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.

Category Code	Method	AD	EF
1.A.3.c	T1, T2	NS, M	CS, D, M

Method(s) applied	
D	Default
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/EEA Emission Inventory Guidebook - 2019, in category chapters.	
(source for) Activity Data	
NS	National Statistics
RS	Regional Statistics
IS	International Statistics
PS	Plant Specific
As	Associations, business organisations
Q	specific Questionnaires (or surveys)
M	Model / Modelled
C	Confidential
(source for) Emission Factors	
D	Default (EMEP Guidebook)
CS	Country Specific
PS	Plant Specific
M	Model / Modelled
C	Confidential

NO_x	NMVOC	SO_2	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn	PCDD/F	B(a)P	B(b)F	B(k)F	I(x)P	PAH1-4	HCB	PCBs
-/-	-/-	-/-	-/-	**L/-**	**L/-**	**L/-**	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-

L/-	key source by **L**evel only
-/T	key source by **T**rend only
L/T	key source by both **L**evel and **T**rend
-/-	no key source for this pollutant
IE	emission of specific pollutant **I**ncluded **E**lsewhere (i.e. in another category)
NE	emission of specific pollutant **N**ot **E**stimated (yet)
NA	specific pollutant not emitted from this source or activity = **N**ot **A**pplicable
*	no analysis done

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 over 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 following. 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, 2023) [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, studies were carried out in 2012 [3], 2016 [4] and 2021 [5]. During these studies, 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.

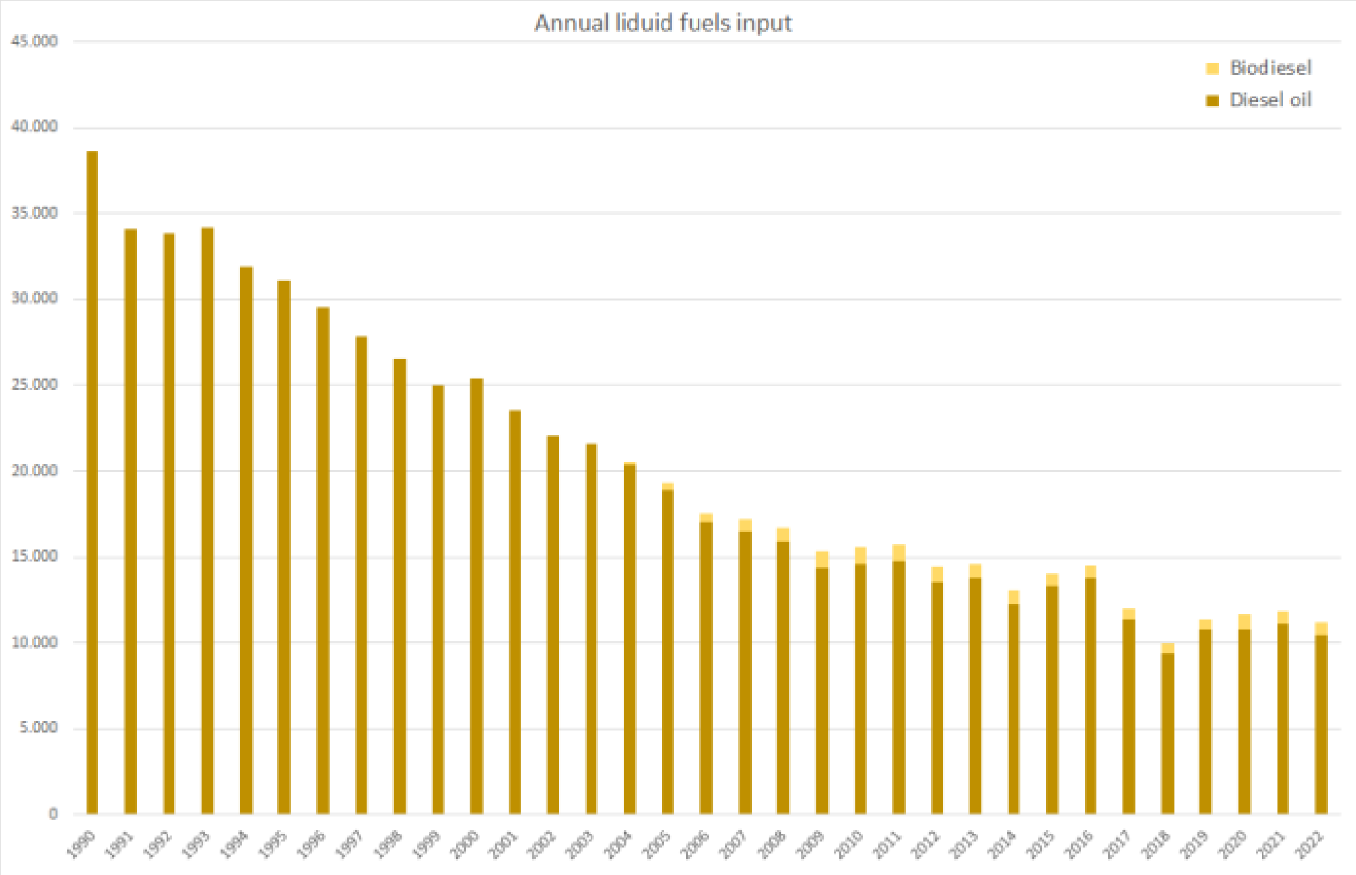
Table 1: Overview of activity-data sources for domestic fuel sales to railway operators

