SNAP CODES :

080100
080200
080300
080600
080700
080800
080900

SOURCE SECTOR TITLES :

Military
Railways
Inland Waterways
Agriculture
Forestry
Industry
Household and Gardening

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	-
$\frac{[1]-\Sigma[2]..[5]*100}{[1]}$	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).

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

SNAP	Code	Vehicle / Machinery Type	Engine 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	

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:

$$E_{Pb} = 0.75 \sum_{j} \sum_{l} k_{Pb,l}\, b_{j,l} \qquad (4)$$

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:

$$E = N \times HRS \times HP \times LF \times EF_i \qquad (5)$$

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:

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

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 [g/kWh]	Power Range in kW							
	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 $P \leq 130$ kW: $12.0 - 6.5 \cdot P^{0,1}$; for $P > 130$ kW: 1.3

CO: for $P \leq 130$ kW: $26.0 - 14 \cdot P^{0,1}$; for $P > 130$ kW: 3.0

PM: for $P \leq 130$ 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 $P \leq 130$ 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 ≤ 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 ≤ 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 [g/kWh]	Power Range in kW							
	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: Exhaust gases, 4-stroke engine		Gasoline: Evaporation	Diesel	LPG
	(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] CO_2	CO	NM VOC	CH_4	NO_x	N_2O	NH_3	SO_2	PM	Age Distri-bution	Engine Design Distributio
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 (al types of con- structio 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, Moto boats, Personal watercraft	D	C	E	D	D	D	E	E	E	E	E	E	E	E	E	E	E
	04 Inland Goods Carryin 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 Waterway	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

19. RELEASE VERSION, DATE AND SOURCE

Version : 3.0

Date : December 1995

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SNAP CODES : **080402**
080403
080404

SOURCE SUB-SECTOR TITLE : **Maritime Activities**

1. ACTIVITIES INCLUDED

The maritime activities include all ship activities which are not classified as Inland Waterways (SNAP activities 080301-080304).

Fuel used by ships should be split as follows:

- sold for use on Inland Waterways (SNAP sub-sector 0803)
- sold for use by Maritime Activities (SNAP sub-sector 0804)
  - sold for use by National sea traffic within EMEP area (SNAP 080402)
  - sold for use by National Fishing within EMEP area (SNAP 080403)
  - sold for use by International sea traffic (SNAP 080404)

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.

On board incineration 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

EU sales represent 30% of world demand of 133 million tons of residual Bunker Fuel Oil and distillate Marine Diesel Oils.

It is not well known how much of this is used by national traffic within the EMEP area. EU/DG XI, January 1994 estimates that 6 million tons of these fuels are consumed in territorial waters which extend 12 nautical miles off shore. Given the complicated and often concave coastline of the European countries it may be assumed as a first approximation that a similar amount is used by national traffic outside of territorial waters.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	SNAP-code	Contribution to total emissions [%]							
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Maritime Activities *	080400	1.2	3.9	0.4	0	0.2	0.6	0.1	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = CORINAIR90 split this sub-sector into: Harbours, National Sea Traffic and National Fishing.

3. GENERAL

3.1 Description

Emissions arise as exhaust emission from

- marine diesel engines used as main propulsion engines or
- auxiliary engines
- boilers for steam turbine propulsion
- other boilers

3.2 Definitions

Maritime Activities

The distinction between Inland waterways (SNAP 08 03) and Maritime activities (SNAP 08 04) is the defined coastline. This is also the case if a ship moves from the sea up river.

Emissions should be split at the defined coastline.

The coastline is always defined by the map in question. For CORINAIR the map is the digitised map in Arc-info in the European Environment Agency. It is quite detailed and Norwegian and Danish fjords 150 km long and only 300 m in width at the narrowest point are mapped as sea.

National Sea Traffic

This activity includes all national ship transport including ferries, irrespective of flags, between ports in the same country, localised within the EMEP area. The EMEP area is defined in a polar conical projection but is approximately the area East of 40 deg W, West of 60 deg E and North of 30 deg N.

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 Acores and Madeira and Spanish traffic to the Canary islands are excluded.

3.3 Techniques

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/high speed engines, generally operating on the four stroke cycle at speeds ranging from 400-1500 rpm, are normally trunk piston engines of up to 12 cylinders in vee formation.

Current designs can develop powers of the order of 1000 kW/cylinder and with brake mean effective pressures in the region of 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.

3.4 Controls

The simplest technical way to reduce SO_2 emissions is reducing the sulphur content of the bunker oil. Legislation on this is presently being prepared by The European Commission and by IMO.

SO_2 can be removed more than 90% by sea-water scrubbing (CONCAWE, 1994). By the use of SCR/oxi catalytic exhaust treatment systems NO_x may be reduced > 95% and VOC may be reduced > 85% (IVL, 1993).

NO_x will be reduced in new engines following legislation by IMO. However, there already exist some technological possibilities for reducing NO_x from ships. Three options shall be mentioned here (based on Klokk, 1995):

- exhaust gas recirculation 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;
- exhaust gas treatment 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 where the exhaust gas is treated as for the 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 installed yet on ships.

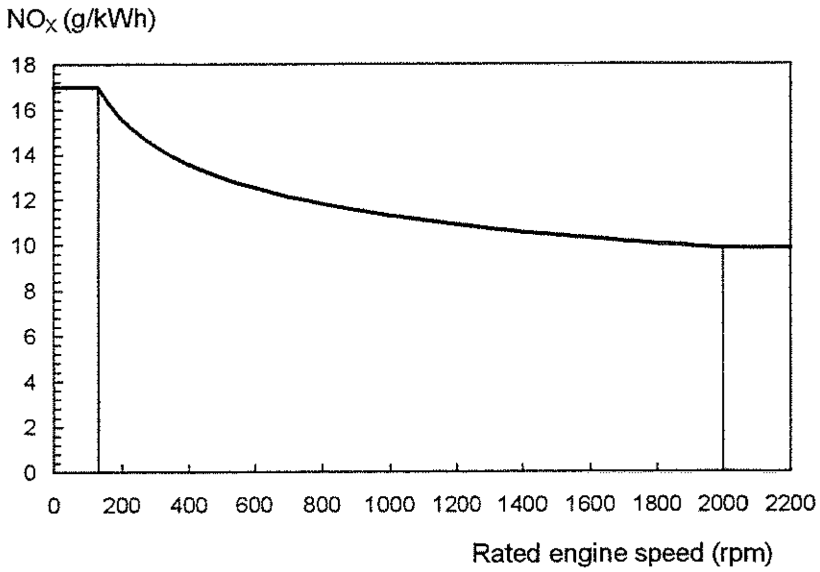
In terms of regulations on NO_x, it is likely that the following limits will be applied for new diesel engines and be effective in 1999:

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

where n is the rated engine speed in rpm.

