Category		Title
NFR:	**1.A.3.c**	**Railways**
SNAP:	**080200**	**Railways**
ISIC:		
Version	**Guidebook 2013**	

Lead authors
John Norris, Leonidas Ntziachristos

Contributing authors (including to earlier versions of this chapter)
Zissis Samaras, Karl-Heinz Zierock

Contents

1 Overview

This chapter covers emissions from rail transport, one of the mobile sources, and concerns the movement of goods or people by rail. Railway locomotives generally are one of three types: diesel, electric or, less frequently, steam.

Diesel locomotives either use only diesel engines for propulsion or in combination with an on-board alternator or generator to produce electricity which powers their traction motors (diesel-electric). These locomotives fall in three categories:

- shunting locomotives,
- rail-cars,
- line-haul locomotives.

Electric locomotives are powered by electricity generated at stationary power plants as well as other sources. This chapter does not cover these indirect emissions for locomotives; these are accounted for in chapter 1.A.1 Energy industries, i.e. are covered under stationary combustion.

Steam locomotives are now generally used for very localised operations, primarily as tourist attractions, and their contribution to emissions is correspondingly small.

The importance of this sector ranges from negligible for countries that either have a small rail network, or use a high proportion of electrically powered engines, to moderately important. For this latter group, the contribution of emissions from railways originates from the combustion of fuel to propel trains. The pollutants for which rail transport can be important are SO_2, NO_x, CO_2 and PM, and of lesser, but still significant importance, are emissions of CO, NMVOCs (non-methane volatile organic compounds) and some metals.

2 Description of sources

2.1 Process description

Exhaust emissions from railways arise from the combustion of liquid fuels in diesel engines, and solid or liquid fuels in steam engines to provide propulsion, as shown in the flow diagram in Figure 2-1. The different types of engines used are discussed in subsection 2.2.

2.2 Techniques

Diesel engines are the predominant form of power unit within the railways industry. The engines can be fitted into three distinct types of propulsion unit, as follows:

1. shunting locomotives – these locomotives are used for shunting wagons. They are equipped with diesel engines whose power output is typically in the range 200 to 2 000 kW;
2. 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 1 000 kW;

3. line haul locomotives - line haul diesel locomotives are used for long distance rail traction both for freight and passengers. They are equipped with diesel engines having a power output of around 400 to 4 000 kW ([1]).

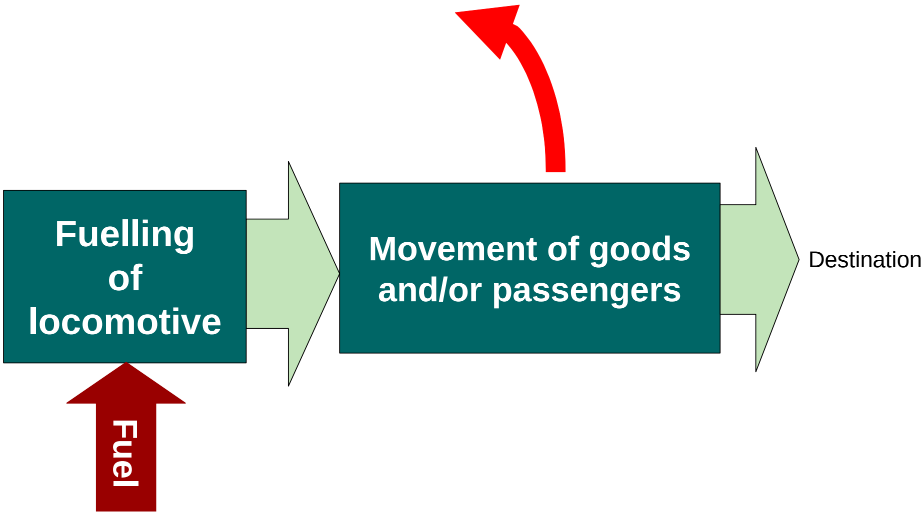

Figure 2-1 Flow diagram for the contribution from railways to mobile sources combustion emissions.

There are currently two types of fuels used in diesel engines in rail transport. The first type is the gas oil which is a middle petroleum distillate and has a high density and sulphur content. The other type is conventional diesel fuel, similar to that used in the road-transport sector. This has a lower density and fuel sulphur content. More on the fuel specifications is given in subsection 2.4 of the present chapter.

Whilst use of steam locomotives is now very localised, coal was used in a significant fraction of locomotives for a few countries up until the 1990s. For completeness, their emissions should be estimated using an approach similar to conventional steam boilers, which are covered in the stationary combustion chapter 1.A.4 Small combustion.

2.3 Emissions

The emissions produced by railways arise from combusting the fuel in an internal combustion engine. Consequently, the principal pollutants are those from diesel engines, i.e. similar to those used in road transport. These are principally CO_2, PM and NO_x, plus to a lesser extent CO and hydrocarbons, together with SO_x and heavy metals originating from the content of fuel in sulphur and metals, respectively.

2.4 Controls

Gaseous emissions can be controlled by two mechanisms: control of the combustion technology combined with exhaust gas treatment and control of the fuel quality. Both these measures are used in rail transport.