Activity	**data source / quality of activity data**
combustion of:	
Diesel oil	1990-2004: NEB lines 74 & 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 line 74; 1995-2004: interpolation; 2005, 2010, 2015, 2019 and 2020: survey data; as of 2021: extrapolation
Hard coal coke	1990-1997: NEB lines 74 & 61; 1998-2004: interpolation; 2005, 2010, 2015, 2019 and 2020: survey data; as of 2021: extrapolation
Raw lignite	from 1990: NEB lines 74 & 61
Lignite briquettes	from 1990: NEB lines 74 & 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**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Diesel Oil	38,605	31,054	25,410	18,877	14,626	13,321	13,775	11,344	9,425	10,747	10,782	11,072	10,464
Biodiesel				434	976	738	745	618	532	610	882	776	727
Liquids TOTAL	**38,605**	**31,054**	**25,410**	**19,311**	**15,602**	**14,059**	**14,520**	**11,962**	**9,957**	**11,357**	**11,664**	**11,848**	**11,191**
Lignite Briquettes	200	86	1.33	0.79	0.79	0.66	0.63	0.46	0.46	0.43	0.22	0.35	0.35
Hard Coal	576	232	223	267	324	351	361	367	365	362	306	325	325
Hard Coal Coke	2,000	1,309	431	14.6	7.32	0.02	1.19	1.21	1.20	1.20	1.12	1.15	1.15
Solids TOTAL	**2,776**	**1,627**	**655**	**283**	**332**	**352**	**363**	**368**	**367**	**363**	**308**	**327**	**327**
Σ 1.A.3.c	**41,381**	**32,681**	**26,065**	**19,594**	**15,934**	**14,411**	**14,883**	**12,331**	**10,324**	**11,720**	**11,972**	**12,175**	**11,518**

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.



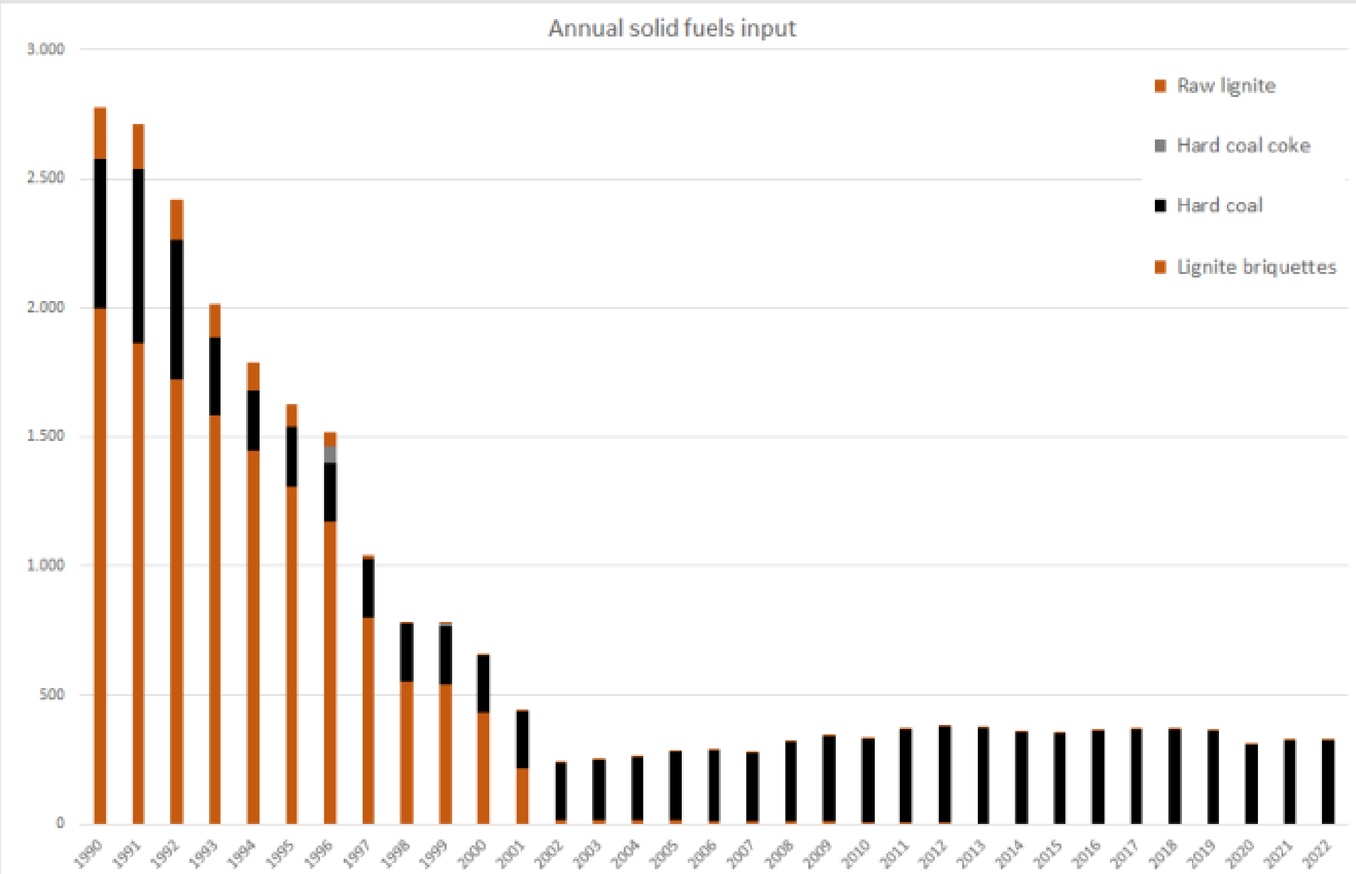


Table 3: Annual transport performance by mode of traction, in Mio tkm (ton-kilometers)

