Appendix 2.3 - Heavy Metal Exhaust Emissions From Mobile Sources

This appendix chapter provides additional information regarding the approaches applied for estimating exhaust heavy metal emissions from mobile sources in:

- Road Transport (1.A.3.b i - iv)
- Non-road Mobile Machinery in 1.A.2.g vii, 1.A.4.a ii/b ii/c ii, and 1.A.5.b
- Railways (1.A.3.c)
- Maritime Vessels and Ships in 1.A.3.d i, 1.A.3.d ii, 1.A.4.c iii and 1.A.5.b
- Aircraft in 1.A.3.a and 1.A.5.b

Road Transport

For heavy-metal exhaust emissions (other then lead from leaded gasoline), energy-related tier1 values have been derived from mass-related tier1 defaults provided in the 2023 EMEP/EEA Guidebook in chapter 1.A.3.b (Update 2024), page 99, table 3-82, taking into account not only the fuel heavy-metal content, but also the contribution of engine wear (*"These values have been calculated by encompassing the impact of engine wear to the heavy metal emissions. Therefore, by multiplying these apparent factors with fuel consumption, it is expected that the combined emissions of fuel and engine wear are estimated."*)

Table 3-82: Heavy metal emission factors for all vehicle categories in ppm/wt fuel

Category	Pb	Cd	Cu	Cr	Ni	Se	Zn	Hg	As
Passenger cars, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
Passenger cars, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
LCVs, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
LCVs, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
HDVs, petrol	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003
HDVs, diesel	0.0005	5 E-05	0.0057	0.0085	0.0002	0.0001	0.018	0.0053	0.0001
L-category	0.0016	0.0002	0.0045	0.0063	0.0023	0.0002	0.033	0.0087	0.0003

From these default values, the following country-specific energy-related tier1 EF were derived via the average NCVs of the fuels used:

Table 1: Tier1 emission factors derived from EMEP/EEA Guidebook 2023 defaults, in g/TJ

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn	additional info:
Diesel oil	0.0116	0.0012	0.1234	0.0023	0.1979	0.1327	0.0047	0.0023	0.4190	
Biodiesel[1]	0.0134	0.0013	0.1423	0.0027	0.2282	0.1531	0.0054	0.0027	0.4833	derivation of tier1 EF
Gasoline fuels	0.0367	0.0046	0.1998	0.0069	0.1447	0.1033	0.0528	0.0046	0.7579	
Natural gas (CNG & LNG)	NE	NE	NE	NE	NE	NE	NE	NE	NE	(MS Excel file)
LPG	NE	NE	NE	NE	NE	NE	NE	NE	NE	
Biomethane	NE	NE	NE	NE	NE	NE	NE	NE	NE	

Here, biodiesel has a slightly lower NCV compared to fossil diesel resulting in higher emissions per TJ, whereas for biogasoline the same NCV is applied as for fossil gasoline.

In addition, the EMEP/EEA Guidebook provides separate values for heavy metals from the unintended co-incineration of lube oil. The latter are reported in NFR sub-category 2.G.4 as emissions from product use. (*Note: This country-specific approach has been discussed and accepted at both the 2018 TFEIP meeting and the 2018 NEC review.*)

Table 3-83: Heavy metal emission factors for all vehicle categories in ppm/wt lubricant

Category	Pb	Cd	Cu	Cr	Ni	Se	Zn	Hg	As
Passenger cars, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
Passenger cars, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
LCVs, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
LCVs, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
HDVs, petrol	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
HDVs, diesel	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0
L-category	0.0332	4.56	778	19.2	31.89	4.54	450.2	0	0

Non-road Mobile Machinery in 1.A.2.g vii, 1.A.4.a ii/b ii/c ii, and 1.A.5.b

Without country-specific information, tier1 values are applied.