A number of technical control technologies are available, including exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) to control NO_x emissions, and diesel particulate filters (DPF) to control PM emissions. These technologies are better developed for the diesel

([1]) EMEP CORINAIR 'Emission Inventory Guidebook — 2005 European Environment Agency' Technical report No 30. Copenhagen, Denmark, (Dec 2005) available from website: http://eea.europa.eu/emep-eea-guidebook engines used in road transport (particularly powering heavy-duty vehicles). However, they tend to be gradually developing for railway engines to meet the mandatory emissions standards.

Within Europe railway engines' emissions are regulated by the non-road mobile machinery (NRMM) directives. The first stage to apply to railways is Stage IIIA (Directive 2004/26/EC) with railway engines having been excluded from the scope of earlier NRMM directives (e.g. 97/68/EC). EC Directive 2004/26/EC distinguishes between engines used in rail-cars and locomotives, and provides phased limits for NO_x, PM, CO and hydrocarbons, known as Stage IIIA and Stage IIIB. The dates for introduction of these limits are given in Table 2-1.

Table 2-1 Implementation dates of EU Directive 2004/26/EC according to engine type (P=engine power output)

	Stage IIIA	Stage IIIB
Railcars, P > 130 kW	1.1.2006	1.1.2012
Locomotives, 130 kW < P < 560 kW	1.1.2006	1.1.2012
560 kW < P	1.1.2008	1.1.2012

Further limits, known as Stage IV, are specified for some NRMM equipment, but are still under discussion for engines used on railways.

The working life of most locomotives is around 30 years ([2]). Some, especially rail-cars, are re-engined more frequently. However, whilst locomotive replacement tends to occur infrequently, replacement tends to occur in episodes (rather than continuously as for road transport). The slow turnover rate and the corresponding slow penetration of new engines in the existing stock means that the new NRMM directives will start to have an impact on emissions not earlier that approximately 2010.

Diesel fuel quality for non-road engines is also regulated. Within Europe, the sulphur content of fuels used in non-road engines is controlled by the Sulphur Content of Liquid Fuels (SCLF) directive (1999/32/EC). This limits the sulphur content of gas oil fuels by mass to less than 0.2 % from 2000 and 0.1 % from 2008. However, in many countries typical road transport diesel fuel is used in railways as well (Hill et al., 2005). Road transport diesel is regulated by Directive 2003/17/EC (which amended Directive 98/70/EC) which has established a maximum limit of 50 ppm (by mass) sulphur from 2005, dropping to 10 ppm wt. (by mass) from 2009. Operators like DB in Germany or the Swedish Railways use only < 10 ppm diesel in their vehicles. Low sulphur fuels will in any case be mandatory for enabling the advanced emission control systems introduced by Directive 2004/26/EC. The shift from gas oil to diesel might require some modifications to the engine due the lower lubricity and viscosity of the latter. With regard to the other pollutant emissions, it is not clear what effect the new fuel may bring. In general, it is known that density decreases, decrease PM and increase NO_x emissions. This is expected to occur also for rail engines.

Other fuels that have started to appear in locomotives are biodiesel and natural gas. However, their contribution is still considered quite small to have an impact on total emissions.

([2]) Rail diesel study — Work Package 1, Status and future development of the fleet, Markus Halder, Andreas Löchter, DB AG, report to UIC, July 2005.

3 Methods

3.1 Choice of method

In Figure 3.1 a procedure is presented to select the method for estimating emissions from railways. This decision tree is applicable to all nations. It basic concepts are:

- if detailed information is available then use as much as possible;
- if this source category is a key source, then a Tier 2 or Tier 3 method must be used for estimating the emissions.

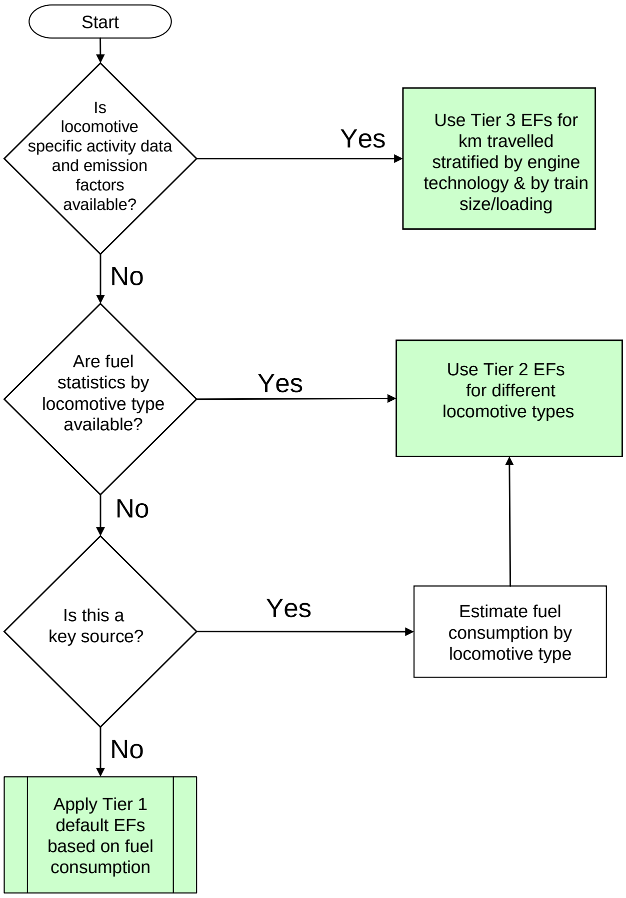

Figure 3-1 Decision tree for emissions from railways

3.2 Tier 1 total fuel used methodology

3.2.1 Algorithm

The Tier 1 approach for railways is a fuel-based methodology and uses the general equation:

$$E_i = \sum_m FC_m \times EF_{i,m} \quad (1)$$

where:

E_i = emissions of pollutant *i* for the period concerned in the inventory (kg or g),

FC_m = fuel consumption of fuel type *m* for the period and area considered (tonnes),

EF_i = emission factor of pollutant *i* for each unit of fuel type *m* used (kg/tonnes),

m = fuel type (diesel, gas oil).