Proposed NO_x emission as a function of the rated engine speed as it will be with the regulation can be seen schematically in Figure 1.

Figure 1: The proposed restriction on NO_x emission as a function of the rated engine speed.



4. SIMPLER METHODOLOGY

For national sea traffic most and in many cases all bunker fuel is used in diesel engines of different sizes. Present knowledge allows us to distinguish between Residual Bunker Fuel Oil and Distillate Marine Diesel Oil especially with respect to sulphur content. The average value of sulphur content % w/w in 1990 (Lloyd's Register, 1995) for residual oil was 2.99, and for distillate oil it was 0.73% w/w.

Emissions can be estimated from the total sales of fuel in marine activities multiplied by emission factors. Relevant emission factors can be seen in Table 8.1.

5. DETAILED METHODOLOGY

Emissions can be estimated from shipping movement data, route distances assigned to the EMEP grid, journey times, and emission factors. The detailed methodology is based on Lloyd's Register (1995). The calculation can be performed in the following way:

1. Ship movement data is gathered for all vessels travelling within the area of concern. This basically means that ports (arrival/departure) and frequencies are registered. Vessel specific speed factors, number of engines used, and journey times are also registered if possible. For larger vessels, this information can be found in Lloyd's Maritime Information Services. For ferries, movements can be registered from schedules or time tables. For smaller vessels (craft, fishing, etc.), the simpler methodology should be followed.
2. Coordinates of each departure and arrival port is linked by a straight line to represent the most likely course between the ports. The EMEP grid is now superimposed on

these routes to calculate the total distance of each individual route and the distance traversed across each grid square along that route.

3. The route distances per EMEP square are converted to total journey times by application of the vessel specific factors. It may be necessary to assume average service speeds for specific vessel types to estimate the journey time in hours. From this information, the time to traverse individual grid squares can be estimated.
4. For each grid and vessel, emissions can be found as the product of the time (in hours) and the emission factor (in kg/hour). Emission factors can be found in Table 8.2 as a function of the motor type.
5. In terms of emissions used in ports, each visit from larger ships and ferries is defined from the ship movements. The fuel use in each harbour is calculated from the average stretch moved in harbour, average time in harbour and average consumption per minute and nautical mile. These contributions are again assigned to the individual EMEP grid squares.
6. Finally, emission totals per grid can be summed to derive annual emission estimates.

6. RELEVANT ACTIVITY STATISTICS

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 and distillate fuel. If not, it may be assumed that fishing boats and other small ships use distillate fuel and that other ships use residual fuel.

Relevant statistics can be found in Thomas Reed Publications (1992), International Maritime Organisation (1987), and Lloyd's Register (1995).

7. POINT SOURCE CRITERIA

8. EMISSION FACTORS

Emission factors vary with the aggregation level that is used for the emission estimation. Therefore there are differences in the factors used for the simpler and the detailed methodology.

8.1 The simple methodology

In Table 2 emission factors are displayed on a per fuel basis.

Table 2: Overview of emission factors for ships on a per fuel basis (source: Lloyd's Register, 1995, and Statistics Norway, 1993)

	kg/tonne fuel		g/kWh	
NO_x	87*	57**	17*	12**
CO	7.4		1.6	
HC	2.4		0.5	
CO_2	3170		660	
SO_2	20 x %S		4.2 x %S	
N_2O	0.2		0.04	

*** slow speed ** medium speed S - sulphur content of oil fuel (% by wt)**

8.2 The detailed methodology

In the detailed methodology the emission factors are dependent upon the particular ship. The emission factors are divided between slow, and medium speed engines:

Table 3: Emission factors for medium and slow speed diesel engines (source: Lloyd's Register, 1995).

	Medium speed kg/hours	Slow speed kg/hours
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 kWh, ⅄ is valid for engines ≥ 2000 kW.

9. SPECIES PROFILE

Measurements of organic micropollutants are given in Lloyd's Register (1995).

VOC profiles may be similar to stationary diesel engines.

10. UNCERTAINTY ESTIMATES

Emissions are highly dependent upon the speed of the ship engines. Lloyd's Register (1995) shows large variations in emission profiles for HC and NO_x. Uncertainties associated with estimates of HC and NO_x may therefore be considered to be ± 20%.

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

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 on 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. In terms of fishing boats, the statistics are not necessarily registering all fuel use. Fishing boats may buy fuel abroad and therefore this fuel would not be registered in the national statistics.

When applying the detailed methodology, fishing ships and small vessels are not registered in the same way. Their contribution must be taken into account as in the simple methodology. Weaknesses of this can be seen above. In the emission estimation, emissions from ships hotelling in port, or at anchor awaiting a berth or awaiting orders, are excluded - and must be estimated using port statistics.

12. SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Described in the detailed methodology.

13. TEMPORAL DISAGGREGATION CRITERIA

Seasonal variation through the year is insignificant (see Lloyd's Register, 1995). However a greater proportion of fishing and 'other activity vessels' (such as dredgers, tugs and research ships) are more active in the late summer months.

14. ADDITIONAL COMMENTS

Military vessels are excluded from these calculations. It may however be of relevance to take into account military ship emissions. 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.

Rypdal, K. (1995): Emissions for ships in Norway. A description of the development of a methodology. Statistics Norway, Oslo.

16. VERIFICATION PROCEDURES

To validate the emission estimates, it can be of importance to compare across countries how ship transport is registered. As of today, the registration is significant for the emission estimates.

17. REFERENCES

CONCAWE, (1994): The contribution of sulphur dioxide emissions from ships to coastal deposition and air quality in the channel and southern north sea area. Report no 2/94. The Oils Companies' European Organization for Environment and Health Protection. Brussels. (Pre-publications).

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Klokk, S.N. (1995): *Measures for Reducing NO_x Emissions from Ships*. MARINTEK. Workshop on control technology for emissions form off-road vehicles and machines, ships and aircrafts, Oslo, 8-9 June.

Lloyd's Register (1995): *Marine Exhaust Emissions Research Programme.* Lloyd's Register Engineering Services, London.

Stubbetud, G. (1995): *Proposed international requirements for reduction of emissions from ships.* From the Workshop on Control Technology for Emissions from Off-Road Vehicles and Machines, Ships and Aircraft, Oslo, June 8-9.

18. BIBLIOGRAPHY

19. RELEASE VERSION, DATE AND SOURCE

Version: 2.0

Date: October, 1995

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SNAP CODE **080501**
080502
080503
080504

SOURCE SUB-SECTOR TITLE **Air Traffic**

1. ACTIVITIES INCLUDED

This chapter presents common guidelines for estimation of emissions of air traffic with the snap code 0805. The guideline includes the four activities:

Table 1.1: Overview of the activities included in the present guideline

Domestic airport traffic (LTO-cycles < 1000 m altitude)	snap code 080501
International airport traffic (LTO-cycles < 1000 m altitude)	snap code 080502
Domestic cruise traffic (> 1000 m altitude)	snap code 080503
International cruise traffic (> 1000 m altitude)	snap code 080504

LTO is short 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 IPCC. Emissions associated with the *LTO-cycle* are to be reported to the ECE. Activities include all civil non-military use of airplanes consisting of scheduled, and charter traffic of passengers and freight. This also includes taxiing and private aviation. Military activities are excluded and should be included under snap code 0801.