However, instead of using the emission factors provided in (EMEP/EEA, 2023) [1], Table 3-1 Tier 1 emission factors for off-road machinery,…

Table 3-1   Tier 1 emission factors for off-road machinery

Tier 1 emission factors				
Fuel	NFR sector	Pollutant	Units	Emission factor
Diesel	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii			
		Cadmium	mg/kg fuel	0.010
		Copper	mg/ kg fuel	1.70
		Chromium	mg/ kg fuel	0.050
		Nickel	mg/ kg fuel	0.07
		Selenium	mg/ kg fuel	0.01
		Zinc	mg/ kg fuel	1.00
Gasoline	1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii and 1.A.4.c.ii			
		Cadmium	mg/kg fuel	0.01
		Copper	mg/kg fuel	1.70
		Chromium	mg/kg fuel	0.05
		Nickel	mg/kg fuel	0.07
		Selenium	mg/kg fuel	0.01
		Zinc	mg/kg fuel	1.00

…the EF for exhaust HMs from NFR 1.A.3.b.i-iv (see above) are applied in order to assure the separate reporting of emissions from fuel and engine wear and the unintended co-incineration of lube oil:

Table 2: Tier1 emission factors derived from EMEPEEA Guidebook 2023 defaults for NFRs 1.A.3.b i-iv, in g/TJ

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Diesel oil	0.0116	0.0012	0.1234	0.0023	0.1979	0.1327	0.0047	0.0023	0.4190
Biodiesel[1]	0.0134	0.0013	0.1423	0.0027	0.2282	0.1531	0.0054	0.0027	0.4833
Gasoline fuels - 4-stroke	0.0367	0.0046	0.1998	0.0069	0.1447	0.1033	0.0528	0.0046	0.7579

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Gasoline fuels - 2-stroke[2]	0.0522	2.29	0.1958	0.0068	9.78	391	16.1	2.28	227
LPG (1.A.4.a ii only)	NE	NE	NE	NE	NE	NE	NE	NE	NE

[1] values differ from EFs applied for fossil diesel oil to take into account the specific NCV of biodiesel
[2] including the HM of 1:50 lube oil mixed to the gasoline

> *Until submission 2017, the EMEP/EEA default EFs provided for NRMM were used in the German inventory. As these EFs do not differentiate between fuel combustion and lubricant co-incineration, the inventory compiler decided to apply the more specific EFs from road transport to NRMM in 1.A.2.g vii, 1.A.4.a ii, b ii and c ii and 1.A.5.b, too. This country-specific approach has been discussed and accepted at both the 2018 TFEIP meeting and the 2018 NEC review.*

Furthermore, as stated in the 2023 EMEP/EEA Guidebook, similar EF are applied for land based military vehicles and mobile machinery as part of NFR 1.A.5.b:

Notes:

For land based military emissions, use emission factors for 1.A.2.g.vii as no other data are available.

Heavy-metal emissions from lubricants (as far as not used in 2-stroke mix) are reported under NFR sub-category 2.G.4 as emissions from product use.

Railways

Tier1 default EF as provided in the corresponding chapter of the EMEP/EEA Guidebook 2023:

Table 3-1   Tier 1 emission factors for railways

Tier 1 emission factor					
	Code	Name			
NFR Source Category	1.A.3.c	Railways			
Fuel	Gas Oil/Diesel				
Not applicable	HCH, PCB, HCB				
Not estimated	SOx, Pb, Hg, As, PCDD/F, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	Upper	
NOx	52.4	kg/tonne fuel	25	93	Aggregated Tier 2 method
CO	10.7	kg/tonne fuel	6	19	Guidebook (2006)
NMVOC	4.65	kg/tonne fuel	2	8	Guidebook (2006)
NH$_3$	0.007	kg/tonne fuel	0.004	0.012	Guidebook (2006)
TSP	1.52	kg/tonne fuel	3	23	Aggregated Tier 2 method
PM10	1.44	kg/tonne fuel	2	16	Aggregated Tier 2 method
PM2.5	1.37	kg/tonne fuel	2	14	Aggregated Tier 2 method
Cd	0.01	g/tonne fuel	0.003	0.025	Guidebook (2006)
Cr	0.05	g/tonne fuel	0.02	0.2	Guidebook (2006)
Cu	1.7	g/tonne fuel	0.5	4.9	Guidebook (2006)
Ni	0.07	g/tonne fuel	0.02	0.2	Guidebook (2006)
Se	0.01	g/tonne fuel	0.003	0.025	Guidebook (2006)
Zn	1	g/tonne fuel	0.3	2.5	Guidebook (2006)
Benzo(a)pyrene	0.03	g/tonne fuel	0.01	0.1	Guidebook (2006)
Benzo(b)fluoranthene	0.05	g/tonne fuel	0.02	0.2	Guidebook (2006)
Benz(a)anthracene	0.08	g/tonne fuel	0.03	0.2	Guidebook (2006)
CO$_2$	3140	kg/tonne fuel	3120	3160	Guidebook (2006)
Dibenzo(a,h)anthracene	0.01	g/tonne fuel	0.004	0.03	Guidebook (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

Besides these emissions from fuel combustion and engine wear, the German inventory also covers **abrasive emissions from brakes, wheels on rail and contact line**. Here, a country-specific approach is applied with emissions of (i) chromium and nickel being estimated as part of the particle emissions from brake wear whereas emissions of copper (ii) copper are estimated as part of the PM emissions from the contact line.