Tier 1 emission factors (EF_i) assume an average technology for the railway locomotive fleet. For the emissions of CO_2, SO_2 and heavy metals, the emission factors are calculated presuming that the carbon in the fuel is fully oxidised to CO_2, and that the sulphur and heavy-metals in the fuel are quantitatively emitted into the atmosphere.

3.2.2 Default emission factors

The Tier 1 default emission factors are listed in Table 3–1. These should be considered applicable both to diesel and gas oil fuels.

Emissions of SO_2 may be calculated by means of the following equation:

$$E_{SO2} = 2 \times \sum_{m} k_{S,\,m} \times FC_m \qquad (2)$$

where:

E_{SO2} = emissions of sulphur dioxide for the period concerned in the inventory [kg],
$k_{S,m}$ = the sulphur content in the fuel (% by mass).

Typical sulphur content in gas oil is 0.1 % by mass and for diesel is 0.005 % by mass. Exact values may be provided by the railways operators in each country.

3.2.3 Activity data

The Tier 1 approach uses fuel sales as the measure of activity. It is based on the premise that the quantities of fuel sold for railways use are available, most probably from nationally collected data or on sales from a rail depot by depot basis. It also presumes that the quantity of fuel sold in a year is the quantity of fuel used in that year. For the Tier 1 method, a distinction to gas oil and diesel is only required for the calculation of SO_2 emissions. All other emission factors are considered equal for the two fuels.

Table 3-1 Tier 1 emission factors for railways

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
Not estimated	SO_x, Pb, Hg, As, PCDD/F, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	52.4	kg/tonne fuel	25	93	Aggregated Tier 2 method
CO	10.7	kg/tonne fuel	6	19	EMEP CORINAIR Gdbk 3.2/2006
NMVOC	4.65	kg/tonne fuel	2	8	EMEP CORINAIR Gdbk 3.2/2006
NH_3	0.007	kg/tonne fuel	0.004	0.012	EMEP CORINAIR Gdbk 3.2/2006
TSP	1.52	kg/tonne fuel	3	23	Aggregated Tier 2 method
PM_{10}	1.44	kg/tonne fuel	2	16	Aggregated Tier 2 method
$PM_{2.5}$	1.37	kg/tonne fuel	2	14	Aggregated Tier 2 method
Cd	0.01	g/tonne fuel	0.003	0.025	EMEP CORINAIR Gdbk 3.2/2006
Cr	0.05	g/tonne fuel	0.02	0.2	EMEP CORINAIR Gdbk 3.2/2006
Cu	1.7	g/tonne fuel	0.5	4.9	EMEP CORINAIR Gdbk 3.2/2006
Ni	0.07	g/tonne fuel	0.02	0.2	EMEP CORINAIR Gdbk 3.2/2006
Se	0.01	g/tonne fuel	0.003	0.025	EMEP CORINAIR Gdbk 3.2/2006
Zn	1	g/tonne fuel	0.3	2.5	EMEP CORINAIR Gdbk 3.2/2006
Benzo(a)pyrene	0.03	g/tonne fuel	0.01	0.1	EMEP CORINAIR Gdbk 3.2/2006
Benzo(b)fluoranthene	0.05	g/tonne fuel	0.02	0.2	EMEP CORINAIR Gdbk 3.2/2006
(*) CO_2	3140	kg/tonne fuel	3120	3160	EMEP CORINAIR Gdbk 3.2/2006
Benz(a)anthracene	0.08	g/tonne fuel	0.03	0.2	EMEP CORINAIR Gdbk 3.2/2006
Dibenzo(a,h)anthracene	0.01	g/tonne fuel	0.004	0.03	EMEP CORINAIR Gdbk 3.2/2006

Notes
B(k)f & Indeno (1,2,3-cd) pyrene and dioxins emission factor values are not available for railway emissions. It is therefore recommended to use values corresponding to old technology heavy duty vehicles from the Exhaust Emissions from Road Transport chapter (1.A.3.b.iii).
BC fraction of PM (f-BC): 0.65. Source: for further information see Appendix A

3.3 Tier 2 fuel used by types of locomotives methodology

3.3.1 Algorithm

The Tier 2 approach is based on apportioning the total fuel used by railways to that used by different generic locomotive technology types as the measure of activity. It assumes that the fuel can be apportion for example using statistics on the number of locomotives, categorised by type, and their average usage, e.g. from locomotive maintenance records. For this approach the algorithm used is:

$$E_i = \sum_m \sum_j (FC_{j,m} \times EF_{i,j,m}) \quad (3)$$

where:

E_i = emissions of pollutant *i* for the period concerned in the inventory (kg or g);

$FC_{j,m}$ = fuel consumption of fuel type *m* used by category *j* for the period and area considered (tonnes);

$EF_{i,j,m}$ = emission factor of pollutant *i* for each unit of fuel type *m* used by category *j* (kg/tonnes);

m = fuel type (diesel, gas oil);

j = locomotive category (shunting, rail-car, line-haul).

