1.A.3.c - Transport: Railways

Short description

In category *1.A.3.c - Railways*, emissions from fuel combustion in German railways and from the related abrasion and wear of contact line, braking systems and tyres on rails are reported.

Method	AD	EF	Key Category
T1, T2	NS, M	CS, D, M	**L&T**: PM_{10}, $PM_{2.5}$ / **L**: TSP

T = key source by Trend **L** = key source by Level

Methods	
D	Default
RA	Reference Approach
T1	Tier 1 / Simple Methodology *
T2	Tier 2*
T3	Tier 3 / Detailed Methodology *
C	CORINAIR
CS	Country Specific
M	Model
* as described in the EMEP/CORINAIR Emission Inventory Guidebook - 2007, in the group specific chapters.	

AD - Data Source for Activity Data	
NS	National Statistics
RS	Regional Statistics
IS	International Statistics
PS	Plant Specific data
AS	Associations, business organisations
Q	specific questionnaires, surveys

EF - Emission Factors	
D	Default (EMEP Guidebook)
C	Confidential
CS	Country Specific
PS	Plant Specific data

Germany's railway sector is undergoing a long-term modernisation process, aimed at making electricity the main energy source for rail transports. Use of electricity, instead of diesel fuel, to power locomotives has been continually increased, and electricity now provides 80% of all railway traction power. Railways' power stations for generation of traction current are allocated to the stationary component of the energy sector (1.A.1.a) and are not included in the further description that follows here. In energy input for trains of German railways, diesel fuel is the only energy source that plays a significant role apart from electric power.

Methodology

Activity Data

Basically, total inland deliveries of *diesel oil* are available from the National Energy Balances (NEBs) (AGEB, 2019) [1)]. This data is based upon sales data of the Association of the German Petroleum Industry (MWV) [2)]. As a recent revision of MWV data on diesel oil sales for the years 2005 to 2009 has not yet been adopted to the respective NEBs, this original MWV data has been used for this five years.

Data on the consumption of biodiesel in railways is provided in the NEBs as well, from 2004 onward. But as the NEBs do not provide a solid time series regarding most recent years, the data used for the inventory is estimated based on the prescribed shares of biodiesel to be added to diesel oil.

Small quantities of *solid fuels* are used for historical steam engines vehicles operated mostly for tourism and exhibition purposes. Official fuel delivery data are available for lignite, through 2002, and for hard coal, through 2000, from the NEBs. In order to complete these time series, a study was carried out in 2012 by Hedel, R., and Kunze, J. (2012) [3)]. During this study, questionaires were provided to any known operator of historical steam engines in Germany. Here, due to limited data archiving, nearly complete data could only be gained for years as of 2005. For earlier years, in order to achieve a solid time series, conservative gap filling was applied. A follow-up study to gain original cosumption data for 2015 was carried out in 2016 by Illichmann, S. (2016) [4)].

Table 1: Overview of activity-data sources for domestic fuel sales to railway operators

Activity	**data source / quality of activity data**
combustion of:	
Diesel oil	1990-2004: NEB lines 74 and 61: 'Schienenverkehr' / 2005-2009: MWV annual report, table: 'Sektoraler Verbrauch von Dieselkraftstoff' / from 2010: NEB line 61
Biodiesel	calculated from official blending rates
Hard coal	1990-1994: NEB lines 74; 1995-2004: interpolated data; from 2005: original data from studies; 2016: forward extrapolation
Hard coal coke	1990-1997: NEB lines 74 and 61; 1998-2004: interpolated data; from 2005: original data from studies; 2016: forward extrapolation
Raw lignite	from 1990: NEB lines 74 and 61
Lignite briquettes	from 1990: NEB lines 74 and 61
abrasion and wear of contact line, braking systems and tyres on rails:	
transport performance data	in Mio ptkm (performance-ton-kilometers) derived from the TREMOD model

Table 2: Annual fuel consumption in German railways, in terajoules

	1990	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Diesel Oil	38.458	31.054	25.410	18.142	14.626	14.730	13.514	13.771	12.283	13.321	13.775	11.344	9.425	9.531
Biodiesel	0	0	0	401	957	974	890	804	751	727	729	606	548	543
Liquids TOTAL	**38.458**	**31.054**	**25.410**	**18.543**	**15.583**	**15.704**	**14.404**	**14.575**	**13.034**	**14.048**	**14.504**	**11.950**	**9.973**	**10.074**
Lignite Briquettes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raw Lignite	0	86	1	1	1	1	1	1	1	1	1	1	1	1