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Diesel	98,812	58,805	37,237	26,540	26,702	21,397	21,484	21,365	19,580	18,058	16,917	23,028	22,733
Electric	361,515	337,853	361,633	356,605	344,546	323,387	295,798	296,280	288,336	281,130	262,268	277,395	288,761

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
Σ 1.A.3.c	**460,326**	**396,658**	**398,870**	**383,145**	**371,248**	**344,785**	**317,282**	**317,645**	**307,916**	**299,188**	**279,184**	**300,423**	**311,494**

Transport performance showed only a moderate pandemic-related decrease in 2020 and has fully recovered in 2021 and 2022.

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. (2023a) [6)] are applied as activity data.

Emission factors

The (implied) emission factors used here for estimating **emissions from diesel fuel combustion** are of very different quality:

For the 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 [7)]. On the other hand, constant default values from (EMEP/EEA, 2019) [8)] are used for all reported PAHs and heavy metals and from Rentz et al. (2008) [9)] 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	2015	2016	2017	2018	2019	2020	2021	2022
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
NMVOC	109	100	90.2	64.8	52.0	39.2	39.0	37.8	36.8	36.3	37.7	37.1	34.7
NO_x	1,170	1,207	1,225	1,111	970	826	802	776	749	707	741	744	697
SO_x	196	60.5	14.1	0.32	0.32	0.32	0.33	0.33	0.33	0.33	0.33	0.33	0.33
PM[2]	44.4	43.6	36.6	23.4	17.7	13.3	13.1	12.4	11.8	11.4	12.2	12.2	11.2
BC[3]	28.8	28.3	23.8	15.2	11.5	8.67	8.52	8.05	7.70	7.40	7.90	7.94	7.27
CO	287	292	255	162	121	95.8	94.6	93.6	90.9	89.8	90.3	90.0	87.5

[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 [10)]: 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 5: 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.