2. CONTRIBUTION TO TOTAL EMISSIONS

Nüsser and Schmidtt (1990) have estimated global aircraft emissions. The estimated numbers are displayed in Table 2.1. The estimations are based on ICAO's figures on ton-km of world scheduled domestic and international passenger traffic using emission factors for cruise conditions as estimated by Lufthansa.

The total contribution of aircraft emissions to CO_2 and NO_x emissions is considered to be about 2% (IPCC, 1990). This relative 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 atmosphere.

Table 2.1: Estimated global fuel consumption and annual emissions of scheduled air traffic in 1988, exclusive of China.
(Source: Nüsser and Schmitt, 1990)

Category	Unit	Domestic		International		Total	
		1988	2000	1988	2000	1988	2000
Traffic	10^9 P-km	940	1710	756	1740	1696	3450
Fuel Cons.	Mton	105	190	45	110	150	300
CO	Kton	225	410	45	105	270	515
VOC*	Kton	60	105	30	70	90	175
NO_x	Kton	785	1430	730	1680	1515	3110
C	Kton	2.1	3.7	0.5	1.0	2.6	4.7
SO_2	Kton	105	190	45	110	150	300
CO_2	Mton	325	590	145	330	470	920
H_2O	Mton	130	230	60	130	190	360

* Total VOC, including methane, excluding emissions from jet fuel handling and fuel jettonising. Methane emissions can be estimated to be about 10% of the total VOC emissions.

3. GENERAL

3.1 Description

The activities covered include all non-military scheduled commercial and charter flights for which passenger and freight kilometres are published. The larger part of these activities can be classified into the aircraft types and engines as outlined in Table 3.1. More types and engines exists and can be seen in ICAO (1995) and EPA (1985). This table presents aircrafts and engines frequently used in European and American aviation.

Military aircraft activities are excluded here. However, it should be emphasised that in some countries military activities may have a significant share of the total country emissions. There may however be some difficulties in obtaining these due to scarce and often confidential military data (Olivier, 1991).

3.2 Definitions

Operations of aircrafts are divided into two parts:

- *The Landing/Take-off (LTO) cycle* which includes all activities near the airport that take place under the altitude of 1000 m. This therefore includes taxi-in and out, climbing and descending.
- *Cruise* which here is defined as all activities that take place at altitudes above 1000 m. No upper limit is given.

Table 3.1: Civil aircraft classification (source: EPA, 1985)

Aircraft	Number of engines	Type of engine	Model/series
Supersonic transport			
BAC/Aerospatiale Concorde	4	TF	Olymp. 593-610
Short, medium, long range and jumbo jets			
BAC 111-400	2	TF	Spey 511
Boeing 707-320B	4	TF	JT3D-7
Boeing 727-200	3	TF	JT8D-17
Boeing 737-200	2	TF	JT8D-17
Boeing 747-200B	4	TF	JT9D-7
Boeing 747-200B	4	TF	JT9D-70
Boeing 747-200B	4	TF	RB211-524
Lockheed L1011-200	3	TF	RB211-524
Lockheed L10100-100	3	TF	RB211-22B
McDonnell-Douglas DC8-63	4	TF	JT3D-7
McDonnell-Douglas DC9-50	2	TF	JT8D-17
McDonnell-Douglas DC10-30	3	TF	CF6-50C
Aircarrier turbopros - commuter, feeder line and freighters			
Beech 99	2	TP	PT6A-28
GD/Convair 580	2	TP	501
DeHavilland Twin Otter	2	TP	PT6A-27
Fairchild F27 and FH227	2	TP	R.Da. 7
Grumman Goose	2	TP	PT6A-27
Lockheed L188 Electra	4	TP	501
Lockheed L100 Hercules	4	TP	501
Swearingen Metro-2	2	TP	TPE 331-3
Business jets			
Cessna Citation	2	TF	JT15D-1
Dassault Falcon 20	2	TF	CF700-2D
Gates Learjet 24D	2	TJ	CJ610-6
Gates Learjet 35, 36	2	TF	TPE 731-2
Rockwell International Shoreliner 75A	2	TF	CF 700
Business turboprops			
Beech B99 Airliner	2	TP	PT6A-27
DeHavilland Twin Otter	2	TP	PT6A-27
Shorts Skyvan-3	2	TP	TPE-331-2
Swearingen Merlin IIIA	2	TP	TPE-331-3
General aviation piston			
Cessna 150	1	0	0-200
Piper Warrior	1	0	0-320
Cessna Pressurised Skymaster	2	0	TS10-360C
Piper Navajo Chieftain	2	0	T10-540

TJ - turbojet, TF - turbofan, TP - turboprop, R- reciprocating piston, O - opposed piston

Some statistics count either a landing or a take-off as one operation. However it is *both* one landing and one take-off that defines one LTO-cycle.

For the purposes of the emissions inventory there is also distinguished between national and international aviation. *National aviation* includes all scheduled, civil, domestic passenger and freight traffic inside a country. *International aviation* is all scheduled civil air traffic coming or leaving one country. It is assumed that the number of out-bound flights equals the number of in-bound flights with international aviation as purpose. 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. It is in this respect not important whether the airport is a domestic or an international airport. 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 is considered an international trip. Also the type of activity (LTO, cruise, national, international) is independent of the nationality of the carrier.

3.3 Techniques

In general there exists two types of engines; reciprocating piston engines, and gas turbines (Olivier, 1990). In piston engines, energy is extracted from a combustion chamber by means of a piston and crank mechanism which drives the propellers to give the aircraft momentum. In gas turbines compressed air is heated by combustion in a combustion chamber and the major part of this is used for propulsion of the aircraft. A small 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 for propulsion.

3.4 Emissions

Air traffic as a source of combustion emissions is different with respect to the type of fuel which is being used, the location (altitude) of the exhaust gases, the efficiency of the engines, and the international and transnational character of activities. Emissions come from use of kerosene and aviation gasoline which is used as fuel on the aircrafts.

Other emissions occur related to aircrafts. Therse are however not included under the present snap codes. Besides the combustion of fuel in the LTO and cruise activities, fuelling and fuelhandling (snap code 050402) in general, maintenance of aircraft engines (snap code 060204), fuel jettonising to avoid accidents (snap code 050402), and service vehicles for catering and other services (snap code 0808) are also emission sources. In the wintertime anti-ice and de-ice treatment of wings and aircrafts is also a source of emission at the airport complex (snap code 060412). Much of the substances used flows off the wings during idle, taxi, and take-off and evaporates.

