier, 1991).

3.5 Controls

The current status of regulations of NO_x is found in ICAO (1993), see Table 3.3. Standards are given for engines first produced before and after 1996. Further regulations will be put on engines manufactured after 31.12.2003 as specified by ICAO's latest regulations set in the CAEP (1998). Aircraft manufacturers are also helping with respect to reducing the fuel consumption by improvements in the aerodynamic properties of the aircraft.

The regulations published by ICAO against which engines are certificated are given in the form of the total quantity of pollutants (D_p) emitted in an LTO cycle divided by the maximum sea level thrust (F_{oo}) and plotted against engine pressure ratio at maximum sea level thrust. The limit values are given by the formulae in Table 3.3.

Table 3.3 Current and future regulations. Certification limits for NO_x for turbo jet and turbo fan engines.

	CURRENT REGULATIONS		RECOMMENDATION
	engines first produced before 31.12.1995 & for engines manufactured up to 31.12.1999	engines first produced after 31.12.1995 & for engines manufactured after 31.12.1999	recommended regulation (CAEP 4th meeting, 1998, CAEP-SG/2-Report pp B-2, B-3) for engines manufactured after 31.12.2003
Applies to engines >26.7 kN	$D_p/F_{oo} = 40 + 2\pi^{\circ}_{oo}$	$D_p/F_{oo} = 32 + 1.6\pi^{\circ}_{oo}$	
Engines of pressure ratio less than 30			
Thrust more than 89 kN			$D_p/F_{oo} = 19 + 1.6\pi^{\circ}_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$D_p/F_{oo} = 37.572 + 1.6\pi^{\circ}_{oo} - 0.208\ F_{oo}$
Engines of pressure ratio more than 30 and less than 62.5			
Thrust more than 89 kN			$D_p/F_{oo} = 7+2.0\pi^{\circ}_{oo}$
Thrust between 26.7 kN and not more than 89 kN			$D_p/F_{oo} = 42.71 +1.4286\pi^{\circ}_{oo} - 0.4013\ F_{oo} +0.00642\pi^{\circ}_{oo} * F_{oo}$
Engines with pressure ratio 62.5 or more			$D_p/F_{oo} = 32+1.6\pi^{\circ}_{oo}$

Source: International Standards and Recommended Practices, Environmental Protection, ICAO Annex 16 Volume II Part III Paragraph 2.3.2, 2nd edition July 1993.

where:

D_p = the sum of emissions in the LTO cycle in g
F_{oo} = thrust at sea level take-off (100%)
π°_{oo} = pressure ratio at sea level take-off thrust point (100%)

The equivalent limits for HC and CO are $D_p/F_{oo} = 19.6$ for HC and $D_p/F_{oo} = 118$ for CO (ICAO Annex 16 Vol. II paragraph 2.2.2). Smoke is limited to a regulatory smoke number = $83\ (F_{oo})^{-0.274}$ or a value of 50, whichever is the lower.

The relevance of these data within this report is to indicate that whilst the certification limits for NO_x are getting lower, those for smoke, CO and HC are unchanged.

3.6 Projections

Future aircraft emissions will be determined by the volume of air traffic, new aircraft technologies and the rate at which the aircraft fleet changes.

According to the IPCC (1999), total global passenger-km will grow by 5 % annually between 1990 and 2015 with a corresponding growth in fuel use of 3 % per year over the same period. The difference is explained by an anticipated improvement in aircraft fuel efficiency. The anticipated growth rates in individual countries will probably be described in the transport plans, which should be available from national Ministries of Transport.

Over the last 30 years, aircraft engines have improved in efficiency, and due to the high cost of fuel, this trend is expected to continue. As mentioned in 3.7, it is expected that tightening the emission regulations will lead to a decrease in NO_x emission factors.
NO_x may be reduced by introducing engines fitted with double annular combustion chambers (MEET, 1998). This technology has been implemented in new aircraft e.g. B737-600. Proposed average changes in emission factors are shown in Table 3.4. Note that these may be larger or smaller according to the rate at which the aircraft fleet is renewed (see below).

Table 3.4 Changes in emission factors relative to current level. Baseline scenario

	NO_x	CO	HC
2010	-10%	-6 %	-6 %
2020	-20 %	-27 %	-24 %

Research is being undertaken on engines to substantially reduce emissions of NO_x, CO and HC (MEET 1998). However, the time scale over which the results from this research will become commercially available is unclear, and therefore their use in baseline projections is not recommended.

Research is also ongoing to improve the aircraft design to further improve fuel efficiency. Also using new materials may prove to be beneficial (MEET, 1998). In a baseline scenario an annual improvement of average fuel efficiency of 1.5-2.5 % is recommended.

The rate of change of the aircraft fleet depends very much on the country of operation. Although an aircraft is expected to have a long life - typically 25 to 35 years, it will often be sold to other operators, possibly in other countries, and possibly converted to other uses (for example for carrying freight). Noise regulations may also influence the rate of change of aircraft fleet. For a projection of national emissions, it is expected that the major airlines are in a position to provide the most accurate information on anticipated fleet changes as part of their long-term plans. An analysis of future aircraft fleet made by UK DTI (MEET, 1998) is shown in Table 3.5.

Table 3.5 World fleet age profile. 2010 and 2020, Per cent

Age (years)	2010	2020
0-5	27.6	32.5
6-10	20.5	22.9
11-15	19.7	17.8
16-20	23.5	16.2
21-25	8.6	10.6

* Growth of fleet from 2010 to 2020 is 26 %.

The commercial use of alternative fuels in aircraft is still a long way off and should not be incorporated into any national baseline emission projection. Hydrogen is the most likely alternative to kerosene (MEET, 1998). This fuel will be more efficient and has lower emissions compared to kerosene (producing NO_x and water vapour, but no carbon compounds). However, the life-cycle emissions depend on how the hydrogen is produced. Hydrogen is very energy-demanding to produce, and introducing hydrogen as an alternative fuel will also require massive investments in ground infrastructure in addition to rebuilding aircraft.

4 SIMPLE METHODOLOGIES

Within different countries, there may be large differences in the resources and data available as well as the relative importance of this emission source. Therefore, three methodologies, the Very Simple, the Simple and the Detailed Methodology, have been developed. The difference between the methodologies lies mainly in the aggregation level assumed for the aircraft.