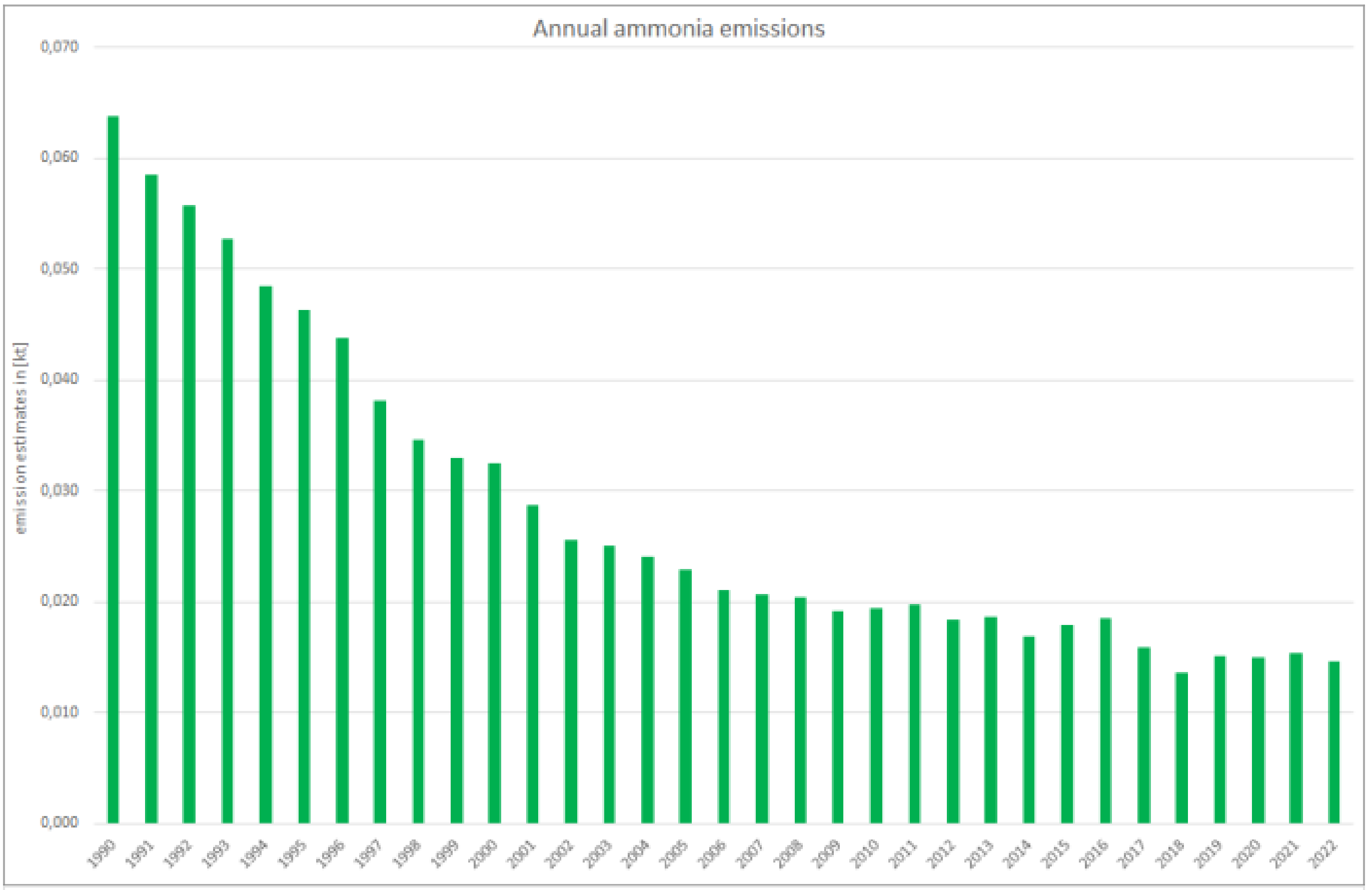
Discussion of emission trends

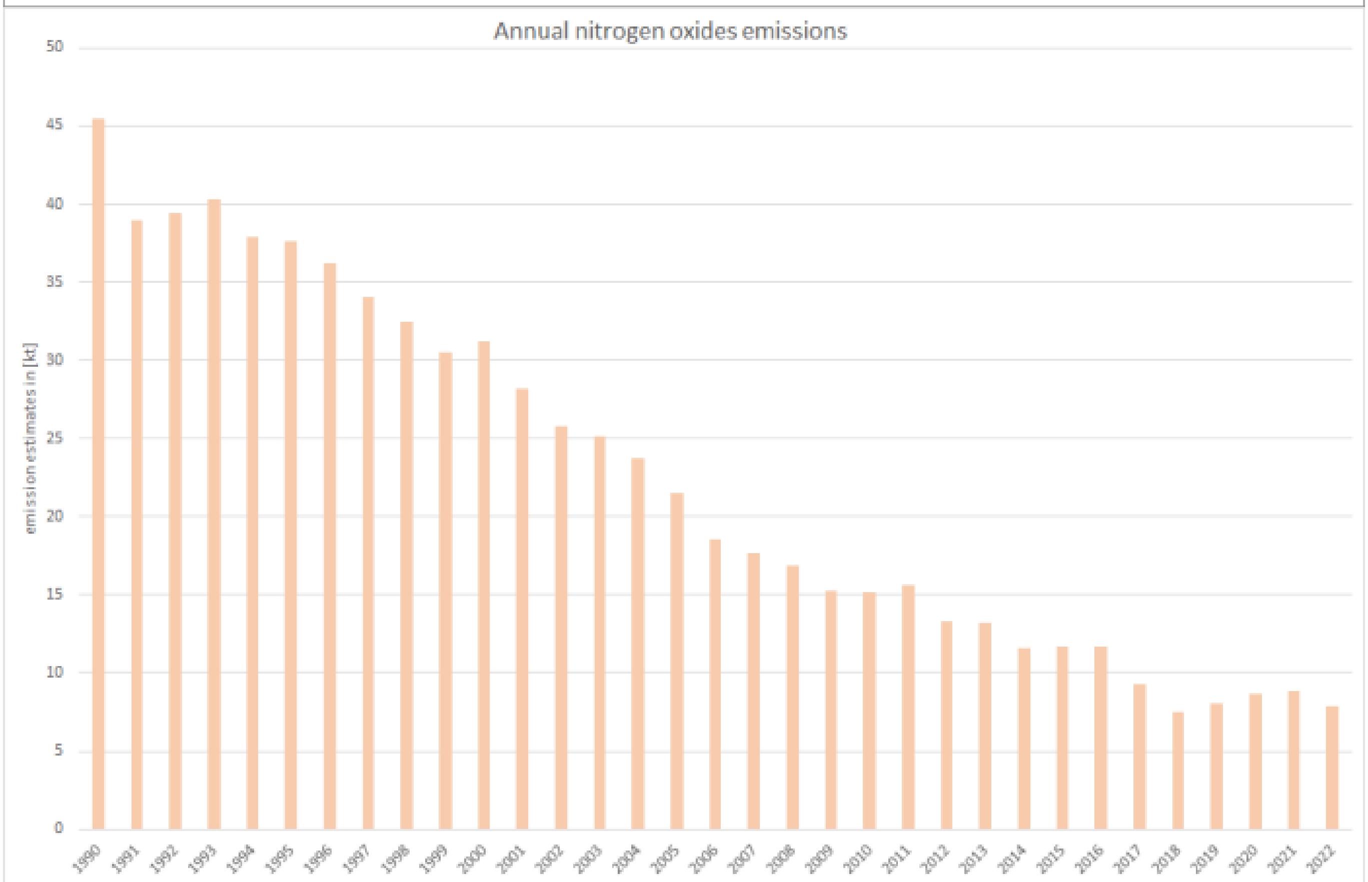
Table 6: Outcome of Key Category Analysis