3.3.2 *Average locomotive — emission factors*

Emission factors have been derived from data in the Rail Diesel Study by UIC (Halder et al. 2005). This study provides an assessment of the diesel locomotive fleet in Europe and average emission factors. Tier 2 emission factors have been calculated by scaling the range of engine powers for each locomotive type and based on an average age distribution. For some pollutants no emission factors were given and these were adopted from on-road heavy-duty trucks.

Table 3-2 Tier 2 emission factors for line-haul locomotives

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
SNAP (if applicable)	080203	Locomotives			
Technologies/Practices	Line-haul locomotives				
Region or regional conditions	NA				
Abatement technologies	NA				
Not estimated	SO_x, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	63	kg/tonne	29	93	Halder et al. 2005
CO	18	kg/tonne	5	21	Note 1
NMVOC	4.8	kg/tonne	2	9	Note 1
NH_3	10	g/tonne	NA	NA	Note 3
TSP	1.8	kg/tonne	0.32	6	Note 2
PM_{10}	1.2	kg/tonne	0.45	3	Halder et al. 2005
$PM_{2.5}$	1.1	kg/tonne	0.42	3	Note 2
(*) N_2O	24	g/tonne	NA	NA	Note 3
(*) CO_2	3140	kg/tonne	3120	3160	Carbon balance
(*) CH_4	182	g/tonne	77	350	Note 1

Table 3-3 Tier 2 emission factors for shunting locomotives

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
SNAP (if applicable)	080201	Shunting locs			
Technologies/Practices	Shunting locomotives				
Region or regional conditions	NA				
Abatement technologies	NA				
Not estimated	SO_x, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NO_x	54.4	kg/tonne	27	85	Halder et al. 2005
CO	10.8	kg/tonne	2	18	Note 1
NMVOC	4.6	kg/tonne	1	8	Note 1
NH_3	10	g/tonne	0	0	Note 3
TSP	3.1	kg/tonne	0.75	5	Note 2
PM_{10}	2.1	kg/tonne	0.53	4	Halder et al. 2005
$PM_{2.5}$	2	kg/tonne	0.5	4	Note 2
(*) N_2O	24	g/tonne	0	0	Note 3
(*) CO_2	3190	kg/tonne	726	5335	Carbon balance
(*) CH_4	176	g/tonne	41	297	Note 1

Table 3-4 Tier 2 emission factors for railcars

Tier 2 emission factors					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
SNAP (if applicable)	080202	Rail Cars			
Technologies/Practices	Rail Cars				
Region or regional conditions	NA				
Abatement technologies	NA				
Not estimated	SO_x, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB, HCB, PCP, SCCP				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NO_x	39.9	kg/tonne	22	78	Halder et al. 2005
CO	10.8	kg/tonne	6	20	Note 1
NMVOC	4.7	kg/tonne	2	8	Note 1
NH_3	10	g/tonne	0	0	Note 3
TSP	1.5	kg/tonne	0.24	9	Note 2
PM_{10}	1.1	kg/tonne	0.28	4	Halder et al. 2005
$PM_{2.5}$	1	kg/tonne	0.26	3	Note 2
(*) N_2O	24	g/tonne	0	0	Note 3
(*) CO_2	3140	kg/tonne	3120	3160	Carbon balance
(*) CH_4	179	g/tonne	93	321	Note 1

Notes

1. Derived Tier 2 EF scaled by the range of engine powers, and specific fuel consumptions, as reported in Halder et al. 2005.
2. PM_{10} EFs taken from Halder et al. 2005. $PM_{2.5}$ was considered 95 % of PM_{10} and PM_{10} was considered 95 % of TSP.
3. Taken from conventional heavy duty trucks included in the Exhaust Emissions from Road Transport Chapter (1.A.3.b.iii)
4. POPs, heavy metals and SO_2: use Tier 1 methods and emission factors
5. BC fraction of PM (f-BC): 0.65. Source: for further information see Appendix A

3.3.3 Activity data

Information on the apportioning of fuel usage between different types of activities is probably not available. Instead the numbers of locomotives and their average fuelling (litres per year) from depot records would be required. The Tier 2 approach requires that national fuel consumption statistics are broken down by locomotive type in order to apply the three different sets of emission factors. Where this level of detail is unavailable from national statistics it can be derived using the number and average hours of use per year of each locomotive type by applying the fuel consumption factors in Table 3-5 below.

Table 3-5 Fuel consumption for different locomotive types

Category	Fuel consumption	Units
Line-haul locomotives	219	kg/h
Shunting locomotives	90.9	kg/h
Railcars	53.6	kg/h

Details of the number of locomotives and the hours of use can be obtained from rail statistics, rail companies, rail timetables or a national rail agency. It is important that the sum of the average fuel consumptions and hours of use for the three types of locomotive sum to the total amount of fuel used. If not then the fuel usage per type of locomotive should be scaled to the national statistics to ensure that the overall energy balance of the inventory is maintained.

3.3.4 Abatement

Technology abatement approach not relevant for this methodology.