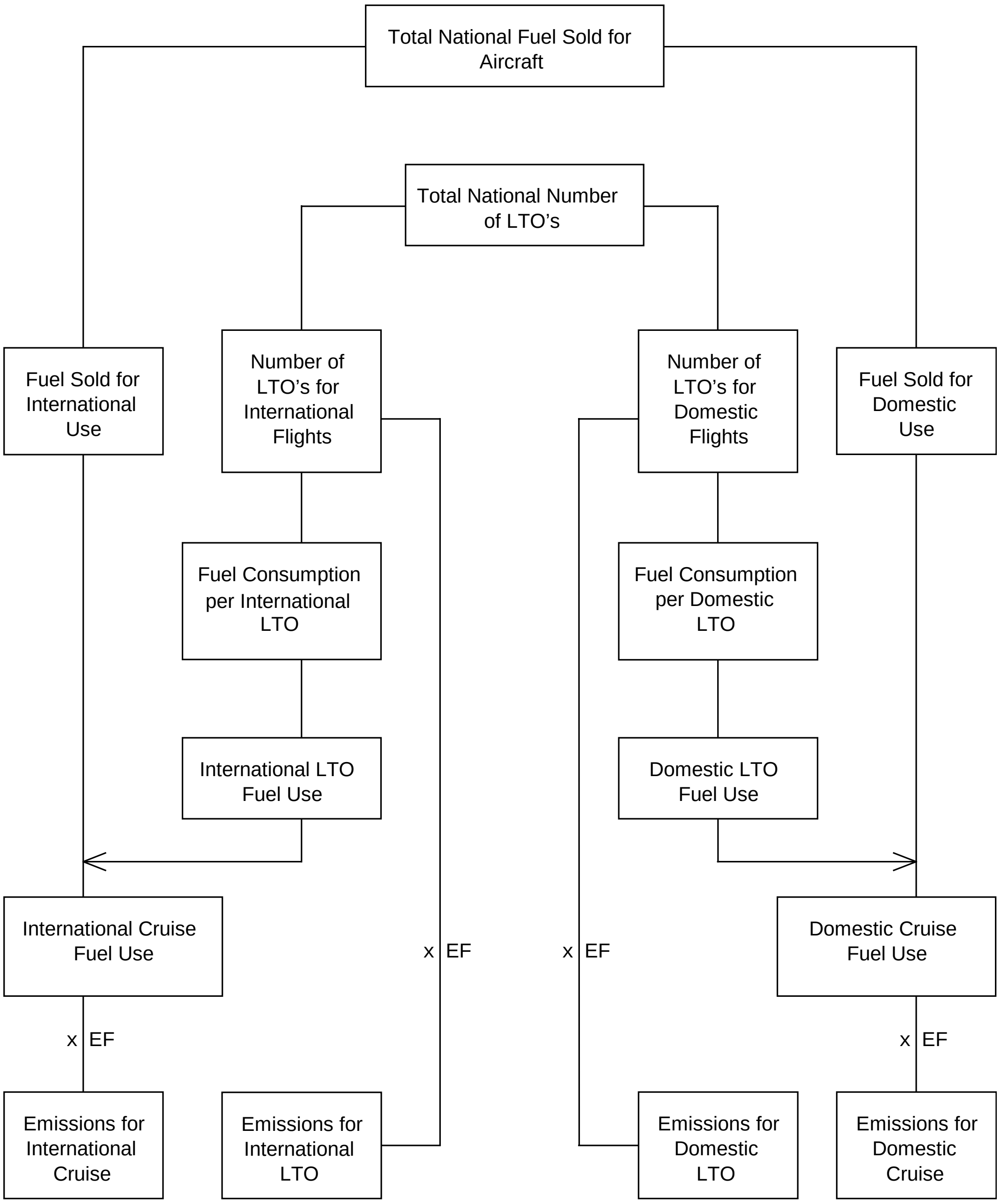
In the very simple methodology, estimations are made without considering the actual aircraft types used. In the simple methodology, it is assumed that information is available on the types of aircraft that operate in the country. Finally, the detailed methodology takes into account cruise emissions for different flight distances and possibly specific LTO times-in-modes. The third (detailed) methodology will be explained in section 5. The differences between the methodologies are shown in Table 4.1. See section 10 for a discussion of the advantages and disadvantages of the various methods.

All three methodologies are based on landing/take-off data. Of the aircraft categories described above (3.1), flight data will be fully available for Category 1, but only partly available or missing for Categories 2, 3 and 4. Thus, these methodologies outlined might only be applicable to Category 1. However this will represent the major part of the emissions. Emissions from the other categories may be roughly estimated from fuel data or hours of operation, if available. Such data may be available from the operating companies. The Detailed Methodology (section 5) will give some information in how to estimate emissions from these non-IFR flights.

Table 4.1 Basis for the methodologies.

		LTO	**Cruise and Climb**
Very Simple	*Activity*	LTO aggregated Time-in-mode (ICAO)	Fuel residual
	Emission factor	Generic aircraft	Generic aircraft
Simple	*Activity*	LTO per aircraft type (generic aircraft) Time-in-mode (ICAO)	Fuel residual
	Emission factor	Per aircraft type	One generic aircraft
Detailed	*Activity*	LTO per aircraft type (generic aircraft) (option also engine type) Time-in-mode: actual if available otherwise ICAO	Distances flown. Independent estimate of cruise fuel use.
	Emission factor	Per aircraft type (generic aircraft) (option also engine type)	Per aircraft type (generic aircraft) and distance flown

Figure 4.1 Estimation of aircraft emissions with the simple fuel based methodologies



The simple methodologies are both based on LTO data and the quantity of fuel sold or used as illustrated in Figure 4.1. It is assumed that fuel used equals fuel sold. From the total fuel sold for aircraft activities, allocations are made according to the requirements for IPCC and UNECE reporting. The emission estimation can be made following one of the two simple methodologies outlined below.

For estimating the total emissions of CO_2, SO_2 and heavy metals the Very Simple Methodology is sufficient, as the emissions of these pollutants are dependent of the fuel only and not technology. The Detailed Methodology may be used to get an independent estimate of fuel and CO_2 emissions from domestic air traffic.

See Table 4.2. for references to the recommended aircraft to be used for these calculations.

4.1 The Very Simple Methodology

Where the number of LTO cycles carried out on a per-aircraft type basis is not known, the Very Simple Methodology should be used. In this case information on the country's total number of LTOs needs to be available, preferably also the destination (long and short distance) for international LTOs, together with a general knowledge about the aircraft types carrying out aviation activities.