Table 4: Country-specific emission factors for abrasive emissions, in g/km

	PM$_{2.5}$	PM$_{10}$	TSP	BC	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Contact line [1]	0.00016	0.00032	0.00032	NA	NA	NA	NA	NA	NA	0.00033	NA	NA	NA
Tyres on rails [2]	0.009	0.018	0.018	NA					NA				
Braking system [3]	0.004	0.008	0.008	NA	NA	NA	NA	NA	0.00008	NA	0.00016	NA	NA
Current collector [4]	NE	NE	NE	NE					NA				

[1] assumption: 100 per cent copper
[2] assumption: 100 per cent steel

[3] assumption: steel alloy containing Chromium and Nickel

[4] typically: aluminium alloy + coal contacts; no particulate matter emissions calculated yet

Inland Vessels and Ships in 1.A.3.d ii

Table 5: Tier1 default emission factors applied to inland ships and vessels, in g/TJ

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Diesel oil	1.21	0.233	0.123	0.002	1.16	39.6	1.63	0.233	23.3
Biodiesel[1]	0.013	0.001	0.142	0.003	0.23	0.15	0.005	0.003	0.48

[1] similar EF for biodiesel applied for all mobile sources

Maritime Vessels and Ships in 1.A.3.d i, 1.A.3.d ii, 1.A.4.c iii and 1.A.5.b

Tier1 default EF as provided in the corresponding chapter of the EMEP/EEA Guidebook 2023:

Table 3-1   Tier 1 emission factors for ships using bunker fuel oil

Tier 1 default emission factors					
	Code	**Name**			
NFR Source Category	1.A.3.d.i	International navigation			
	1.A.3.d.ii	National navigation			
	1.A.4.c.iii	Agriculture / forestry / fishing: National fishing			
	1.A.5.b	Other, mobile (including military, land based and recreational boats)			
Fuel	Bunker Fuel Oil				
Not applicable					
Not estimated	NH$_3$				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	69.1	kg/tonne fuel	0	0	Scipper (2021)
CO	3.67	kg/tonne fuel	0	0	Scipper (2021)
NMVOC	1.67	kg/tonne fuel	0	0	Scipper (2021)
SO$_2$	19.2	kg/tonne fuel	0	0	Scipper (2021)See also note (1)
PM$_{10}$	5.2	kg/tonne fuel	0	0	Scipper (2021)
BC	0.0903	kg/tonne fuel	0	0	Scipper (2021)
Benzo(b)fluoranthene	0.03	g/tonne fuel			average value
Benzo(k)fluoranthene	0.02	g/tonne fuel			average value
Benzo(a)pyrene	0.005	g/tonne fuel			average value
Indeno(1,2,3- cd)pyrene	0.009	g/tonne fuel			average value
Pb	0.18	g/tonne fuel	0	0	average value
Cd	0.02	g/tonne fuel	0	0	average value
Hg	0.02	g/tonne fuel	0	0	average value
As	0.68	g/tonne fuel	0	0	average value
Cr	0.72	g/tonne fuel	0	0	average value
Cu	1.25	g/tonne fuel	0	0	average value
Ni	32	g/tonne fuel	0	0	average value
Se	0.21	g/tonne fuel	0	0	average value
Zn	1.2	g/tonne fuel	0	0	average value
PCB	0.57	mg/tonne fuel	0	0	Cooper (2005)
PCDD/F	0.47	ug I-TEQ /tonne fuel	0	0	Cooper (2005)
HCB	0.14	mg/tonne fuel	0	0	Cooper (2005)

Table 3-2   Tier 1 emission factors for ships using marine diesel oil/marine gas oil