3.4 Tier 3 specific locomotive usage approach

The Tier 1 and Tier 2 approaches use fuel sales as the primary activity indicator, either aggregated (Tier 1) or apportioned to different broad locomotive types (Tier 2). The Tier 3 approach can be applied by estimating the number of locomotives times the average number of hours these are used per year as the activity indicator, and assuming average locomotive emissions characteristics to calculate the emissions inventory. Alternatively, an even more detailed Tier 3 approach stratifies the locomotive usage by individual locomotive types.

This is the same approach as that described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3 (equation 3.4.3). It uses more detailed modelling of the usage of each type of engine and train, which will affect emissions through dependence of emission factors on load. The data needed includes the fuel consumption, which can be further stratified according to typical journey (e.g. freight, intercity, regional) and kilometers travelled by type of train and is converted into hours of use and power produced by locomotive usage for the journey. This type of data may be collected for other purposes (e.g. emissions of air pollutants depending on speed and geography, or from the management of the railway).

3.4.1 Algorithm

The algorithm below is an example of a more detailed Tier 3 methodology which is mainly based on the US Environmental Protection Agency (USEPA) method for calculating off-road emissions. Hence there is a consistency between the approach provided here, that within the 2006 IPCC guidelines, and the analogous Tier 3 methodologies for general off-road equipment (see the chapter on combustion emissions for off-road equipment 1.A.4 Other mobile. The equation uses the following basic formula to calculate emissions:

$$E_i = \sum_m \sum_j \left(N_{j,m} \times H_{j,m} \times P_{j,m} \times LF_{j,m} \times EF_{i,j,m} \right) \tag{3}$$

where

E_i = emissions of pollutant *i* for the period concerned in the inventory (kg or g),

$N_{j,m}$ = the number of locomotives in category *j* using fuel type *m*,

$H_{j,m}$ = the average number of hours that locomotives of category *j*, operate in the time period concerned, using fuel type *m* (h),

$P_{j,m}$ = the average nominal power output of locomotives in category *j* with fuel *m* (kW),

$LF_{j,m}$ = the average (typical) load factor of locomotive category *i* (ranges between 0 to 1),

$EF_{i,j,m}$ = emission factor of pollutant *i* for each unit of power output by locomotives in category *j*, using fuel type m (kg/kWh or g/kWh),

j = locomotive category (line-haul, shunting, railcar),

m = fuel type (gas oil, diesel).

In this methodology the parameters H, P, LF and EF may be sub-divided. For example, H could be an age dependant usage pattern. Similarly, LF could be varied for freight trains to reflect the differing power requirements for pulling different sized freight trains.

A number of detailed modelling tools are available for estimating locomotive emissions using Tier 3 methodologies (e.g. RAILI (VTT, 2008), Nonroad (USEPA 2005a and b), COST 319 (Jorgensen & Sorenson, 1997)). Please refer to Box 3.4.1 for an example of a Tier 3 approach.

Box 3.4.1 An example of a Tier 3 approach

The 1998 EPA non-road diesel engine regulations are structured as a 3-tiered progression (USEPA, 1998). Each USEPA-Tier involves a phase in (by horse power rating) over several years. USEPA-Tier 0 standards were in phase until 2001. The more stringent USEPA-Tier 1 standards took effect from 2002 to 2004, and yet more stringent USEPA-Tier 2 standards phase-in from 2005 and beyond. The main improvements are in the NO_x and PM emissions over the USEPA-Tiers. Use of improved diesel with lower sulphur content contributes to reduced SO_2 emissions. The table below provides broad technology level emission factors for these and other locomotives above 3000 HP. Emission factors may also be provided in g/passenger-kilometre for passenger trains and g/ton-kilometre for freight trains for higher Tiers if country-specific information is available (e.g., Hahn, 1989, United Nations Economic Commission for Europe (UNECE) 2002).

Table 3-5 Broad technology level emission factors

Model	Engine	Power		Brake-specific diesel fuel consumption (kg/kWh)	Reported emission levels (g/kWh)			
		HP	kW		NO_x	CO	HC	CO_2
EMD SD-40	645E3B	3000	2237	0.246	15.82	2.01	0.36	440
EMD SD-60	710G3	3800	2834	0.219	13.81	2.68	0.35	391
EMD SD-70	710G3C	4000	2983	0.213	17.43	0.80	0.38	380
EMD SD-75	710G3EC	4300	3207	0.206	17.84	1.34	0.40	367
GE dash 8	7FDL	3800	2834	0.219	16.63	6.44	0.64	391
GE dash 9	7FDL	4400	3281	0.215	15.15	1.88	0.28	383
GE dash 9	7FDL (Tier 0)	4400	3281	0.215	12.74	1.88	0.28	383
Evolution	GEVO 12	4400	3281	NA	10.86	1.21	0.40	NA
2TE116	1А-5Д49	6035	2●2250	0.214	16.05	10.70	4.07	382
2TE10M	10Д100	5900	2●2200	0.226	15.82	10.62	4.07	403
ТЕП60	11Д45	2950	2200	0.236	16.05	10.62	3.84	421
ТЕП70	2А-5Д49	3420	2550	0.211	15.83	10.55	4.01	377
2M62	14Д40	3943	2●1470	0.231	13.40	9.01	3.23	412

Sources:

1. EMD and GE locomotive information based on Dunn, 2001. Lower Tier CO and HC estimates for line-haul locomotives are 6.7 g/kWh and 1.3 g/kWh respectively.
2. For the TE models and 2M62, estimations are based on GSTU 1994.