Aircraft emission estimates according to the Very Simple Methodology can be obtained by following the steps below:

1. Obtain the *total* amount of *fuel* sold for all aviation (in ktonnes)
2. Obtain the amount of *fuel* used for *domestic* aviation only (in ktonnes).
3. Calculate the total amount of *fuel* used for *international* aviation by subtracting the domestic aviation (step 2) from the total fuel sold (step 1).
4. Obtain the total *number of LTOs* carried out for domestic aviation.
5. Calculate the *total fuel use for LTO* activities for domestic aviation by multiplying the number of domestic LTOs by the domestic fuel use factors for one representative aircraft (Table 8.2) (step 4 x fuel use for representative aircraft). Fuel use factors are suggested for an old and an average fleet.
6. Calculate the *fuel used for cruise* activities for domestic aviation by subtracting the fuel used for domestic LTO (step 5) from the total domestic fuel used (step 2).
7. Estimate the *emissions related to domestic LTO activities* by multiplying the emission factors (per LTO) for domestic traffic with the number of LTO for domestic traffic. Emission factors are suggested for an old and an average fleet by representative aircraft (Table 8.2).
8. Estimate the *emissions related to domestic cruise activities* by multiplying the respective emission factors (in emission/fuel used) in Table 8.2 with the domestic cruise fuel use. Emission factors are suggested for an old and an average fleet by representative aircraft.
9. Repeat step 4 to 8 substituting domestic activities with *international*. It is for international flights preferable to distinguish between short (< 1000 nm[2]) and long distance flights (> 1000 nm). The latter is normally performed by large fuel consuming aircraft compared to the shorter distance flights (e.g. within Europe). If this distinction cannot be made the LTO emissions are expected to be largely overestimated in most countries.

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[2] Where nm = nautical miles, 1nm = 1.852 km.

The estimated emissions are allocated to SNAP codes as follows:

- LTO, domestic aviation found in step 7 go under the SNAP code 080501;
- LTO, international aviation found in step 7 go under the SNAP code 080502;
- Cruise, domestic aviation found in step 8 go under SNAP code 080503;
- Cruise, international aviation found in step 8 go under SNAP code 080504.

4.2 The Simple Methodology

If it is possible to obtain information on LTOs per aircraft type but there is no information available on cruise distances, it is recommended to use the Simple Methodology. The level of detail necessary for this methodology is the aircraft types used for both domestic and international aviation, together with the number of LTOs carried out by the various aircraft types. The approach can best be described by following the steps:

1. Obtain the *total amount of fuel* sold for all aviation (in ktonnes).
2. Obtain the total amount of *fuel* used for *domestic aviation* (in ktonnes).
3. Calculate the amount of *fuel used for international aviation* by subtracting the domestic aviation (step 2) from the total fuel sold (step 1) (in ktonnes).
4. Obtain the total *number of LTOs* carried out *per aircraft type* for domestic aviation. Group the aircraft into the groups of generic aircraft given in Table 4.2. Use table 4.3 for miscellaneous smaller aircraft.
5. Calculate the *fuel use for LTO activities* per aircraft type for domestic aviation. For each aircraft type, multiply the fuel use factor in Table 8.3 corresponding to the specific aircraft type in Table 4.2 with the number of domestic LTOs carried out for the generic aircraft (fuel use factor in LTO for aircraft type * number of LTOs with the same aircraft type). The calculations are carried out for all types of generic aircraft. Calculate the total fuel use for LTO activities by summing all contributions found under step 5 for domestic aviation. If some types of national aircraft in use are not found in the table, use a similar type taking into account size and age. For LTOs for smaller aircraft and turboprops, see also section on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.
6. Calculate the total *fuel use for domestic cruise* by subtracting the total amount of fuel for LTO activities found in step 6 from the total in step 2 (estimated as in the Very Simple Methodology).
7. Estimate the *emissions from domestic LTO activities* per aircraft type. The number of LTOs for each aircraft type is multiplied by the emission factor related to the particular aircraft type and pollutant. This is done for all generic aircraft types. Relevant emission factors can again be found in Table 8.3. If some types of national aircraft in use are not found in the table, use a similar type taking into account size and age. For LTOs for smaller aircraft and turboprops, see also section on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.
8. Estimate the emissions from domestic *cruise activities*. Use the domestic cruise fuel use and the corresponding emission factor for the most common aircraft type used for domestic cruise activities (the Very Simple Methodology or Detailed Methodology). Relevant

emission factors can be found in Table 8.2 or attached spreadsheet for Detailed Methodology.

9. Calculate the *total emissions for LTO activities* for domestic aviation: Add up all contributions from the various aircraft types as found under step 7. The summations shall take place for each of the pollutants for which emissions are to be estimated (for CO_2, NO_x, SO_2, etc.).
10. Calculate the *total emissions for cruise activities* for domestic aviation. Add up all contributions from the various types of aircraft types as found under step 8). The summations shall take place for each of the pollutants for which emissions are to be estimated (for CO_2, NO_x, SO_2, etc.).
11. Repeat the calculation (step 4-10) for *international aviation*.

The estimated emissions are allocated to SNAP codes as follows:

- LTO, domestic activities found in step 9 go under the SNAP code 080501;
- LTO, international aviation found in step 9 go under the SNAP code 080502;
- Cruise, domestic aviation found in step 10 go under SNAP code 080503;
- Cruise, international aviation found in step 10 go under SNAP code 080504.