for:	**TSP**	**PM_{10}**	**$PM_{2.5}$**
by:	Level	L/-	L/-

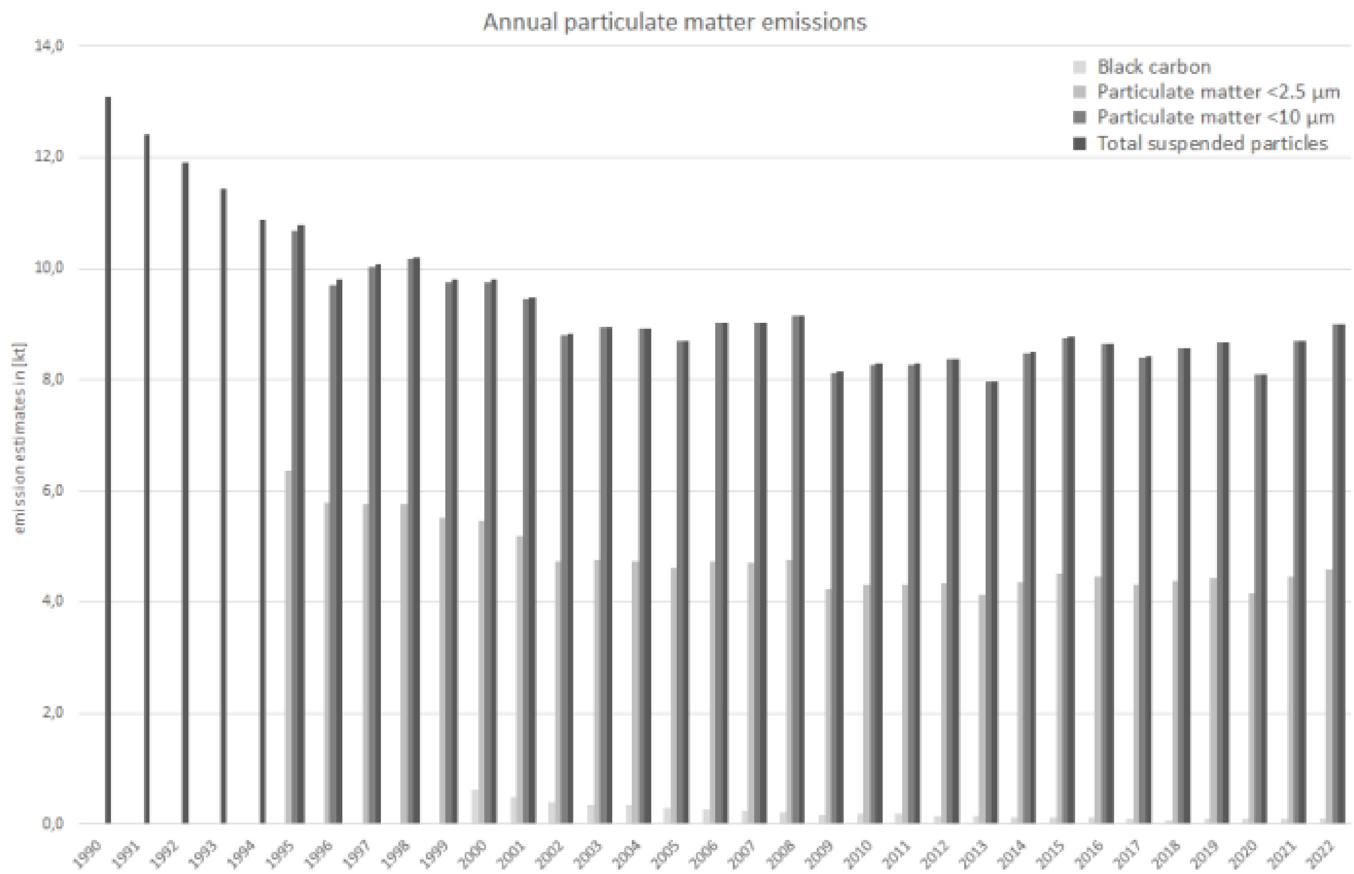
Basically, for all unregulated pollutants, emission trends directly follow the trend in over-all fuel consumption.