Use of energy, and therefore emissions, is dependent on the aircraft operations and the time spent at each stage. Table 3.2 shows engine power settings and time used for typical LTO-cycles.

Table 3.2: Standard landing and take-off cycles in terms of thrust settings and time spent in the specific mode (source: ICAO, 1982)

Operating mode	Thrust setting (% of F)	Time-In-Mode (min)
Take-off	100%	0.7
Climb	85%	2.2
Descent	N.A.	N.A.
Approach	30%	4.0
Taxi/ground idle	7%	26.0

A substantial part of the fuel consumption takes place outside the LTO-cycle. Studies indicate that the major part of NO_x (60-80%), and for 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

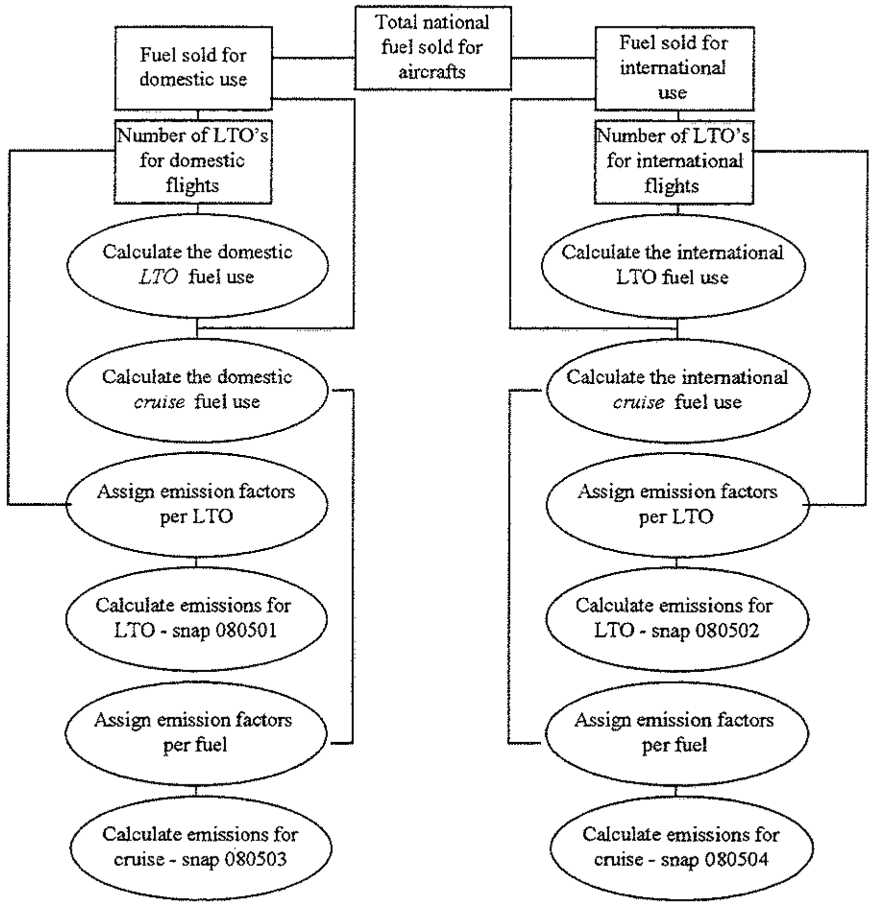
In order to reduce emissions from aircrafts the following can be done:

- fuel efficiency in engine design can give large improvements (> 40% in the specific fuel consumption of jet engines). The design is particularly related to high by-pass ratio turbofan engines where high temperature materials and cooling technologies can increase efficiency of the engines;
- technically, two stage fuel combustion should make it possible to avoid oxidation of NO_x. This should give a reduction in NO_x levels of 30-40%. However, to date point there is no real usage of this technique. It is however expected to be used within the coming years.

4. THE SIMPLER METHODOLOGIES

In Sections 4 and 5 are described three methodologies for estimation of emissions. The fundamental basis for all methodologies are schematically presented in Figure 4.1.

Figure 4.1: Estimation of aircraft emissions with the general approach



From the total fuel sold for aircraft activities, splits are made according to the requirements for IPCC and ECE reporting. The emission estimation can be made following the steps outlined below.

Within different countries, there may be large divergence in data and information available. Therefore, distinction is made between three methodologies; very simple, simple, and detailed. The difference between the methodologies lies mainly in the aggregation level assumed for the aircrafts. In the very simple methodology, estimations are made without consideration of the variations of aircraft types used. In the simple methodology, it is assumed that information is available on the types of aircrafts which carry out aviation activities in the country. Finally, the detailed methodology estimates emissions on the basis of information on the aircraft types of engines. The very simple and simple methodologies are described in this section. The detailed methodology is presented in section 5.

The methodologies are, as already mentioned, based on the same fundamental basis. This means that there are large similarities between the methodologies. In order to provide the user of the various methodologies with the best overview and consistent methodology, each methodology is described in full although there will be some repetitions.

4.1 The Very Simple Methodology

If it is not possible to get information on the number of LTOs carried out on a per aircraft type basis, the very simple methodology should be used. It is in this case assumed that information on the country's total number of LTOs is available as well as a general knowledge about the aircraft types carrying out aviation activities. Aircraft emission estimates obtained by the very simple methodology can be found by following the steps 1-8:

The very simple methodology

1. Obtain the amount of total fuel sold for *all* aviation (in ktons)

2. Obtain the amount of fuel sold for *domestic* aviation only (in ktons). Domestic aviation is defined as all scheduled, civil, passenger and freight traffic where aviation takes place between national airports.

3. Calculate the total amount of fuel sold for *international* aviation by subtracting the domestic aviation (step 2) from the total fuel sold (step 1). International aviation is defined as all scheduled, civil, passenger and freight traffic coming or leaving one country.

4. Obtain the total number of LTOs carried out for a) *domestic aviation* and b) *international aviation* respectively. The LTO cycle includes all activities near the airport that take place under the altitude of 1000 m. The cycle consists of two operations; both one landing and one take-off.

5. Calculate the total fuel use for *LTO* activities for a) *domestic aviation* by multiplying the number of domestic LTOs by the domestic fuel use for one average aircraft (step 4a x fuel use for average national aircraft), and b) *international aviation* by multiplying the number of international LTOs with the international fuel use for one average aircraft (step 4b x fuel use for average international fuel use). Fuel use for an average aircraft for national and international aviation can be found in Table 8.1.

   It is assumed that activities take place mainly using an aircraft which can be defined as an average aircraft type. The average aircraft assumed for domestic aviation is a 2 engine aircraft of the type BOEING 737 with engines 7T8D-17 or similar. For international aviation, the average aircraft is assumed to be a 4 engine aircraft of the type BOEING 747 with engines JT9D-7-R4D or similar.