3.4.2 Tier 3 detailed methodology

The most detailed rail inventory methodology sums the activities of railcars, line-haul locomotives and shunting locomotives on a trip by trip, or hours of activity basis. It takes into account:

- the length of journeys, our hours shunting,
- the type of locomotives used,
- the weight of freight trains.

Generally, freight trains are heavier than passenger trains, they travel more slowly, and they are often pulled by different types of locomotives to those used for passenger services. Therefore, the emission factors per train-km travelled differ for the two types of trains.

Whilst this is a comprehensive approach, its principal weaknesses are the availability of detailed journey/locomotive-used data and, most crucially, locomotive-specific emission factors. In such cases approximations and assumptions have to be made. For example, the ratio passenger train-km to freight train-km could be assumed to be a default value of 0.8 to 0.2. However, this ratio will vary from nation to nation.

3.4.3 Tier 3 emission factors

Individual countries have reported emission factors for specific 'representative' engine types as part of the UIC Rail Diesel study (Halder and Löchter, 2005). This study focussed principally on emissions of PM and NO_x. Some emission factors can be found within the report.

More Tier 3 emission factors can be found in the technical reports of the Artemis project (Boulter and McCrae, 2007).

3.4.4 Activity data

Tier 3 approaches require activity data for operations (for example gross tonne kilometre (GTK) and duty cycles) at specific line-haul locomotive level. These methods also require other locomotive-specific information, such as source population (with age and power ranges), mileage per train tonnage, annual hours of use and age-dependent usage patterns, average rated horse power (with individual power distribution within given power ranges), load factor, section information (such as terrain topography and train speeds). There are alternate modelling approaches for Tier 3 estimation (VTT 2008,, EMEP Corinair 2005).

The railway or locomotive companies, or the relevant transport authorities may be able to provide fuel consumption data for the line haul and yard locomotives. The contribution from yard locomotives is likely to be very small for almost all countries. If the annual fuel consumption is not provided separately for yard locomotives, it may be possible to estimate fuel use if typical data on their use and daily fuel use is available according to the following equation:

Inventory fuel consumption = number of yard locomotives ×

average fuel consumption per locomotive and day ×

average number of days of operation per locomotive in the year

The number of yard locomotives can be obtained from railway companies or transport authorities. If average fuel consumption per day is unknown, a value of 863 litres per day can be used (USEPA, 2005a). The number of days of operation is usually 365. If data for the number of yard locomotives cannot be obtained, the emissions inventory can be approximated by assuming that all fuel is consumed by line-haul locomotives.

4 Data quality

4.1 Completeness

Diesel fuel is the most common fuel type used in railways, but inventory compilers should be careful not to omit or double count the other fuels that may be used in diesel locomotives for traction purposes. These may be mixed with diesel and may include petroleum fuels (such as residual fuel, fuel oils, or other distillates), bio-diesel (e.g. oil esters from rape seed, soy bean, sunflower, Jatropha, or Karanjia oil, or recovered vegetable and animal fats), and synthetic fuels. Bio-diesel can be used in all diesel engines with slight or no modification. Blending with conventional diesel is possible. Synthetic fuels include synthetic middle distillates (SMD) and Dimethyl Ether (DME) to be produced from various carbonaceous feedstocks, including natural gas, residual fuel oil, heavy crude oils, and coal via the production of synthesis gas. The mix varies and presently it is between 2 to 5 per cent bio-diesel and the remaining petroleum diesel. The emission properties of these fuels are considered to be similar to those used for the road transport sector. CO_2 emissions from fuels derived from biomass should be reported as information items, and not included in the national total to avoid double counting.

Diesel locomotives may combust natural gas or coal for heating cars. Although these energy sources may be ‘mobile,’ the methods for estimating emissions from combustion of fuels for heat are covered under the stationary combustion chapter of this Guidebook – 1.A.4 Small combustion. Inventory compilers should be careful not to omit or double count the emissions from energy used for carriage heating in railways.

Diesel locomotives also consume significant amounts of lubricant oils. The related emissions should be estimated.

There are potential overlaps with other source sectors. A lot of statistical data will not include fuel used in other activities such as stationary railway sources; off-road machinery, vehicles and track machines in railway fuel use. Their emissions should not be included here but in the relevant non-railway categories as stationary sources, off-road, etc. If this is not the case and it is impossible to separate these other uses from the locomotives, then it is good practice to note this in any inventory report or emission reporting tables.

4.2 Avoiding double counting with other sectors

Carbon dioxide emissions based on biodiesel combustion should not be reported for railways as these emissions are attributed to the Land Use, Land-Use Change and Forestry sector under reporting to UNFCCC. However, bio-fuel consumption should be included in the energy balances, together with fossil-fuel combustion to correctly allocate energy use in railways. Also, all other greenhouse gases due to biofuel use (N_2O, CH_4, etc,) should be similarly reported as for fossil fuels.

4.3 Verification

No specific issues.

4.4 Developing a consistent time series and recalculation

Emissions of species excluding CO_2 and SO_2 and heavy metals will depend on engine type and technology. Unless technology-specific emission factors have been developed, it is good practice to use the same fuel-specific set of emission factors for all years.