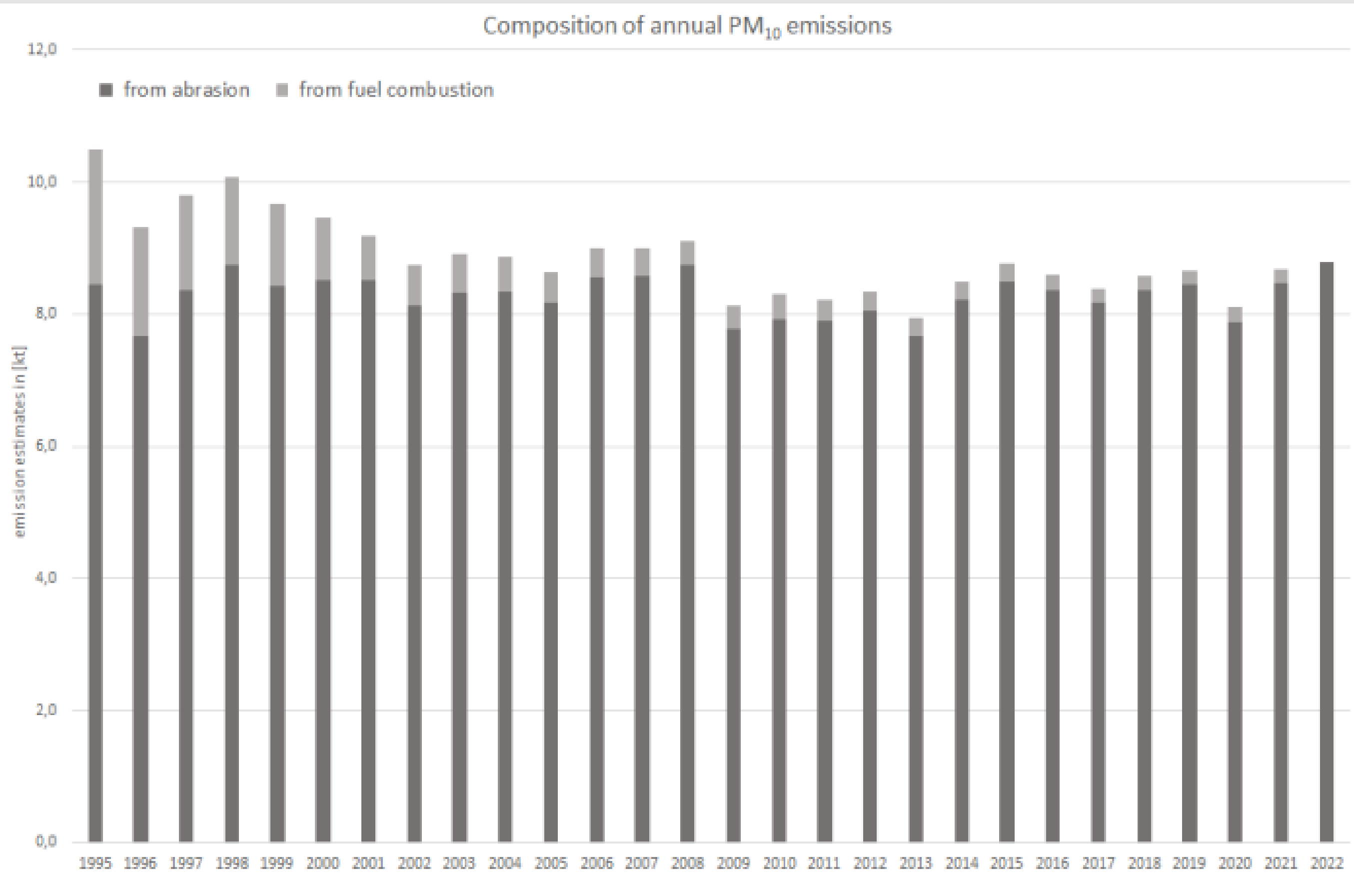
Here, as emission factors for solid fuels tend to be much higher than those for diesel oil, emission trends are disproportionately effected by the amount of solid fuels used. Therefore, for the **main pollutants**, **carbon monoxide**, **particulate matter** and **PAHs**, emission trends show remarkable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