Hard Coal	576	250	250	255	314	345	357	352	341	339	340	340	340	340
Hard Coal Coke	0	0	431	0	0	0	0	0	0	0	0	0	0	0
Solids TOTAL	**576**	**336**	**682**	**256**	**315**	**346**	**357**	**353**	**342**	**340**	**341**	**341**	**341**	**341**
Σ 1.A.3.c	**39.034**	**62.444**	**51.502**	**37.342**	**31.481**	**31.755**	**29.165**	**29.503**	**26.411**	**28.436**	**29.348**	**24.240**	**20.286**	**20.488**

The use of other fuels – such as vegetable oils or gas – in private narrow-gauge railway vehicles has not been included to date and may still be considered negligible.

Table 3: Annual transport performance, in Mio tkm (ton-kilometers)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Electric Traction	361,515	337,853	361,633	356,605	344,546	342,701	350,085	335,298	331,235	323,387	295,798	296,280	288,336	
Diesel Traction	98,812	58,805	37,237	26,540	26,702	27,403	26,791	23,768	23,734	21,397	21,484	21,365	19,580	
Σ 1.A.3.c	**460,326**	**396,658**	**398,870**	**383,145**	**371,248**	**370,104**	**376,876**	**359,065**	**354,970**	**344,785**	**317,282**	**317,645**	**307,916**	

Regarding particulate-matter and heavy-metal emissions from **abrasion and wear of contact line, braking systems, tyres on rails**, annual transport performances of railway vehicles with electrical and Diesel traction derived from Knörr et al. (2019a) [5)] are applied as activity data.

Emission factors

The (implied) emission factors used here for estimating **emissions from diesel fuel combustion** of very different quality: For main pollutants, CO and PM, annual tier2 IEF computed within the TREMOD model are used, representing the development of German railway fleet, fuel quality and mitigation technologies [6)]. On the other hand, constant default values from (EMEP/EEA, 2019) [7)] are used for all reported PAHs and heavy metals and from Rentz et al. (2008) [8)] regarding PCDD/F. As no emission factors are available for HCB and PCBs, no such emissions have been calculated yet.

Regarding **emissions from solid fuels** used in historic steam engines, all emission factors displayed below have been adopted from small-scale stationary combustion.

Furthermore, regarding **emissions from abrasion and wear**, emission factors are calculated from PM,,10,, emission estimates directly provided by the German railroad company Deutsche Bahn AG. As these original emissions are only available as of 2013, implied EF(PM,,10,,) were calculated from the emission estimates extrapolated backwards from 2013 to 1990 and the transport performance data available from TREMOD. Regarding PM,,2.5,,, and TSP, due to leck of better information, a fractional distribution of 0.5 : 1 : 1 (PM,,2.5,, : PM,,10,, : TSP) is assumed for now. Emission factors for emssions of copper, nickel and chrome are calculated via typical shares of the named metals in the contact line (copper) and in the braking systems (Ni and Cr). Other heavy metals contained in alloys used for the contact line (silver, magnesium, tin) are not taken into account here. Furthermore, emissions from other wear parts (e.g. the current collector) are not estimated. However, these components are not supposed to contain any of the nine heavy metals to be reported here (current collectors are made of aluminium alloys and coal).

Table 3: Annual country-specific emission factors for diesel fuels[1], in kg/TJ

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NH_3	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54
NMVOC	109	100	90,2	64,8	52,0	54,3	44,8	41,9	41,2	38,5	38,2	37,2	35,2	35,0
NO_x	1170	1207	1225	1111	970	990	919	899	886	826	801	775	747	724
SO_x	191	60,5	14,1	0,32	0,32	0,32	0,32	0,32	0,33	0,32	0,33	0,33	0,33	0,33
BC[3]	28,8	28,3	23,8	15,2	11,5	12,0	10,4	9,5	9,3	8,6	8,5	8,0	7,6	7,3
$PM_{2.5}$	44,4	43,6	36,6	23,4	17,7	18,5	16,0	14,6	14,3	13,3	13,1	12,4	11,7	11,2
PM_{10}	44,4	43,6	36,6	23,4	17,7	18,5	16,0	14,6	14,3	13,3	13,1	12,4	11,7	11,2
TSP[2]	44,4	43,6	36,6	23,4	17,7	18,5	16,0	14,6	14,3	13,3	13,1	12,4	11,7	11,2
CO	287	292	255	162	121	121	105	101	98,9	94,7	93,3	92,6	88,5	88,2