Table 4.2 Correspondence between aircraft type and representative aircraft

GENERIC AIRCRAFT TYPE	ICAO	IATA AIRCRAFT IN GROUP	GENERIC AIRCRAFT TYPE	ICAO	IATA AIRCRAFT IN GROUP	GENERIC AIRCRAFT TYPE	ICAO	IATA AIRCRAFT IN GROUP	GENERIC AIRCRAFT TYPE	ICAO	IATA AIRCRAFT IN GROUP
BAe 146	BA46	141	**Airbus A320**	A320	320	**Boeing 747-400**	B744	744	**McDonnell Douglas DC10**	DC10	D10
		143			32S	**Boeing 757**		757			D11
		146			321			75F			D1C
		14F	**Airbus A319**	A319	319			TR2			D1F
Airbus A310	A310	310	**Airbus A330**	A330	330	**Boeing 767**		762			L10
		312			332			763			L11
		313			333			767			L12
		A31	**Airbus A340**	A340	340			AB3			L15
Boeing 727-100	B721	721			342			AB6			M11
Boeing 727-200	B722	722			343			A3E			M1F
Boeing 727-300	B727	727	**BAe 111**	BA11	B11			ABF	**McDonnell Douglas DC8**		DC8
		72A			B15			AB4			D8F
		72F			CRV	**Boeing 777**		777			D8M
		72M			F23	**Boeing 777-200**	B772	772			D8S
		72S			F24	**Boeing 777-300**	B773	773			707
		TU5			YK4	**McDonnell Douglas DC-9**		D92			70F
Boeing 737-200	B732	732	**Boeing 747-100-300**	B741	741			D93			IL6
Boeing 737-500	B735	735		B742	742			D94			B72
		73A		B743	743			D95			
		73B			747			D98			
		73F			74D			D9S			
		73M			74E			DC9			
		73S			74F			F21			
		D86			A4F			TRD			
		JET			74L			YK2			
		DAM			74M	**McDonnell Douglas M81-88**	MD81-88	M80			
Boeing 737-400	B734	734			74R			M81			
Boeing 737-300	B733	733			IL7			M82			
Boeing 737-700	B737	737			ILW			M83			
Fokker 100	F100	100			NIM			M87			
Fokker F-28	F28	F28			VCX			M88			
		TU3			C51						

* MD90 goes as MD81-88 and B737-600 goes as B737-400.

** DC8 goes as double the B737-100. F50, Dash8 -see separate table.

Table 4.3 Overview of smaller aircraft types

Aircraft type	Aircraft category/engine principle	Maximum Take Off Weight according to Frawley's	Rank in Danish inventory 1998
Can_CL604 (CL60)	L2J	18	19
Canadair RJ 100 (CARJ)	L2J	24	17
CitationI (C500)	L2J	5.2	10
Falcon2000 (F2TH)	L2J	16.2	-
Falcon900 (F900)	L3J	20.6	8
Avro_RJ85 (BA46)	L4J	42	1
F50 (F50)	L2T	20.8	1
Shorts360 (SHD3)	L2T	12.3	3
Bae31 (JSTA)	L2T	7	4
Bae41 (JSTB)	L2T	10.4	10
Dash8-400 (DHC8)	L2T	27.3	9
Saab2000 (SB20)	L2T	22.8	13
MetroIII (SW3)	L2T	5	7
F27 (F27)	L2T	20.4	8
C130 (C130)	L4T	70.3	1
P3B_Orion (L188)	L4T	52.7	2
AS50 (AS50)	H1T	2	2
S61 (S61)	H2T	8.6	1

* L = Landplane, H= Helicopter, J = Jet engine, T = Turboprop, 1, 2 or 4 equals the number of engines

Source: Supplied by Danmarks Miljøundersøkelser

5 THE DETAILED METHODOLOGY

The data sources available for performing a Detailed Methodology may vary between countries. Also the scope of such a study may vary. We will present two detailed methodologies for aircraft here, one based on *aircraft movement data* recommend for *IFR flights* and one based on *fuel statistics or operational hours* recommended for *non-IFR flights*. In addition, both methodologies could be used to prepare an airport inventory e.g. for inclusion in an urban emission inventory.

The *Aircraft Movement Methodology* (based on aircraft movement data) is the preferred option for IFR flights when detailed aircraft movement data for LTO and cruise together with technical information on the aircraft are available. Basically, the use of the Detailed Methodology means that emissions are estimated for all the different types of aircraft which are in use and have been registered by LTO movements in the airports of the country. The Detailed Methodology may also include the actual times-in-mode at individual airports. The primary use of this method is to determine the fuel used and emissions from national and international aviation activities of a country, but it may also be used for other applications that may be required by research or monitoring. The methodology may be quite time consuming to perform.

The *Fuel Consumption Methodology* is particularly suited to use for aircraft categories where LTO data may be incomplete or not available at all, e.g. military aircraft, and miscellaneous uncertificated aircraft such as helicopters, taxi aircraft and pleasure aircraft.

5.1 The aircraft movement methodology for IFR-flights

The total emissions from aircraft are given by the sum of emissions from various technologies of aircraft in a continuous set of flying modes. In this methodology we will simplify the calculations by classifying the aircraft into a representative set of generic aircraft types and into two classes of flying modes, that of LTO and that of cruise. However, the methodology allows adjustment for actual times-in-mode of LTO at individual airports. This method also permits the use of individual aircraft/engine combinations if the data are available.

The methodology involves the following steps:

1. Select the aircraft and flight details from National data, for example Civil Aviation records, airport records, an ATC provider such as Eurocontrol in Europe, or the OAG timetable. This will identify the aircraft that were used in the inventory period, the number of LTOs for each and the mission distance flown. For the aircraft actually flying, select the aircraft used to represent them from the table of equivalent aircraft (Table 4.2). This is called the ‘representative aircraft’. Use Table 4.3 for miscellaneous smaller aircraft. See also Section 5.2. on non-IFR flights. Their emissions will have to be estimated separately, by a simpler method.
2. Note the distance of the mission. See Section 6 “activity data” for a description of how this may be determined.

3. From the Table 4.2, Table 4.3. or Table 8.3, select the data corresponding to the LTO phase for the representative aircraft, for both fuel used and all emissions. The fuel used and associated emissions from this table represent the fuel and emissions in the boundary layer below 3000 ft (1000 m). This gives an estimate of emissions and fuel used during the LTO phase of the mission.
4. From the table of representative aircraft types vs mission distance (Tables 4.2. and Table 4.3), select the aircraft, and select the missions which bracket the one which is actually being flown. The fuel used is determined as an interpolation between the two. This is an estimate of fuel used during operations above 3000 ft (1000 m) (cruise fuel use).
5. The total quantity of fuel used for the mission is the sum of the fuel used for LTO plus the fuel used in all operations above 3000 ft (1000 m).
6. Now apply step 4 to the table of pollutants (NO_x, CO and HC) emitted vs mission distance and here again interpolate between the missions, which bracket the one being flown. This is an estimate of emissions during operations above 3000 ft (1000 m) (cruise emissions).
7. The total pollutants emitted during the flight is the sum of the pollutants emitted in LTO plus the quantity emitted in the rest of the mission.

See Section 8.3 for an example on how to apply the method.

If a specific aircraft-engine combination is required, then the LTO data must be calculated from the data contained in the ICAO Engine Emissions Data Bank for which the standard method of calculation is included (ICAO, 1995). This may increase the accuracy in the LTO emission estimate, but the cruise estimate based on generic aircraft cannot be changed based on these individual ICAO data.