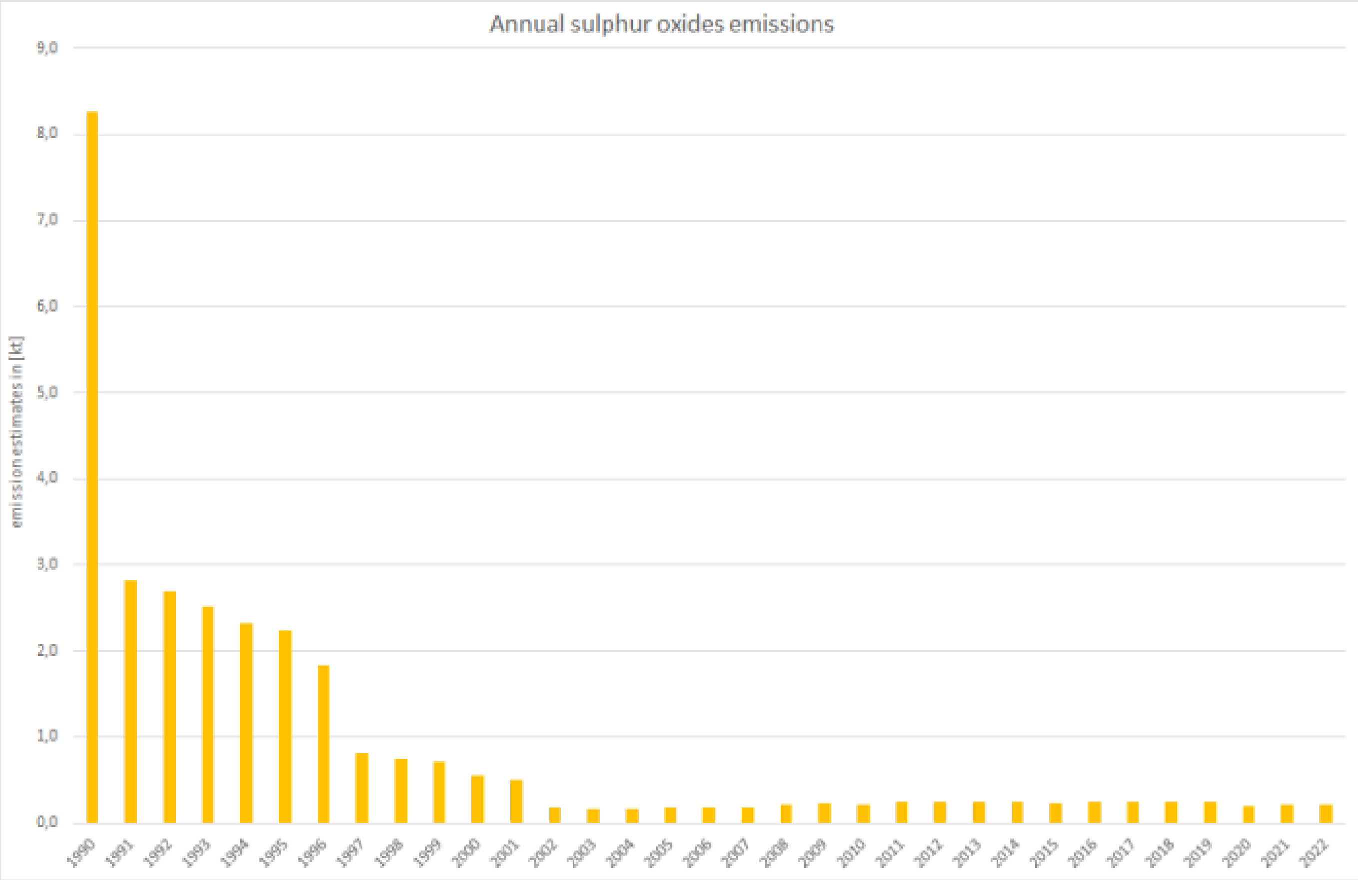


For all fractions of **particulate matter**, the majority of emissions generally result from abrasion and wear and the combustion of diesel fuels. Additional jumps in the over-all trend result from the use of lignite briquettes (1996-2001). Here, as the EF(BC) for fuel combustion are estimated via fractions provided in [11)], black carbon emissions follow the corresponding emissions of $PM_{2.5}$.

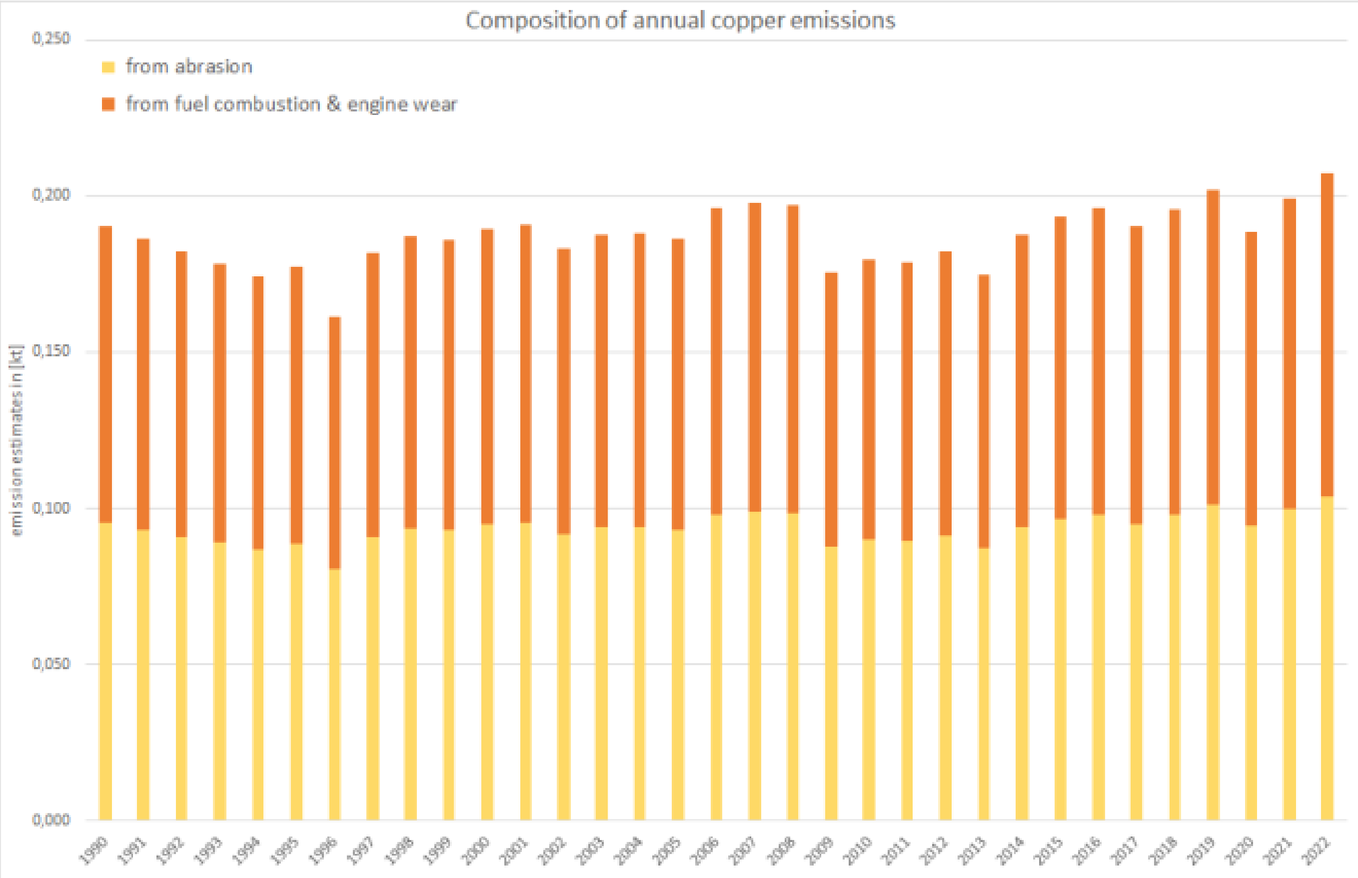




Due to fuel-sulphur legislation, the trend of **sulphur dioxide** emissions follows not only the trend in fuel consumption but also reflects the impact of regulated fuel-qualities. For the years as of 2005, sulphur emissions from diesel combustion have decreased so strongly, that the over-all trend shows 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

Activity data have been recalculated widely due to the revision of the National Energy Balances (NEB) 2003 to 2021. In addition, for 1990, the (erroneous) value applied so far has been replaced with the original NEB value.