Mitigation options that affect emission factors can only be captured by using engine-specific emission factors, or by developing control technology assumptions. These changes should be adequately documented.

For more information on determining base year emissions and ensuring consistency in the time series, see the General Guidelines chapter.

4.5 Uncertainty assessment

Emissions from railways are typically much smaller than those from road transport, aviation and shipping because the amounts of fuel consumed are less, and also because operations often occur on electrified lines, in which case the emissions associated with railway energy use will be reported under power generation and will depend on the characteristics of that sector.

To reduce uncertainty, a comprehensive approach is needed for both emission factors and activity data, especially where bottom-up activity data are used. The use of representative locally estimated data is likely to improve accuracy although uncertainties may remain large. It is good practice to document the uncertainties both in the emission factors as well as in the activity data. Further guidance on uncertainty estimates for emission factors can be found in the General Guidance notes chapter.

4.5.1 Emission factor uncertainties

The emission factors in Table 3-2 to Table 3-4 provide ranges indicating the uncertainties associated with diesel fuel. In the absence of specific information, the percentage relationship between the upper and lower limiting values and the central estimate may be used to derive default uncertainty ranges associated with emission factors for additives.

4.5.2 Activity data uncertainties

The uncertainty in top-down activity data (fuel use) is likely to be of the order 5 per cent. The uncertainty in disaggregated data for bottom-up estimates (usage or fuel use by type of train) is unlikely to be less than 10 per cent and could be several times higher, depending on the quality of the underlying statistical surveys. Bottom-up estimates are however necessary for estimating emissions of NO_x, CO, hydrocarbons, PM, etc. at higher Tiers. These higher Tier calculations could also yield estimates for CO_2, SO_2 and heavy metals, but these will probably be more uncertain than use of Tier 1 or Tier 2 methodology. Thus the way forward where railways are a key category is to use with country-specific fuel carbon contents, and higher Tier estimates for the other gases. A bottom-up CO_2 estimate can then be used for QA/QC cross-checks.

Further guidance on uncertainty estimates for activity data can be found in the General Guidance chapter on Uncertainties (part A, chapter 5).

4.6 Inventory quality assurance/quality control QA/QC

It is good practice to conduct quality control checks. Specific procedures of relevance to this source category are outlined below.

Review of emission factors

Inventory compilers should ensure that the original data source for national factors is applicable to each category and that accuracy checks on data acquisition and calculations have been performed. For the emission factors included in this chapter, the inventory compiler should ensure that the factors are applicable and relevant to the category. If possible, these factors should be compared to national factors to provide further indication that the factors are applicable and reasonable.

Check of activity data

The source of the activity data should be reviewed to ensure applicability and relevance to the category. Where possible, the data should be compared to historical activity data or model outputs to look for anomalies. Data could be checked with productivity indicators such as fuel per unit of distance railway performance (freight and passenger kilometres) compared with other countries and compared across different years.

4.7 Gridding

No specific issues.

4.8 Reporting and documentation

It is good practice to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter of the General Guidance notes.

In addition to reporting emissions, it is good practice to provide:

- the way in which detailed information needed for bottom-up estimates has been obtained, and what uncertainties are to be estimated;
- how any bottom-up method of fuel use has been reconciled with top-down fuel use statistics.
- emission factors used and their associated references, especially for additives
- the way in which any biofuel components have been identified.

5 Glossary

CH_4:	methane
CO:	carbon monoxide
CO_2:	carbon dioxide
Cd:	cadmium
Cu:	copper
FC:	fuel consumption
HM:	heavy metals
IPCC:	Intergovernmental Panel on Climate Change
NH_3:	ammonia
NMVOC:	non-methane volatile organic compounds
NO_x:	nitrogen oxides
NO_2:	nitrogen
N_2O:	nitrous oxide
P:	nominal power output
Pb:	lead
PM:	particulate matter
POP:	persistent organic pollutants
SNAP:	Selected Nomenclature for Air Pollution
SO_2:	sulphur dioxide
VOC:	volatile organic compounds
Zn:	zinc

6 References

Boulter P and McCrae I (eds.) (2007). Artemis: Assessment and reliability of transport emission models and inventory systems. Final report. Deliverable No 15. TRL unpublished report UPR/IE/044/07. TRL Limited, Wokingham.

Dunn, R. (2001). 'Diesel fuel quality and locomotive emissions in Canada'. Transport Canada Publication No Tp 13783e (Table 8).

EMEP Corinair 'Emission Inventory Guidebook — 2005 European Environment Agency'. Technical report No 30. Copenhagen, Denmark, (Dec 2005)

GSTU (1994). 'Emissions of pollution gases with exhaust gases from diesel locomotive.' Rates and definition methods (GSTU, 32.001-94) — in Russian (ГСТУ 32.001-94. Выбросы загрязняющих веществ с отработавшими газами тепловозных дизелей. Нормы и методы определения).

Hahn, J. (1989). Eisenbahntechnishne Rundschau, No 6, pp. 377—384.