Where *times-in-modes* are different from the assumptions made in this report, corrections may be made from basic data in the spreadsheets or in the ICAO databank.

Please note: If this methodology is used for UNFCCC reporting (and UNECE reporting of CO_2) the total estimated fuel use for domestic aviation must be compared to sales statistics or direct reports from the airline companies. If the estimated fuel deviates from the direct observation, the main parameters used for estimating the fuel must be adjusted in proportion to ensure that the mass of fuel estimated is the same as the mass of fuel sold.

5.2 Non IFR-flights

For some types of military or pleasure aircraft the numbers of hours in flight is a better activity indicator for estimating the fuel used and the emissions produced than the number of LTOs. In some cases the quantity of fuel used may be directly available.

1. Compile information on fuel used by aircraft category. The fuel types kerosene and aviation gasoline should be reported separately. If not directly available, estimate the fuel used from the hours of operation and fuel consumption factors.
2. Select the appropriate emission factors and fuel use factors from Tables 8.6-8.10.

3. Multiply the fuel consumption data in tonnes by the fuel-based emission factors to obtain an annual emission estimate.

6 RELEVANT ACTIVITY STATISTICS

The activity statistics which are required will depend on the methodology. The available statistics may, however, to some extent determine the choice of methodology.

Fuel use statistics:
These should be split between national and international as defined above. Sources of these data include:
- The airline companies;
- The oil companies;
- Energy statistics;
- Estimations from LTOs and cruise distances (see also the Detailed Methodology);
- Estimation from time tables (see also the Detailed Methodology);
- Airport authorities.

The landing/take-off statistics:
These can be obtained directly from airports, from the official aviation authorities or from national reports providing aggregated information on the number of landings- and take-offs taking place for national and international aviation.

National time- in-mode LTO-data:
If data for individual aircraft at individual airports are to be used instead of standard ICAO values, these may be obtained from the airports or the operators of the aircraft.

Fuel use or numbers of hours in operation:
For particular aircraft types these may be obtained from the airline, taxi or helicopter companies (usually a limited number at national level). Also sales statistics of fuels and energy balances may give some information. Data on the quantity of fuel used in military aircraft may be obtained from fuel sales statistics and energy balances or directly from the defence authorities. These data may be classified information and therefore estimates might have to be made.

Distance tables:
Average cruise distances may be derived from timetables, national aircraft authorities or ATC providers. Note that distances given may be Great Circle and might not reflect the actual distances flown, for example deviations around restricted areas or stacking at busy airports. Total flight distance must be used and not only that part within the national territory.

7 POINT SOURCE CRITERIA

If an airport has more than 100.000 LTOs per year (national plus international), the airport should be considered as a point source.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors used for the three methodologies are based on different levels of detail of the aircraft used to represent the fleet in the calculations.

ICAO (1995) (exhaust emission databank) provides basic aircraft engine emission data for certificated turbojet and turbofan engines covering the rate of fuel used, and the emission factors for HC, CO and NO_x at the different thrust settings used. Other relevant emission data are derived from other sources.

The *heavy metal* emissions are, in principle, determined from the metal content of kerosene or gasoline. Thus, general emission factors for stationary combustion of kerosene and combustion of gasoline in cars may be applied. The only exception is *lead*. Lead is added to aviation gasoline to increase the octane number. The lead content is higher than in leaded car gasoline, and the maximum permitted levels in UK are shown in Table 8.1 below.

Table 8.1 Lead content of aviation gasoline, UK.

AVGAS designation	Maximum lead content (as Tetra ethyl lead)
AVGAS 80	0.14 g/l
AVGAS Low Lead 100	0.56 g/l
AVGAS 100	0.85 g/l

A value of 0.6 g lead per litre gasoline should be used as the default value if there is an absence of better information. Actual data may be obtained from the oil companies.

Little information is currently available about possible exhaust emissions of POPs (Persistent Organic Polutants) from aircraft engines. USEPA has derived a PAH-16/VOC fraction of $1.2*10^{-4}$ and a PAH-7/VOC fraction of $1.0*10^{-6}$ for commercial aviation (USEPA 1999). PAH-7 here includes the four UNECE PAHs and three additional species.

Emissions of *water* (H_2O) may be derived from the fuel consumption at the rate of 1.237 kg water/kg fuel.

Unfortunately, there is insufficient information on emissions of particulate matter from aircraft.

8.1 Very Simple Methodology

The emission factors in Table 8.2. should be applied when using the Very Simple Methodology. The average international aircraft fleet is represented by a long distance aircraft (large aircraft). If the international trips from the inventory country are mostly short distance (smaller aircraft), it may be more accurate to use the information for domestic aircraft, or to make an appropriate split into short (< 1000 nm) and long (> 1000 nm) distance flights, see 4.1. The emission factors may also be averaged whenever appropriate. LTO emission estimates will in most countries be far too high using the average aircraft only. Such a distinction cannot be made for cruise emissions using the simple methodology. This is, however, a small error as the emissions are estimated from the fuel residual.

Table 8.2 Emission factors and fuel use for the *Very Simple* methodology. Emission factors are given on a representative aircraft basis.

Domestic	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NM-VOC**	**CH_4**	**N_2O**
LTO (kg/LTO) – Average fleet (B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1
LTO (kg/LTO) – Old fleet (B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1
Cruise (kg/tonne) – Average fleet (B737-400)	-	1.0	3150	2.0	10.3	0.1	0	0.1
Cruise (kg/tonne)- Old fleet (B737-100)	-	1.0	3150	2.0	9.4	0.8	0	0.1
International	**Fuel**	**SO_2**	**CO_2**	**CO**	**NO_x**	**NM-VOC**	**CH_4**	**N_2O**
LTO (kg/LTO) – Average fleet (B767)	1617	1.6	5094	6.1	26.0	0.2	0.0	0.2
- LTO (kg/LTO) – Average fleet (short distance, B737-400)	825	0.8	2600	11.8	8.3	0.5	0.1	0.1
- LTO (kg/LTO) – Average fleet (long distance, B747-400)	3400	3.4	10717	19.5	56.6	1.7	0.2	0.3
LTO (kg/LTO) – Old fleet (DC10)	2400	2.4	7500	61.6	41.7	20.5	2.3	0.2
- LTO (kg/LTO) – Old fleet (short distance, B737-100)	920	0.9	2900	4.8	8.0	0.5	0.1	0.1
- LTO (kg/LTO) – Old fleet (long distance, B747-100)	3400	3.4	10754	78.2	55.9	33.6	3.7	0.3
Cruise (kg/tonne)- Average fleet (B767)	-	1.0	3150	1.1	12.8	0.5	0.0	0.1
Cruise (kg/tonne)- Old fleet (DC10)	-	1.0	3150	1.0	17.6	0.8	0.0	0.1

*Sulphur content of the fuel is assumed to be 0.05% S (by mass) for both LTO and cruise activities.