6. Calculate the fuel use for *cruise* activities for the *average aircraft* for a) *domestic aviation* by subtracting the fuel used for domestic LTO (step 5a) from the total domestic fuel sold (step 2) and b) *international aviation* by subtracting the international LTO fuel (step 5b) from the total international fuel sold (step 3).

7. Estimate the emissions related to LTO activities. This is done for both the domestic, and international LTO activities by multiplying the respective emission factors (per LTO) for the specific activity with the number of LTO for a) domestic and b) international traffic respectively.

8. Estimate the emissions related to cruise activities. This is done for both a) domestic, and b) international cruise activities by multiplying the respective emission factors as can be found in Table 8.1 with the fuel use for the specific activity.

The emission estimates from LTO, domestic aviation found in step 7a go under the snap code 080501. Emission estimates from LTO, international aviation found in step 7b go under the snap code 080502. The emission estimates from cruise, domestic aviation found in step 8a go under snap code 080503. And finally the emission estimates from cruise, international aviation found in step 8b go under snap code 080504.

4.2 The Simple Methodology

If it is possible to obtain information on a per aircraft type, it is recommended to use the simple method. The level of detail necessary for this methodology are the aircraft types used for both domestic and international aviation, as well as the number of LTOs carried out with the various aircraft types. The approach can best be described by following the steps 1-11:

The simple methodology

1. Obtain the total amount of fuel sold for all aviation (in ktons).

2. Obtain the total amount of fuel sold for domestic aviation (in ktons). Domestic aviation is defined as all scheduled, civil, passenger and freight traffic where aviation takes place between national airports.

3. Calculate the amount of fuel sold for *international* aviation by subtracting the domestic aviation (step 2) from the total fuel sold (step 1) (in ktons). International aviation is defined as all scheduled, civil, passenger, and freight traffic coming or leaving one country.

4. Obtain the total number of LTOs carried out per aircraft type for a) *domestic aviation* (a1) aircraft type a1, a2) aircraft type a2, etc.) and for b) *international aviation* (b1) aircraft type b1, b2) aircraft type b2, etc.).

5. Calculate the fuel use for LTO activities per aircraft type:
a) for *domestic aviation* by for each aircraft type multiplying the fuel use corresponding to the specific aircraft type with the number of domestic LTOs carried out for the specific aircraft (fuel use of LTOs for aircraft type a1(see Table 8.2) x number of LTOs with the same aircraft type a1 (step 4a1). The calculations are carried out for all types of aircrafts).
b) for *international aviation* by for each aircraft multiply the fuel use corresponding to the specific aircraft type with the number of international LTOs carried out (fuel use for aircraft type b1 (see Table 8.2) x the number of LTOs for aircraft type b1) (step 4, b1). The calculations are carried out for all types of aircrafts).
The fuel use per aircraft type can be found by use of Table 8.2, and EPA (1985). If aircraft types used are not displayed here, the average values from Table 8.1 can be used.

6. Calculate the total fuel use for *LTO* activities by summing all contributions found under step 5 for respectively a) *domestic aviation* (add all contributions under step 5a) and b) *international aviation* (add all contributions under step 5b).

7. Calculate the total fuel use for *cruise* activities for both domestic and international aviation by subtracting the total amount of fuel for LTO activities found in step 6 from the total in step 2. The domestic cruise fuel use is then found a) *domestic aviation* (step 2 - step 6a), and the international cruise is found by b) *international aviation* (step 3 - step 6b).

8. Calculate the fuel use for cruise activities per aircraft type. This must be done according to the registration of aircraft types and their fraction of the total number of LTOs. This means that the fuel used for domestic cruise activities for aircraft type a1 is estimated in the following way: Total amount of fuel used for domestic cruise x (number of domestic LTOs carried out with aircraft type a1 / total number of domestic LTOs). For the international cruise, the estimation is made in a similar way. Fuel use for international cruise for aircraft type b1 is: total amount of fuel used for international cruise x (number of international LTOs carried out with aircraft type b1 / total number of international LTOs). The estimation is made for all aircraft types as registered under step 4.

9. Estimate the emissions for LTO activities per aircraft type:
   a) for domestic LTO activities
   The number of LTOs for each aircraft type is multiplied with the emission factor related to the particular aircraft type. This is done for all aircraft types and all relevant emission factors. Example: to find the emission of CO_2 from domestic LTO activities from aircraft type a1 do the following: number of LTOs of aircraft type a1 (under domestic, LTO activities) x emiss. factor CO_2 for aircraft type a1 (related to LTO activities). The result is the emission of CO_2 in kg CO_2/LTO. All relevant emission factors can be found in Table 8.2.
   b) for international LTO activities
   Do as under domestic LTO activities but use the aircraft types, international fuel use, and corresponding emission factors registered under international LTO activities. All relevant emission factors can again be found in Table 8.2.

10. Estimate the emissions for cruise activities per aircraft type:
    a) for *domestic cruise* activities
    Do as under domestic LTO activities but use the aircraft types, domestic cruise fuel use, and corresponding emission factors registered under domestic cruise activities. Relevant emission factors can be found in Table 8.3.
    b) for *international cruise* activities
    Do as under domestic LTO activities but use the aircraft types, international cruise fuel use, and corresponding emission factors registered under international cruise activities. Relevant emission factors can be found in Table 8.3.
    In Table 8.3 emission factors for cruise are displayed on a per engine basis. This means that the emission factors shall be related to the typical type and number of engines the various aircrafts carry. See Section 8.2 for more detail on how to estimate the cruise emission factors to be used here.

11. Calculate the total emissions for LTO activities
    a) for domestic aviation:
    Add up all contributions from the various aircraft types as found under step 9a). 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.).
    b) for international aviation:
    Add up all contributions from the various aircraft types found under step 9b). 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.).

12. Calculate the total emissions for cruise activities
    a) for domestic aviation
    Add up all contributions from the various types of aircraft types as found under step 10a). 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.).
    b) for international aviation
    Add up all contributions from the various types of aircraft types as found under step 10b). 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.).

The emission estimates from LTO, domestic activities found in step 11a go under the snap code 080501. Emission estimates from LTO, international aviation found in step 11b go under the snap code 080502. The emission estimates from cruise, domestic aviation found in step 12a go under snap code 080503. And finally, the emission estimates from cruise, international aviation found in step 12b go under snap code 080504.

5. THE DETAILED METHODOLOGY

If it is possible to obtain information on LTOs on a per aircraft engine type basis, the detailed methodology should be applied. Basically, the use of the detailed methodology means that emissions are estimated from all the different types of aircraft engines which are in use and have been registered by LTOs in the airports of the country. The detailed methodology can be followed by steps 1-12.