Table 5: Revised fuel consumption data 2020, in terajoule

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
current submission	41,381	32,681	26,065	19,594	15,934	14,411	14,883	12,331	10,324	11,720	11,972	12,175
previous submission	41,234	32,681	26,065	18,826	15,915	14,400	14,867	12,318	10,340	11,722	11,985	12,168
absolute change	147	0	0	768	19.1	11.3	16.3	12.6	-16.1	-2.51	-13.6	7.23
relative change	0.36%	0.00%	0.00%	4.08%	0.12%	0.08%	0.11%	0.10%	-0.16%	-0.02%	-0.11%	0.06%

Furthermore, due to the routine revision of the TREMOD model [12], tier2 **emission factors** changed for recent years.

In addition, the transport performance data as activity data for the estimation of abrasive emissions from current line, wheels and brakes have been revised for more recent years:

Table 7: Revised transport performance data 2017-2021, in [Mio km]

	2017	2018	2019	2020	2021
current submission	317,645	307,916	299,188	279,184	300,423
previous submission	317,282	317,645	307,916	299,188	279,184
absolute change	363	-9,729	-8,728	-20,004	21,239
relative change	0.11%	-3.06%	-2.83%	-6.69%	7.61%

Abrasive particulate matter and heavy metal emissions were revised accordingly.

For **pollutant-specific information on recalculated emission estimates for Base Year and 2021**, please see the recalculation tables following chapter 8.1 - Recalculations.

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) [13].

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 the 2019 EMEP/EEA Guidebook [14] 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.

[1] AGEB, 2023: Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen (Hrsg.), AGEB): Energiebilanz für die Bundesrepublik Deutschland; https://ag-energiebilanzen.de/daten-und-fakten/bilanzen-1990-bis-2030/?wpv-jahresbereich-bilanz=2021-2030, (Aufruf: 12.12.2023), Köln & Berlin, 2023
[2] MWV (2021): Association of the German Petroleum Industry (Mineralölwirtschaftsverband, MWV): Annual Report 2018, page 65, Table 'Sektoraler Verbrauch von Dieselkraftstoff 2012-2019'; URL: https://www.mwv.de/wp-content/uploads/2020/09/MWV_Mineraloelwirtschaftsverband-e.V.-Jahresbericht-2020-Webversion.pdf, Berlin, 2021.
[3] Hedel, R., & Kunze, J. (2012): Recherche des jährlichen Kohleeinsatzes in historischen Schienenfahrzeugen seit 1990. Probst & Consorten Marketing-Beratung. Dresden, 2012.
[4] Illichmann, S. (2016): Recherche des Festbrennstoffeinsatzes historischer Schienenfahrzeuge in Deutschland 2015, Probst & Consorten Marketing-Beratung. Study carried out for UBA; FKZ 363 01 392; not yet published; Dresden, 2016.
[5] Hasenbalg (2021): Recherche des Festbrennstoffeinsatzes historischer Schienenfahrzeuge in Deutschland 2019 & 2020, Probst & Consorten Marketing-Beratung. Study carried out for UBA; FKZ 363 01 392; not yet published; Dresden, 2021.
[6], [7], [12] Knörr et al. (2023a): Knörr, W., Heidt, C., Gores, S., & Bergk, F.: ifeu Institute for Energy and Environmental Research (Institut für Energie- und Umweltforschung Heidelberg gGmbH, ifeu): Fortschreibung des Daten- und Rechenmodells: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2035, sowie TREMOD, im Auftrag des Umweltbundesamtes, Heidelberg & Berlin, 2022.
[8], [11], [14] EMEP/EEA (2019): EMEP/EEA air pollutant emission inventory guidebook 2019, https://www.eea.europa.eu/publications/emep-eea-guidebook-2019/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-c-railways/view; Copenhagen, 2019.
[9] Rentz et al. (2008): Nationaler Durchführungsplan unter dem Stockholmer Abkommen zu persistenten organischen Schadstoffen (POPs), im Auftrag des Umweltbundesamtes, FKZ 205 67 444, UBA Texte | 01/2008, January 2008 - URL: http://www.umweltbundesamt.de/en/publikationen/nationaler-durchfuehrungsplan-unter-stockholmer
[10] (bibcite 6)
[13] Knörr et al. (2009): Knörr, W., Heldstab, J., & Kasser, F.: Ermittlung der Unsicherheiten der mit den Modellen TREMOD und TREMOD-MM berechneten Luftschadstoffemissionen des landgebundenen Verkehrs in Deutschland; final report; URL: https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/3937.pdf, FKZ 360 16 023, Heidelberg & Zürich, 2009.
[1]

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.