** Assuming a cruise distance of 500 nm for short distance flights and 3000 nm for long distance flights.

Source: Derived from ANCAT/EC2 1998, Falk 1999 and MEET 1999.

The emission factors for the new fleet can well be higher than that for the fleet it replaces. The reason is that the newer fleet has engines which, in comparison with those of the older fleet, have higher pressure ratios and therefore operate more efficiently, but, at higher combustion temperatures, thus producing more emissions of NO_x. Other pollutants increase for other reasons. However, the increase in aircraft seating capacity of the newer fleet over the old one may lead to a reduction in emissions per passenger.

8.2 Simple Methodology

For the Simple Methodology emission factors in Table 8.3 should be used. For aircraft not contained here, the general factors (Table 8.2) may be used, or use correspondence tables for the Detailed Methodology.

Table 8.3 Examples of aircraft types and emission factors for LTO cycles as well as fuel consumption per aircraft type, kg/LTO

Aircraft type[a]	CO_2	CH_4	N_2O[b]	NO_x	CO	NMVOC	SO_2[c]	Fuel
A310	4853	0.5	0.2	23.2	25.8	5.0	1.5	1540.5
A320	2527	0.3	0.1	10.8	17.6	1.6	0.8	802.3
A330	7029	0.9	0.2	36.1	21.5	1.2	2.2	2231.5
A340	6363	1.9	0.2	35.4	50.6	16.9	2.0	2019.9
BAC1-11	2147	0.3	0.1	4.9	37.7	21.1	0.7	681.6
BAe146	1794	0.2	0.1	4.2	9.7	0.8	0.6	569.5
B727	4450	0.6	0.1	12.6	26.4	6.6	1.4	1412.8
B737 100	2897	0.4	0.1	8.0	4.8	0.2	0.9	919.7
B737 400	2600	0.3	0.1	8.3	11.8	0.3	0.8	825.4
B747 100-300	10754	1.4	0.3	55.9	78.2	35.9	3.4	3413.9
B747 400	10717	1.4	0.3	56.6	19.5	0.5	3.4	3402.2
B757	3947	0.5	0.1	19.7	12.5	0.7	1.3	1253.0
B767 300 ER	5094	0.6	0.2	26.0	6.1	0.2	1.6	1617.1
B777	8073	2.3	0.3	53.6	61.4	20.5	2.6	2562.8
DC9	2760	0.1	0.1	7.3	5.4	0.7	0.9	876.1
DC10	7501	2.3	0.2	41.7	61.6	20.5	2.4	2381.2
F28	2098	0.3	0.1	5.2	32.7	32.6	0.7	666.1
F100	2345	0.3	0.1	5.8	13.7	1.1	0.7	744.4
MD81-88	3160	0.4	0.1	12.3	6.5	1.5	1.0	1003.1

(a) For CH_4 and NMVOC it is assumed that the emission factors for LTO cycles be 10% and 90% of total VOC (HC), respectively (Olivier, 1991). Studies indicate that during cruise no methane is emitted (Wiesen et al., 1994).

(b) Estimates based on IPCC Tier 1 default values.

(c) Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities.

For the DC8 use double the fuel consumption of the B737-100 because it is fitted with four engines instead of two. MD90 goes as MD81-88 and B737-600 goes as B737-400.
Source: Derived from ANCAT/EC2 1998, Falk (1999) and MEET 1999.

The CO_2 emissions are based on the following factor: 3.15 kg CO_2 /kg fuel.

We recommend that the Very Simple Methodology (emission factor for a generic aircraft) is used to estimate the cruise emissions also when using the Simple Methodology. Alternatively pick another aircraft from Table 8.4 or Table 8.5 that may be assumed to be more representative and assume an appropriate cruise distance. The reason is that the residual step of the Simple Methodology does not rely on any knowledge of the proportion of aircraft types in the cruise mode nor the cruise distances.

Using the emission factors, special emphasis should be put on the assumptions of the weight percent of sulphur (assumed at 0.05%). If the sulphur percent of the fuel used is different, this should be taken into account. If the sulphur percent used for example is 0.01% instead of 0.05%, the emission factor should be divided by 5 to show the true factor.

8.3 Detailed Methodology

8.3.1 IFR-flights

For the Detailed Methodology emission factors for the representative aircraft are given in Table 8.4. The correspondence between actual aircraft and representative aircraft is given in Table 4.2.

Table 8.4 Emission factors and fuel use factors for various aircraft per LTO and distance cruised.

Table is given in associated spreadsheets available in the internet version of this Guidebook. Extracts of the tables are displayed below.