[1] due to lack of better information: similar EF are applied for fossil diesel oil and biodiesel
[2] EF($PM_{2.5}$) also applied for PM_{10} and TSP (assumption: >99% of TSP consists of $PM_{2.5}$)
[3] EFs calculated via f-BCs as provided in [9]: diesel fuels: 0.56 (Chapter: 1.A.3.c - Railways, Appendix A: tier1), solid fuels: 0.064 (Chapter: 1.A.4 - Small Combustion: Residential combustion (1.A.4.b): Table 3-3, Zhang et al., 2012)

Table 4: Emission factors applied for solid fuels, in kg/TJ

	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{10}	TSP	BC	CO
Hard coal	4.00	15.0	120	650	222	250	278	14.2	500
Hard coal coke	4.00	0.50	120	500	15.0	15.0	15.0	0.96	1,000

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

With respect to the emission factors applied for particulate matter, given the circumstances during test-bench measurements, condensables are most likely included at least partly. [1]

For information on the **emission factors for heavy-metal and POP exhaust emissions**, please refer to Appendix 2.3 - Heavy Metal (HM) exhaust emissions from mobile sources] and Appendix 2.4 - Persistent Organic Pollutant (POP) exhaust emissions from mobile sources].

Discussion of emission trends

Outcome of Key Category Analysis
L&T: PM_{10}, $PM_{2.5}$ / **L**: TSP

Basically, for all unregulated pollutants, emission trends directly follow the trend in over-all fuel consumption.

Here, as emission factors for solid fuels tend to be much higher than those for diesel oil, emission trends are disproportionately effected by the amount of solid fuels used. Therefore, for the **main pollutants**, **carbon monoxide**, **particulate matter** and **PAHs**, emission trends show remarkable jumps especially after 1995 that result from the significantly higher amounts of solid fuels used.

For all fractions of **particulate matter**, the majority of emissions generally result from abrasion and wear and the combustion of diesel fuels. Additional jumps in the over-all trend result from the use of lignite briquettes (1996-2001). Here, as the EF(BC) for fuel combustion are estimated via fractions provided in [10], black carbon emissions follow the corresponding emissions of PM,,2.5,,.

Due to fuel-sulphur legislation, the trend of **sulphur dioxide** emissions follows not only the trend in fuel consumption but also reflects the impact of regulated fuel-qualities. For the years as of 2005, sulphur emissions from diesel combustion have decreased so strongly, that the over-all trend shows a slight increase again due to the now dominating contribution of sulphur from the use of solid fuels.

Regarding **heavy metals**, emissions from combustion of diesel oil and from abrasion and wear are estimated from tier1 default emission factors. Therefore, the emission trends reflect the development of diesel use and - for copper, chromium and nickel emissions resulting from the abrasion & wear of contact line and braking systems - the annual transport performance (see description of activity data above).

Recalculations

Given the revised NEB 2018, both the**activity data** fo diesel oil and the annual amounts of blended biodiesel were revised accordingly.

<u>Table 5: Revised fuel consumption, in terajoule</u>

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
DIESEL OIL																	
Submission 2021	38.458	31.054	25.410	18.142	17.101	16.730	16.389	14.336	14.626	14.730	13.514	13.771	12.283	13.321	13.775	11.344	9.425
Submission 2020	38.458	31.054	25.410	18.142	17.101	16.730	16.389	14.336	14.626	14.730	13.514	13.771	12.283	13.321	13.775	11.344	10.961
absolute change	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1.536
relative change	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	-14,0%
BIODIESEL																	
Submission 2021	0	0	0	401	503	754	817	996	957	974	890	804	751	727	729	606	548
Submission 2020	0	0	0	397	498	747	810	987	949	966	882	798	745	720	724	602	633
absolute change	0,00	0,00	0,00	4,31	4,71	7,10	6,84	8,99	8,33	8,92	7,53	6,67	6,41	6,55	5,32	3,95	-84,8
relative change				1,09%	0,95%	0,95%	0,84%	0,91%	0,88%	0,92%	0,85%	0,84%	0,86%	0,91%	0,74%	0,66%	-13,4%
TOTAL FUEL CONSUMPTION																	
Submission 2021	39.034	31.390	26.092	18.799	17.867	17.740	17.507	15.655	15.898	16.050	14.761	14.928	13.376	14.388	14.845	12.290	10.314
Submission 2020	39.034	31.390	26.092	18.795	17.862	17.733	17.500	15.646	15.890	16.041	14.754	14.921	13.370	14.381	14.839	12.286	11.934
absolute change	0,00	0,00	0,00	4,31	4,71	7,10	6,84	8,99	8,33	8,92	7,53	6,67	6,41	6,55	5,32	3,95	-1.621
relative change	0,00%	0,00%	0,00%	0,02%	0,03%	0,04%	0,04%	0,06%	0,05%	0,06%	0,05%	0,04%	0,05%	0,05%	0,04%	0,03%	-13,6%