Tier 1 emission factor						
	Code	Name				
NFR Source Category	1.A.3.d.i 1.A.3.d.ii 1.A.4.c.iii 1.A.5.b	International navigation National navigation Agriculture / forestry / fishing: National fishing Other, mobile (including military, land based and recreational boats)				
Fuel	Marine diesel oil/marine gas oil (MDO/MGO)					
Not applicable	HCH					
Not estimated	NH$_3$					
Pollutant	Value	Unit	95% confidence interval		Reference	
			Lower	Upper		
NOx	72.2	kg/tonne fuel	0	0	Scipper (2021)	
CO	3.84	kg/tonne fuel	0	0	Scipper (2021)	
NMVOC	1.75	kg/tonne fuel	0	0	Scipper (2021)	
SO$_2$	1.82	kg/tonne fuel	0	0	Scipper (2021) See also note (1)	
PM$_{10}$	1.07	kg/tonne fuel	0	0	Scipper (2021)	
BC	0.0483	kg/tonne fuel	0	0	Scipper (2021)	
Benzo(b)fluoranthene	0.01	g/tonne fuel			average value	
Benzo(k)fluoranthene	0.01	g/tonne fuel			average value	
Benzo(a)pyrene	0.002	g/tonne fuel			average value	
Indeno(1,2,3- cd)pyrene	0.001	g/tonne fuel			average value	
Pb	0.13	g/tonne fuel	0	0	average value	
Cd	0.01	g/tonne fuel	0	0	average value	
Hg	0.03	g/tonne fuel	0	0	average value	
As	0.04	g/tonne fuel	0	0	average value	
Cr	0.05	g/tonne fuel	0	0	average value	
Cu	0.88	g/tonne fuel	0	0	average value	
Ni	1	g/tonne fuel	0	0	average value	
Se	0.1	g/tonne fuel	0	0	average value	
Zn	1.2	g/tonne fuel	0	0	average value	
PCB	0.038	mg/tonne fuel	0	0	Cooper (2005)	
PCDD/F	0.13	ug I-TEQ/tonne	0	0	Cooper (2005)	
HCB	0.08	mg/tonne fuel	0	0	Cooper (2005)	

From these mass-related default emission factors, energy-related tier1 EF were derived via average NCVs for the fuels used:

Table 6: Tier1 emission factors derived from EMEP/EEA Guidebook 2023 defaults, in g/TJ

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Heavy Fuel oil[1]	4.46	0.50	0.50	16.9	17.8	31.0	793	5.20	29.7
Diesel oil[2]	3.03	0.23	0.70	0.93	1.16	20.5	23.3	2.33	27.9
LNG	NE								

[1] tier1 defaults from [2], Chapter: 1.A.3.d.i, 1.A.3.d.ii, 1.A.4.c.iii Navigation: Table 3-1
[2] tier1 defaults from [3], Chapter: 1.A.3.d.i, 1.A.3.d.ii, 1.A.4.c.iii Navigation: Table 3-2

These "country-specific" values are similarily applied for exhaust HMs from ships and vessels in NFR categories 1.A.3.d i, 1.A.3.d ii, 1.A.4.c iii, and 1.A.5.b.

Aircraft in 1.A.3.a and 1.A.5.b

The EMEP/EEA Guidebook 2023 does not provide specific default values for heavy metal emissions from the combustion of jet kerosene and aviation gasoline, stating that for aviation gasoline these emissions are *not estimated* (NE):

Therefore, the inventory compiler decided to adopt the tier1 EF from gasoline fuel used in non-road mobile machinery as a proxy. Although the Party assumes that HM emissions are also likely to occur from the combustion of jet kerosene, no gap-filling is carried out for this fuel. Instead, all heavy metal emission from jet kerosene are reported as *not estimated* (NE).

Table 7: Tier1 default emisison factors applied to aircraft, in g/TJ

	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
Kerosene	NE								
Aviation gasoline	9,481[1]	0.005	0.200	0.007	0.145	0.103	0.053	0.005	0.758

[1] estimated from average lead content of AvGas 100 LL (see also: 1.A.3.a ii (i) and FAQs) of 0.56 g Pb/liter

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[1), 2), 3)] EMEP/EEA, 2023: EMEP/EEA air pollutant emission inventory guidebook 2023; Chapter 1.A - Combustion; URL: https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion, Copenhagen, 2023 & 2024 (road transport).