The detailed methodology

1. Obtain the total fuel sold for *all* aviation (in ktons)

2. Obtain the total fuel sold for *domestic* aviation (in ktons). Domestic aviation is defined as all scheduled, civil, passenger, and freight traffic where aviation takes place between national airports.

3. Calculate the total fuel sold for *international* aviation by subtracting the domestic aviation (step 2) from the total fuel sold (step 1) (in ktons). International aviation is defined as all scheduled, civil, passenger and freight traffic coming or leaving one country.

4. Obtain the total number LTOs carried out per aircraft engine type for a) *domestic aviation (*aircraft engine type y1, aircraft engine type y2, etc.), and for b) *international aviation* (aircraft engine type z1, aircraft engine type z2, etc.). Furthermore make registrations of the types of engines used on the different aircrafts, and also register the number of engines used on each aircraft type.

5. Calculate the fuel use for LTO activities per aircraft type:
a) for *domestic aviation* by for each aircraft engine type used in domestic aviation multiply the single parts of the TIME column with the single parts of the FUEL FLOW column in Figure 8.1 and sum all contributions. In the example given in Table 8.1 this means that the following operation is performed: $0.7 \times 1.173 + 2.2 \times 0.9344 + 4.0 \times 0.3304 + 26.0 \times 0.1401) \times 60$ (the 60 is multiplied to convert the units to seconds). To obtain the fuel use of one particular aircraft, the fuel use per engine must be summed. To find the fuel use of a 4 engine aircraft for example, multiply the fuel use per engine by 4.
b) for *international aviation* by for each aircraft engine type, do as under 5a) but for the engines used for international aviation.

6. Calculate the total fuel use for *LTO* activities by summing all contributions found under step 5 for respectively a) *domestic aviation* (add all contributions under step 4a) and b) *international aviation* (add all contributions under step 4b). The summation is probably best carried out on a per aircraft type basis.

7. Calculate the total fuel use for *cruise* activities for both domestic and international aviation by subtracting the total amount of fuel for LTO activities found in step 6 from the total in step 2. The domestic cruise fuel use is then found by a) *domestic aviation* (step 2 - step 6a), and the international cruise is found by b) *international aviation* (step 3 - step 6b).

8. Calculate the fuel use for cruise activities per aircraft engine type. This must be done according to the registration of aircraft engine types and their fraction of the total number of LTOs. This means that the fuel used for domestic cruise activities for aircraft engine type y1 is estimated in the following way: Total amount of fuel used for domestic cruise x (number of domestic LTOs carried out with aircraft engine type y1/total number of domestic LTOs). For the international cruise, the estimation is made in a similar way. Fuel use for international cruise for aircraft emission type z1 is: total amount of fuel used for international cruise x (number of international LTOs carried out with aircraft engine type z1 / total number of international LTOs). The estimations are made for all aircraft engine types as registered under step 4.

9. Estimate the emissions for LTO activities per aircraft type:
a) for domestic LTO activities
The fuel use for each aircraft type is multiplied with the emission factor related to the particular aircraft engine type. This is done for all aircraft types and all relevant emission factors in the following way: to find the emission of HC from domestic LTO activities from aircraft engine type y1, again use the FUEL FLOW, TIME columns of the ICAO (1995) tables along with the relevant emission indices column of the same tables. The multiplications are performed as follows using the example of Figure 8.1: Emissions of

engine type y1, from LTO activities are (0.7 × 1.173 × 0.25 + 2.2 × 0.9344 × 0.30 + 4.0 × 0.3304 × 0.64 + 26.0 × 0.1401 × 6.6) × 60 (to convert the minutes and seconds to the same unit). Perform similar calculations with the other emission factors for each engine type.
To find the emission on a per aircraft type basis, the contributions from the engine types must be summed. For a 4 engine aircraft, the above sum is multiplied by 4.
b) for international LTO activities
Do as under domestic LTO activities but use the aircraft engine types and corresponding emission factors registered under international LTO activities.

10. Estimate the emissions for cruise activities per aircraft type:
a) for *domestic cruise* activities
For the fuel use of each engine performing respectively domestic and international cruise found in step 8 shall now be used. For each engine type and plane, the fuel use found in step 8 is multiplied with the emission factors for cruise found in Table 8.3. In the case where one aircraft carries engines of another type than specified in Table 8.3, the average emission factors of Table 8.1 must be used. The calculations are carried out for all types of aircrafts used for domestic and international aviation respectively.
b) for *international cruise* activities
Do as under domestic LTO activities but use the aircraft types and corresponding emission factors registered under international cruise activities.

11. Calculate the total emissions for LTO activities
a) for domestic aviation:
Add up all contributions from the various types of aircraft types as found under step 9a). The summations shall take place for each of the emissions estimated (for CO_2, NO_x, SO_2, etc.).
b) for international aviation:
Add up all contributions from the various types of aircraft types found under step 9b). The summations shall take place for each of the emissions estimated (for CO_2 , NO_x , SO_2, etc.).

12. Calculate the total emissions for cruise activities
a) for domestic aviation
Add up all contributions from the various types of aircraft types as found under step 10a). The summations shall take place for each of the pollutants to be estimated (for CO_2 , NO_x , SO_2, etc.).
b) for international aviation
Add up all contributions from the various types of aircraft types as found under step 10b). The summations shall take place for each of the pollutants to be estimated (for CO_2 , NO_x , SO_2 , etc.).

The emission estimates from LTO, domestic aviation found in step 10 go under the snap code 080501. Emission estimates from LTO, international aviation found in step 10 go under the snap code 080502. The emission estimates from cruise, domestic aviation found in step 12 go under snap code 080503. And finally the emission estimates from cruise, international aviation also found in step 12 go under snap code 080504.

6. RELEVANT ACTIVITY STATISTICS

The data used for the emission estimations can be found partly as national statistics directly from airports or from national reports providing aggregated information on the number of landings- and take-offs taking place for national and international aviation.

Other information sources relevant for the estimations are:
ICAO (1989) exhaust emission databank which provides a list of aircraft engine emissions, and ICAO (1995) which provides a list of emission factors per engine types.

7. POINT SOURCE CRITERIA

If an airport has more than 100.000 LTOs per year (national or 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 views. The emission factors therefore vary with the methodology used.

8.1 Very Simple Methodology

The following emission factors should be applied for the emission calculations for the very simple methodology.

Table 8.1: Emission factors and fuel use for the very simple methodology. Emission factors are given on a per aircraft type basis. Sulphur content of the fuel is assumed to be 0.05% S for both LTO and cruise activities.