Due to the routine revision of the TREMOD model [11], tier2 **emission factors** changed for recent years. Here, the revision results mainly from the consideration of revised NCvs for diesel oil as provided by the AGEB.

Table 6: Revised country-specific emission factors for diesel fuels, in kg/TJ

	2013	2014	2015	2016	2017	2018
Nitrogen oxides - NO,,x,,						
Submission 2020	41,9	41,2	38,5	38,2	37,2	35,2
Submission 2019	42,2	41,2	38,5	38,2	37,2	35,9
absolute change	-0,24	0,00	0,00	0,01	0,01	-0,68
relative change	-0,56%	0,00%	0,00%	0,03%	0,02%	-1,89%
Non-methane volatile organic compounds - NMVOC						
Submission 2020	899	886	826	801	775	747
Submission 2019	899	886	826	801	775	748
absolute change	0,54	0,00	0,00	0,02	-0,03	-1,38
relative change	0,06%	0,00%	0,00%	0,00%	0,00%	-0,18%
Particulate matter - PM (PM,,2.5,, = PM,,10,, = TSP)						
Submission 2020	14,6	14,3	13,3	13,1	12,4	11,7
Submission 2019	14,7	14,3	13,3	13,1	12,4	11,8
absolute change	-0,05	0,00	0,00	0,00	0,00	-0,07
relative change	-0,31%	0,00%	0,00%	0,01%	0,00%	-0,57%
Black carbon - BC						
Submission 2020	9,52	9,29	8,65	8,48	8,05	7,60
Submission 2019	9,55	9,29	8,65	8,48	8,05	7,64
absolute change	-0,03	0,00	0,00	0,00	0,00	-0,04
relative change	-0,31%	0,00%	0,00%	0,01%	0,00%	-0,57%

Carbon monoxide - CO						
Submission 2020	101	98,9	94,7	93,3	92,6	88,5
Submission 2019	101	98,9	94,7	93,3	92,6	89,6
absolute change	-0,63	0,00	0,00	0,02	0,01	-1,04
relative change	-0,62%	0,00%	0,00%	0,03%	0,01%	-1,16%

For more information on recalculated emission estimates for Base Year and 2018, please see the pollutant-specific recalculation tables following chapter 8.1 - Recalculations

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Uncertainties

Uncertainty estimates for **activity data** of mobile sources derive from research project FKZ 360 16 023 (title: “Ermittlung der Unsicherheiten der mit den Modellen TREMOD und TREMOD-MM berechneten Luftschadstoffemissionen des landgebundenen Verkehrs in Deutschland”) carried out by Knörr et al. (2009) [12].

Planned improvements

Besides the scheduled **routine revision** of TREMOD, no further improvements are planned for the next annual submission.

FAQs

Why are similar EF applied for estimating exhaust heavy metal emissions from both fossil and biofuels?

The EF provided in [13] represent summatory values for (i) the fuel's and (ii) the lubricant's heavy-metal content as well as (iii) engine wear. Here, there might be no heavy metals contained in the biofuels. But since the specific shares of (i), (ii) and (iii) cannot be separated, and since the contributions of lubricant and engine wear might be dominant, the same emission factors are applied to biodiesel.

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During test-bench measurements, temperatures are likely to be significantly higher than under real-world conditions, thus reducing condensation. On the contrary, smaller dillution (higher number of primary particles acting as condensation germs) together with higher pressures increase the likeliness of condensation. So over-all condensables are very likely to occur but different to real-world conditions.