B737 400		Standard flight distances (nm)			[1nm = 1.852 km]			
		125	**250**	**500**	**750**	**1000**	**1500**	**2000**
Distance (km)	Climb/cruise/descent	231.5	463	926	1389	1852	2778	3704
Fuel (kg)	Flight total	1603.1	2268.0	3612.8	4960.3	6302.6	9187.7	12167.6
	LTO	825.4	825.4	825.4	825.4	825.4	825.4	825.4
	Taxi out	183.5	183.5	183.5	183.5	183.5	183.5	183.5
	Take off	86.0	86.0	86.0	86.0	86.0	86.0	86.0
	Climb out	225.0	225.0	225.0	225.0	225.0	225.0	225.0
	Climb/cruise/descent	777.7	1442.6	2787.4	4134.9	5477.2	8362.3	11342.2
	Approach landing	147.3	147.3	147.3	147.3	147.3	147.3	147.3
	Taxi in	183.5	183.5	183.5	183.5	183.5	183.5	183.5
NO$_x$ (kg)	Flight total	17.7	23.6	36.9	48.7	60.2	86.3	114.4
	LTO	8.3	8.3	8.3	8.3	8.3	8.3	8.3
	Taxi out	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	Take off	1.591	1.591	1.591	1.591	1.591	1.591	1.591
	Climb out	3.855	3.855	3.855	3.855	3.855	3.855	3.855
	Climb/cruise/descent	9.462	15.392	28.635	40.425	51.952	78.047	106.169
	Approach landing	1.240	1.240	1.240	1.240	1.240	1.240	1.240
	Taxi in	0.784	0.784	0.784	0.784	0.784	0.784	0.784
EINO$_x$ (g/kg fuel)	Taxi out	4.27	4.27	4.27	4.27	4.27	4.27	4.27
	Take off	18.51	18.51	18.51	18.51	18.51	18.51	18.51
	Climb out	17.13	17.13	17.13	17.13	17.13	17.13	17.13
	Climb/cruise/descent	12.17	10.67	10.27	9.78	9.49	9.33	9.36
	Approach landing	8.42	8.42	8.42	8.42	8.42	8.42	8.42
	Taxi in	4.27	4.27	4.27	4.27	4.27	4.27	4.27
HC (g)	Flight total	817.6	912.9	995.8	1065.2	1118.1	1240.4	1374.1
	LTO	666.8	666.8	666.8	666.8	666.8	666.8	666.8
	Taxi out	321.18	321.18	321.18	321.18	321.18	321.18	321.18
	Take off	3.09	3.09	3.09	3.09	3.09	3.09	3.09
	Climb out	10.58	10.58	10.58	10.58	10.58	10.58	10.58
	Climb/cruise/descent	150.78	246.13	329.05	398.47	451.33	573.67	707.37
	Approach landing	10.74	10.74	10.74	10.74	10.74	10.74	10.74
	Taxi in	321.18	321.18	321.18	321.18	321.18	321.18	321.18
EIHC (g/kg fuel)	Taxi out	1.75	1.75	1.75	1.75	1.75	1.75	1.75
	Take off	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Climb out	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Climb/cruise/descent	0.19	0.17	0.12	0.10	0.08	0.07	0.06
	Approach landing	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	Taxi in	1.75	1.75	1.75	1.75	1.75	1.75	1.75
CO (g)	Flight total	14252.5	15836.0	17525.5	19060.6	20369.3	23298.2	26426.3
	LTO	11830.9	11830.9	11830.9	11830.9	11830.9	11830.9	11830.9
	Taxi out	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45
	Take off	77.19	77.19	77.19	77.19	77.19	77.19	77.19
	Climb out	202.29	202.29	202.29	202.29	202.29	202.29	202.29
	Climb/cruise/descent	2421.54	4005.06	5694.59	7229.65	8538.39	11467.26	14595.41
	Approach landing	500.54	500.54	500.54	500.54	500.54	500.54	500.54
	Taxi in	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45	5525.45

EICO (g/kg fuel)	Taxi out	30.11	30.11	30.11	30.11	30.11	30.11	30.11
	Take off	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Climb out	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Climb/cruise/descent	3.11	2.78	2.04	1.75	1.56	1.37	1.29
	Approach landing	3.40	3.40	3.40	3.40	3.40	3.40	3.40
	Taxi in	30.11	30.11	30.11	30.11	30.11	30.11	30.11

Example:

A B737-400 aircraft is travelling a mission distance of 1723 nm. We want to estimate the fuel use:

> The fuel use for LTO is taken directly from the table and is 825 kg (independent of mission distance).
>
> For operation above 3000 feet (cruise/climb/descent), the fuel used is 8362 + ((11342-8362)*(1723-1500)/(2000-1500)) = 9691 kg
>
> The emissions of the various pollutants may be estimated in the same way:
>
> The LTO NO_x may be read directly from the table = 8.3 kg.
>
> For operation above 3000 feet (flight less LTO), the NO_x is 78+ ((106-78)*(1723-1500)/(2000-1500)) = 90.5 kg
>
> EINOx for the mission is therefore (8.3+90.5)kg/(826+9691)kg = 8.9 g NO_x per kg fuel. This may be used as a check to ensure that no arithmetic error has been made in the calculations.

For pollutants not given in the Table 8.3 we recommend using the Simple Methodologies based on the estimated fuel use in the Detailed Methodology.

Emissions from smaller IFR flight aircraft engines are not certificated, and emission data are less well known. Larger turboprops may be in use for domestic flights and short international flights. Though they do not contribute to emissions on a larger scale, they may be important when estimating domestic emissions. Default emission factors are given in Table 8.5.

Table 8.5 Fuel consumption and emission factors for Dash 8, Fokker 50 and similar size turboprops.

A spreadsheet will be included as soon as data are available (likely 2001).

8.3.2 Non-IFR

There is little information available on emission factors for non-IFR flights. Generally, the NO_x emission factors will be lower and the CO and VOC factors substantially higher than for IFR flights.

It is at present not possible to recommend default emission factors.

Fuel consumption factors are given for two categories of aircraft (Cessna and others) to be used if other information of fuel used not is available (Table 8.6). Please note that the tables apply to single engine aircraft only. If the aircraft is fitted with two engines (e.g. Cessna 500), then double the fuel consumption. Ranges of emission factors are shown in MEET (1997). A summary is given in Table 8.7.

Some emission factors and fuel use factors for helicopters and military flights are given in Tables 8.8, 8.9 and 8.10. Also note that many types of military aircraft may have civil equivalents. Helicopters are also included in Table 8.5.

Table 8.6 Fuel consumption for piston engined aircraft, litre/hour

Cessna C 152, C 172, C 182 (single engine)	**0 feet altitude**	**2000 feet alt.**	**4000 feet alt**
75 % power (=135 HP)	41	42	no data
70 % power (=126 HP)	37	38	39
65 % power (=117 HP)	33.5	34	34.5

For an average use 36 litre/hour.

Robin (French aircraft), various Piper types (single engine)	**0 feet altitude**	**4000 feet alt.**
70 % power	36.5	no data
64 % power	34	33.5
58 % power	31	31

For an average use 33 litre/hour.

Table 8.7 Examples of emission factors for piston engined aircraft, g/kg fuel

		NO_x	**HC**	**CO**	**SO_2**
Netherlands	FL 0-30	2.70	20.09	1,054	0.21
	FL 30-180	4.00	12.50	1,080	0.17
Germany		3.14	18.867	798	0.42

* Multiply FL by 100 to obtain the altitude in feet.
Source: MEET Deliverable No 18.