	Domestic						International					
	Fuel	SO_2	CO	CO_2	NO_x	VOC	Fuel	SO_2	CO	CO_2	NO_x	VOC
LTO kg/LTO	1000	1.0	16.9	3150	9.0	4.1	2400	2.4	101.3	7560	23.6	72.5
Cruise kg/ton		1.0	4.0	3150	23.75	0.75		1.0	1.75	3150	34.5	3.75

The emission factors for domestic aviation have been derived from an average 2 engine aircraft, for example on aircraft type BOEING 737, with engine type 7T8D-17. For the LTO cycle the factors have been derived from an average of the values of BOEING 737 and DC 9 which can be found in EPA (1985), and partly in Table 8.2. For domestic cruise, an altitude of 7.6 km has been assumed. This value is derived from Olivier (1991) (see also Table 8.3). The emission factors for international aviation have been derived from an average 4 engine aircraft. For example aircraft type BOEING 747 with engines JT9D-7-R4D. For the LTO cycle, the factors have been derived from an average of the values of DC8, BOEING 707, and BOEING 747 which can be found in EPA (1985) and partly in Table 8.2. For cruise, an altitude of 10.7 km has been assumed. This value is derived from Olivier (1991) (see also Table 8.3).

8.2 Simple Methodology

For the simple methodology emission factors from EPA (1985) should be used. Table 8.2 displays some relevant examples.

Table 8.2: Examples of aircraft types and emission factors for LTO cycles as well as fuel consumption per aircraft type (source: EPA, 1985). (E) indicates that the figure is based on estimations

	Emission factors kg/LTO				
Aircraft type	**CO**	**NO_x**	**VOC**	**SO_x**	**Particulate**
Concorde	384	41	112	6,4	0,7
BOEING 737	16,9	9,0	4,1	1,0	0,4
BOEING 727, 757	25,4	13,4	6,1	1,5	0,5
BOEING 747	65,8	47,7	19,6	3,4	2,4
BOEING 767, 707	119,1 (E)	11,6(E)	99,0 (E)	1,9 (E)	2,1 (E)
LOCK L 1011 (100-200)	29,1	35,8	33,1	2,4	
AIRBUS A300, 310	119,1 (E)	11,6	99,0 (E)	1,9 (E)	2,1 (E)
AIRBUS A320	24,6 (E)	9,7(E)	5,9 (E)	1,9 (E)	0,4 (E)
DC8	119,1	11,6	99,0	1,9	2,1
DC9	16,9	9,0	4,1	1,0	0,4
DC10	53,0	22,2	21,4	2,3	0,1
TUPOLEV 154	25,4 (E)	13,4(E)	6,1 (E)	1,5 (E)	0,5 (E)
TUPOLEV 134	24,6 (E)	9,7(E)	5,9 (E)	1,9 (E)	0,4 (E)
FOKKER F27	22,1	0,3	14,1	0,3	0,0
FOKKER F28, 50, 100	64,1	8,2	47,1	0,9	0,7
BAC 1.11, 1.46	46,9	6,8	32,9	0,8	0,7
CARAVELL	24,6	9,7	5,9	1,9	0,4
SAAB 340	22,1 (E)	0,3(E)	14,1 (E)	0,3 (E)	0,0 (E)

The sulphur content of the fuel is assumed to be 0.05% S.

To derive the CO_2 emissions, use the following factor: 3.15 kg CO_2 /kg fuel.

For the cruise activities, average emission factors per engine have been estimated and are displayed in Table 8.3.

Table 8.3: Average emission factors for various engine types at cruise levels (Derived from Olivier, 1991).(a sulphur content of 0.05% (weight) has been assumed)

Engine type	Altitude (km)	Fuel consumption (kg/h)	Emission factor (g/kg)				
			CO	CO_2	VOC	NO_x	SO_x
JT8D-9/9A	7.6 10.7	1,620 1,440	3.75 3.50	3150 3150	0.75 0.75	20.75 18.75	1.0 1.0
JT8D-17	7.6 10.7	1,840 1,650	4.0 4.0	3150 3150	0.75 0.75	23.75 21.50	1.0 1.0
JT8D-209	7.6 10.7	1,740 1,550	6.0 6.0	3150 3150	2.25 2.25	26.75 24.25	1.0 1.0
JT9D-7R4D	7.6 10.7	2,590 2,350	1.75 1.75	3150 3150	3.75 3.75	40.75 34.50	1.0 1.0
JT9D-7R4G2	10.7	2,600	1.75	3150	0.50	34.00	1.0
CF6-80A	10.7	2,120	3.50	3150	0.75	35.00	1.0
CF6-50C2	7.6 10.7	2,620 2,400	3.75 3.75	3150 3150	1.50 1.50	39.00 34.50	1.0 1.0
RB211-22	10.7	2,360	3.50	3150	1.0	45.25	1.0

The cruise emission factors shall be related to the number of engines of the specific aircrafts. For the typical aircrafts, as they are assumed to be here, Table 3.1 can be used to show typical number and types of engines used for various aircraft types.

In the case where aircraft types used in a country are not presented in EPA (1985) it is suggested to use the average emission factors displayed in Table 8.1.

Using the emission factors, special emphasis should be put on the assumptions of the sulphur weight percent (there is assumed a weight percentage of 0.05% for the emission factors). 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%, the emission factor should be divided by 5 to show the true factor.

8.3 Detailed Methodology

For the detailed methodology, the emission factors have to be derived from the ICAO (1995). The following Figure 8.1 illustrates the approach for deriving the appropriate emission factors.

Figure 8.1: Example on calculation of emission factors to be used in the detailed methodology. The example is taken from the ICAO (1995). The engine type JT8D-17A is used as example.

ICAO ENGINE EXHAUST EMISSIONS DATA BANK ISSUE 1 - OCTOBER 1993

Note : Dp/F∞ and SN values are NOT the characteristic levels.

UNIQUE ID NUMBER: JT8D-17A
ENGINE IDENTIFICATION: 1PW014
ENGINE TYPE: MTF

BY-PASS RATIO: 1.05
PRESSURE RATIO: 16.87
RATED OUTPUT (kN): 71.17

DATA TYPE
- PRE-REGULATION
x CERTIFICATION
- REVISED (SEE REMARKS)

DATA SOURCE
- NEWLY MANUFACTURED ENGINES
- IN-SERVICE ENGINES
  - BEFORE OVERHAUL
  - AFTER OVERHAUL
x DEDICATED TEST ENGINES TO PRODUCTION STANDARDS

EMISSIONS DATA
- UNCORRECTED
x CORRECTED FOR AMBIENT EFFECTS

MODE	POWER SETTING (%F∞)	TIME mins	FUEL FLOW kg/s	EMISSIONS INDICES (g/kg) HC	CO	NO_x	SMOKE NUMBER
TAKE-OFF	100	0.7	1.173	0.25	1.07	19.1	16.8
CLIMB OUT	85	2.2	0.9344	0.30	1.16	14.3	-
APPROACH	30	4.0	0.3304	0.64	2.88	6.7	-
IDLE	7	26.0	0.1401	6.6	12.46	3.2	-
NUMBER OF TESTS				7	8	5	5
NUMBER OF ENGINES				2	3	2	3
D_p/F_∞ (AVERAGE) (g/kN) OR SN (MAX)				6.6	43.8	55.1	16.8
D_p/F_∞ (g/kN) OR SN (SIGMA)				-	-	-	-
D_p/F_∞ (g/kN) OR SN RANGE				-	-	-	-