Halder M., Löchter, A. (2005). 'Status and future development of the diesel fleet'. Rail diesel study, WP1 final report. UIC, p. 54. www.uic.org/download.php/environnement/2006-01-diesel-study-wp1.pdf

Hill, N., Kollamthodi, S., Hazeldine, T., Cross, S., Bergdorff, M., Halder, M., Köhler, T., Collin R., et al. (2005). 'Technical and operational measures to improve the emissions performance of diesel rail'. Rail diesel study, WP2 final report: report No ED05010/WP2/R02, AEA Technology, Oxfordshire, UK p. 219.

ISO 8178-4 (1996). 'Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications'.

Jorgensen, M.W. and. Sorenson, S.C (1997). 'Estimating emission from railway traffic'. DTU report, No ET-EO-97-03, Dept of Energy Eng. Lyngby, Denmark, p. 135.

TRANS/SC.2/2002/14/Add.1 13 AUGUST (2002). Economic Commission for Europe. Inland Transport Committee. Working Party on rail transport. Productivity in rail transport. Transmitted by the International Union of Railways (UIC).

UNECE (2002). 'Productivity in rail transport UN Economic Commission For Europe, Inland Transport Committee Working Party on Rail Transport'. (Fifty-sixth session, 16–18 October 2002, agenda item 15). Transmitted by the International Union of Railways (UIC) TRANS/SC.2/2002/14/Add.1

USEPA (1998). www.epa.gov/fedrgstr/EPA-AIR/1998/October/Day-23/a24836.htm

USEPA (2005a). NONROAD 2005 Model, for software, data and information. see website: www.epa.gov/otaq/nonrdmdl.htm

USEPA (2005b). User's Guide for the final NONROAD2005 model. Environment Protection Agency. Report EPA420-R-05-0, 13 December 2005, Washington DC, USA.

VTT (2008). RAILI (2008). Calculation system for Finnish railway traffic emissions. For information see website http://lipasto.vtt.fi/railie/

7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Transport. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.

Appendix A: BC fractions of PM emissions from railways

Basically the same diesel engine technologies are used by railway locomotives and heavy duty trucks in road transport, however, measurement data for BC and PM are scarce for the engines used by railway locomotives as such. Hence, for railways as a source category in the guidebook the decision is to use the f-BC fractions and +/- uncertainty ranges proposed for road transport heavy duty engines, as the f-BC figures for these engines are derived from a comprehensive literature survey of EC and OC fractions of total exhaust PM made by Ntziachristos et al. (2007). This is also explained in Annex 3 in the guidebook chapter for road transport. The examined OC data from Ntziachristos et al. (2007) can be input for the further assessment of OC fractions of PM (f-OC).

Tier 1

Tier 1 PM emission factors for diesel usage in general are shown in Table 3-1 of the present Guidebook chapter for railways. However, references for these emission factors as well as descriptions of engine technologies or exhaust after treatment technologies are not presently available. So, in order to keep a general engine consistency with road transport heavy duty engines, for railways engines on a Tier 1 level (1995 average engine technology levels) it is proposed to use the f-BC fraction for Euro I road transport engines (f-BC = 0.65) which are assumed to be equal to the engine technology level for railways engines in 1995.

Tier 2

Tier 2 emission factors are shown in the Tables 3-2, 3-3 and 3-4 for line haul locomotives, shunting locomotives and rail cars, respectively: The Guidebook emission factor values are derived from the Rail diesel study by UIC (Halder et al. 2005) for shunting locomotives, rail cars and line haul locomotives based on a questionnaire send out to railway operating companies. No details in terms of the distribution into engine technologies or exhaust after treatment technologies are provided by Halder et al. (2005). The latter source, however, finds relatively high average ages for rail cars (16 years) and locomotives (27 years).

For road transport engines, the f-BC fractions vary between 0.50 and 0.75 for increasingly modern engine technology levels going from conventional to Euro V engines (c.f. Annex 3 in the guidebook chapter for road transport). Since no details are provided by the source for PM emission factor information in the guidebook (Halder et al., 2005), 0.65 as an average number is proposed to be used for f-BC at the Tier 2 level for railways.

Tier 3

For Tier 3, no explicit PM emission factor information is given. Instead, as quoted from the main Guidebook chapter text above, countries are advised to seek information themselves: “More Tier 3 emission factors can be found in the technical reports of the Artemis project (Boulter and McCrae, 2007)”. In this case it is proposed to use the f-BC fractions proposed for road transport heavy duty engines and to distinguish between engines with or without DPF. For railways engines without filters installed the f-BC fraction range between 0.50 and 0.75, and for railways engines with filters installed it is proposed to use a f-BC fraction of 0.15.

Table A1 Proposed f-BC fractions and +/- uncertainty ranges for Tier 1-3 for railways

Table no.	Tier level	f-BC	+/- uncertainty (%)
3-1	Tier 1	0.65	20
3-2/4	Tier 2	0.65	20
3-5	Tier 3	0.5-0.75	20
3-5	Tier 3, DPF	0.15	30

References

Halder M., Löchter, A. (2005). 'Status and future development of the diesel fleet'. Rail diesel study, WP1 final report. UIC, p. 54. www.uic.org/download.php/environnement/2006-01-dieselstudy-wp1.pdf.

Ntziachristos, L., Mellios, G., Fontaras, G., Gkeivanidis, S., Kousoulidou, M., Gkatzoflias, D, Papageorgiou, Th., and Kouridis, C. (2007), Updates of the Guidebook Chapter on Road Transport. LAT Report No 0706, p. 63.