Table 8.8 Examples of emission factors for helicopters and military flights. g/kg fuel

	Nature of flights	**NO_x**	**HC**	**CO**	**SO_2**
Germany	LTO-cycle	8.3	10.9	39.3	1.1
	Helicopter cruise	2.6	8.0	38.8	1.0
	combat jet	10.9	1.2	10.0	0.9
	cruise 0.46-3 km	10.7	1.6	12.4	0.9
	cruise >3 km	8.5	1.1	8.2	0.9
Netherlands	average	15.8	4.0	126	0.2
	F-16	15.3	3.36	102	0.2
Switzerland	LTO-Cycle	4.631	2.59	33.9	1.025
	cruise	5.034	0.67	14.95	0.999

Source: MEET Deliverable No 18.

Table 8.9 Emission factors for Helicopters of Germany

g/kg	NO_x	HC	CO	SO_2
Germany: cruise	2.6	8.0	38.8	0.99
Netherlands: cruise	3.1	3.6	11.1	0.20
Switzerland	13.3	0.3	1.1	0.97

Source: MEET Deliverable No 18.

Table 8.10 Fuel consumption factors for military aircraft

Group	Sub-group	Representative type	Fuel flow kg/hour
1. Combat	Fast Jet- High Thrust	F16	3283
	Fast Jet - Low Thrust	Tiger F-5E	2100
2. Trainer	Jet trainers	Hawk	720
	Turboprop trainers	PC-7	120
3. Tanker/transport	Large Tanker/Transport	C-130	2225
	Small Transport	ATP	499
4. Other	MPAs, Maritime Patrol	C-130	2225

Source: ANCAT, British Aerospace/Airbus

9 SPECIES PROFILES

Since very few experiments have been reported where the exhaust gas from aircraft turbines has been analysed in detail, it is not possible to give a specific species profile. In terms of NO_x and VOC, the profiles vary, amongst other reasons, with the thrust setting of the aircraft and therefore on the activity. In terms of aircraft cruise, it is not possible to obtain accurate estimates for emission factors.

In terms of the LTO activity, the situation is similar. Attempts have been made to estimate the composition of the VOC profile. Shareef et al., (1988) have estimated a VOC profile for a jet engine based on an average LTO cycle for commercial and general aviation. The composition is presented in Table 9.1.

PAH species profiles can be found in USEPA (1999), but not all species are available.

Table 9.1 The VOC profile for a jet engine based on an average LTO cycle for commercial and general aviation.

Compound in VOC profile	Percentage of total VOC (weight) Commercial aircraft	General aviation
Ethylene	17.4	15.5
Formaldehyde	15.0	14.1
$C_6H_{18}O_3Si_3$	9.1	11.8
Methane	9.6	11.0
Propene	5.2	4.6
Acetaldehyde	4.6	4.3
$C_8H_{24}O_4Si_4$	2.9	4.2
Ethyne	4.2	3.7
Acetone	2.4	2.9
Glyoxal	2.5	2.5
Acrolein	2.3	2.1
Butene	2.0	1.8
Benzene	1.9	1.8
1,3-butadiene	1.8	1.6
Methyl glyoxal	2.0	1.8
n-dodecane	1.1	1.2
Butyraldehyde	1.2	1.2
Others < 1%	14.8	13.9
Others	<1	<1
Total	100	100

Source: Shareef et al., 1988

Please note that the thrust setting during the landing and the take-off of the aircraft are different (see Table 3.1). Therefore, it is likely that the species profile will be different for the two situations. Again nothing is known on these aspects.

10 UNCERTAINTY ESTIMATES

The uncertainties of the estimated aircraft emissions are closely associated with the emission factors assigned to the estimations.

The emissions of NO_x (and fuel use) are generally determined with a higher accuracy than the other pollutants.

10.1 Very Simple Methodology

The accuracy of the distribution of fuel between domestic and international will depend on the national conditions.

The use of 'representative' emission factors may contribute significantly to the uncertainty. In terms of the factors relating to the LTO activities, the accuracy is better than for cruise (due to the origin of the factors from which the average values are derived from). It would be hard to calculate a quantitative uncertainty estimate. The uncertainty may however lie between 20-30% for LTO factors and 20-45% for the cruise factors.

10.2 Simple Methodology

The accuracy of the distribution of fuel between domestic and international will depend on the national conditions.

The uncertainties lie mainly in the origin of the emission factors. There is a high uncertainty associated with the cruise emission factors.

10.3 Detailed Methodology

Uncertainties lie in emission factors for the engines. ICAO (1995) estimates that the uncertainties of the different LTO factors are about 5-10%. For cruise, the uncertainties are assumed to be 15-40%.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The list given below summarises causes for concern and areas where further work may be required.

LTO

- Estimates of fuel used and emissions based on ICAO cycles (refer to ICAP Annex 16, Volume I) it may not reflect accurately the situation of aircraft and airport operations.
- The relationship between the minor pollutants and the regulated pollutants (HC, CO, NO_x) may need to be investigated in more detail.

Emissions above 3000 ft (3000 m)

- The emission factors and fuel use for short distances (125 and 250 nm) are difficult to model and the suggested values are highly uncertain.
- The actual distance flown compared with Great Circle distances that are given in the OAG timetable may vary by up to 10 to 11 % in Europe (ANCAT/EC2 1998).
- The actual altitude flown will vary according to air traffic management constraints compared with ideal altitudes flown by the PIANO computer model used by the UK DTI. Altitude will influence fuel consumed (lower cruise altitudes equal higher fuel consumption rate and hence also the emissions) and also the rate of production of NO_x.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Airports and emissions should be associated with the appropriate territorial unit (for example country). The airports can be divided into territorial units in the following way:

1. The fuel and emissions from specific airports can be identified, and then summed to show the emissions from region, which in turn can be summed for a country as a whole. Airports located in the various territorial areas should be identified

2. From the total national emission estimate emissions can be distributed to the territorial areas and airports using a key reflecting the aviation activity (e.g. the number of landings and take-off cycles) between territorial areas and airports.

13 TEMPORAL DISAGGREGATION CRITERIA

The temporal data may be obtained from flight timetables. There may be diurnal variations as well as variations over months and weekdays.

14 ADDITIONAL COMMENTS

The methodologies and data described in this chapter reflect the current state of the art knowledge. Obviously, the methods and data may be improved in the future.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

The methodology presented here could be used with international flight statistics (for example ATC providers) to provide a crosscheck against estimates made by individual national experts on the basis of national fuel and flight statistics.

National estimates may be checked against central inventories like ANCAT (1998) and NASA (1996) for 1991/92 and 1992, respectively.

Estimated emissions and fuel use per available seat kilometres travelled may also be compared between countries and aircraft types to ensure the credibility of the data which have been collected.

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