ACCESSORY LOADS

POWER EXTRACTION: 0 (kW) AT: - POWER SETTINGS(S)
STAGE BLEED: 0 % CORE FLOW AT: - POWER SETTING

ATMOSPHERIC CONDITIONS

PRESSURE	kPa	-
TEMPERATURE	°C	-7 to 24
ABS HUMIDITY	kg/kg	-

FUEL

SPEC	H/C	AROM (%)
Jet A	-	-

MANUFACTURER: Pratt & Whitney
TEST ORGANIZATION: P&WA
TEST LOCATION: E Hartford, CT, USA
TEST DATES: FROM 07 Dec 79 TO 19 Jun 80

REMARKS: Reduced emissions combustor incorporated 1/1/84

Above in the left corner, the different engine types are displayed by the identification code. In the table itself, it is necessary to do the following:

- calculate the total fuel flow of the LTO cycle by multiplying the TIME column elements with the the FUEL FLOW column's elements of the Tables of the ICAO (1995) engines. In the example of Figure 8.1, the LTO fuel flow for one engine is $(0.7 \times 1.173 + 2.2 \times 0.9344 + 4.0 \times 0.3304 + 26.0 \times 0.1401) \times 60$ (to convert the units from minutes to seconds). This gives a total of 470 kg.
- calculate the emissions per engine type for each relevant substance. This is done by multiplying the elements of the TIME column with the elements of the FUEL FLOW column with the elements of the relevant emission indices column. Again for the present example this gives for HC emissions: $(0.7 \times 1.173 \times 0.25 + 2.2 \times 0.9344 \times 0.30 + 4.0 \times 0.3304 \times 0.64 + 26.0 \times 0.1401 \times 6.6) \times 60$ (to convert the minutes to seconds).

- to obtain the emissions of CO_2 use the following emission factor: 3.15 kg CO_2 per kg fuel.
- in order to obtain the emission factor on a per aircraft basis, it is necessary to assign the number of engines on the specific aircraft to the emission factors per engine.

To obtain the emission factors for cruise, the factors and procedure as described under section 8.2 is followed.

9. SPECIES PROFILES

Since there exists very few experiments measuring the exhaust gas from aircraft turbines, it is not possible to give a specific species profile. In terms of NO_x and VOC, the profiles vary among others 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 almost the same. There has been some attempt 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.

Table 9.1: The VOC profile for a jet engine based on an average LTO cycle for commercial and general aviation (source: Shareef et al., 1988).

	Percentage of total VOC (weight)	
Compound in VOC profile	**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	< 1
Total	100.0	100.0

It should be noted that the thrust setting is very much different in the landing and the take-off of the aircraft (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 uncertainty of the estimated aircraft emissions are closely associated with the emission factors assigned to the estimations.

10.1 Very Simple Methodology

The use of 'average' emission factors may contribute significantly to the uncertainty. In terms of the factors relating to the LTO activities, these must be said to be better than for the cruise (due to the origin of the factors 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 uncertainties lie mainly in the origin of the emission factors. For the LTO factors, uncertainties are assumed to be about 10-20%. For cruise factors uncertainties are substaintially higher; 15-40%. Again uncertainties may vary with aircraft and engine type. It is not possible to give uncertainty estimates on such a detail level.

10.3 Detailed Methodology

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

11. WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Due to the assumptions for simplifying the problem of accounting emissions from aircraft activities, there are some weak aspects of the methodologies.

First of all, there is the emission factors. In the reporting of emission factors for LTO-activities, there is in the literature assumed that LTO-activities take place under altitudes of 1000 m. In the methodologies, the emission factors used for LTO-activities are associated with altitudes under 3000 feet or 915 m.

Cruise emission factors used in the methodology must be said to be very uncertain. The validity of the use of average values should be examined in more detail when more estimates become available.

In the methodology used here, there is a problem in the detail level of aircrafts used and emission factors for both LTO and cruise. The introduction of 'average aircrafts' and 'average emission factors' can therefore give a rough overview over the emissions. It would be preferred to use more detailed information to obtain a picture closer to reality.

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. from the specific airports, and later added up to show the emissions from region and subsequently country as a whole. identify airports located in the various territorial areas. Emissions can be accounted for
2. from the total national emission estimate emissions can be distributed to the territorial areas and airports using a key reflecting the aviation activity between territorial areas and airports.

13 TEMPORAL DISAGGREGATION CRITERIA

Most aircraft activities take place evenly distributed over the year. There may be some months during the year which are a more busy than others (in Denmark appears that May, August and October include about 26% of the total aviation and are therefore slightly more busy than other months, Københavns Lufthavn, 1993). Variations can be seen on a weekly basis. Weekdays are more busy than Sundays. Again this will vary with the airport and country. Within the day, it is known that most activities take place in peak hours during the morning (from about 7-10.30 a.m.) and in the afternoon (from about 3.30-7 p.m.). There is also a distinction between the aircrafts used and when the activities take place during 24 hours. In Kastrup Airport, Copenhagen, the variations can be seen in Table 13.1.

Table 13.1: Example on the variation of aircrafts used and their aviation intensity during 24 hours. Figures are related to the year 2000 but are only one percent higher in the evening and night than 1990 values. (source: Københavns Lufthavn, 1993)

Arrivals/ departures	Day	Evening	Night	Aircraft category
Arr. Dept.	69% 66%	21% 11%	10% 23%	I (< 30 tons)
Arr. Dept.	73% 76%	21% 14%	6% 10%	II (30-60 tons)
Arr. Dept.	70% 73%	25% 17%	5% 10%	III (60-70 tons)
Arr. Dept.	73% 79%	16% 13%	11% 8%	IV (70-120 tons)
Arr. Dept.	71% 82%	10% 11%	19% 7%	V (120-300 tons)
Arr. Dept.	58% 66%	7% 22%	35% 12%	VI (> 300 tons)

Variations are airport and country specific. In Oliver (1995) can be seen time profiles for different regions of the world.

14. ADDITIONAL COMMENTS

Military traffic could be taken into consideration too. This would imply that there should be made a certain classification of aircraft types used in military activities, as well as there should be made estimations of appropriate emission factors to associate with the various types and activities. This kind of information can be hard to obtain since many military activities are confidential and therefore data are scarce.

15. SUPPLEMENTARY DOCUMENTS

None.

16. VERIFICATION PROCEDURES

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

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19. RELEASE VERSION, DATE AND SOURCE

Version: 1.0

Date: October, 1995

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