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				
	NO_x	NMVOC	SO_2	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO	PB	Cd	Hg	Diox	PAH	HCB
Key Category:	-/-	-/-	-/-	-/-	L/-	L/-	L/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-

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

Methods	
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 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 (or surveys)
M	Model / Modelled
C	Confidential

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

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, 2022) [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 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

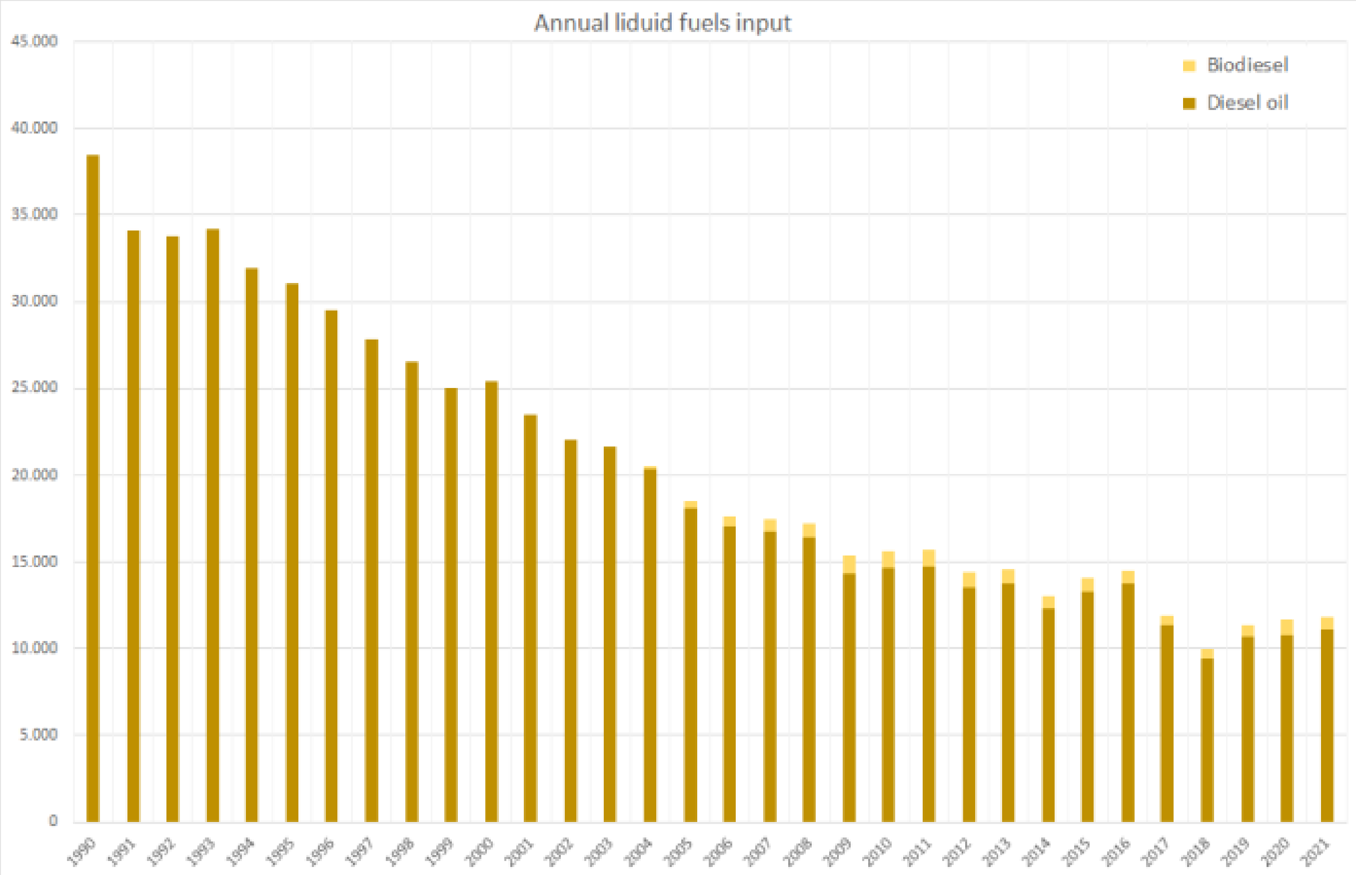
Table 2: Annual fuel consumption in German railways, in terajoules

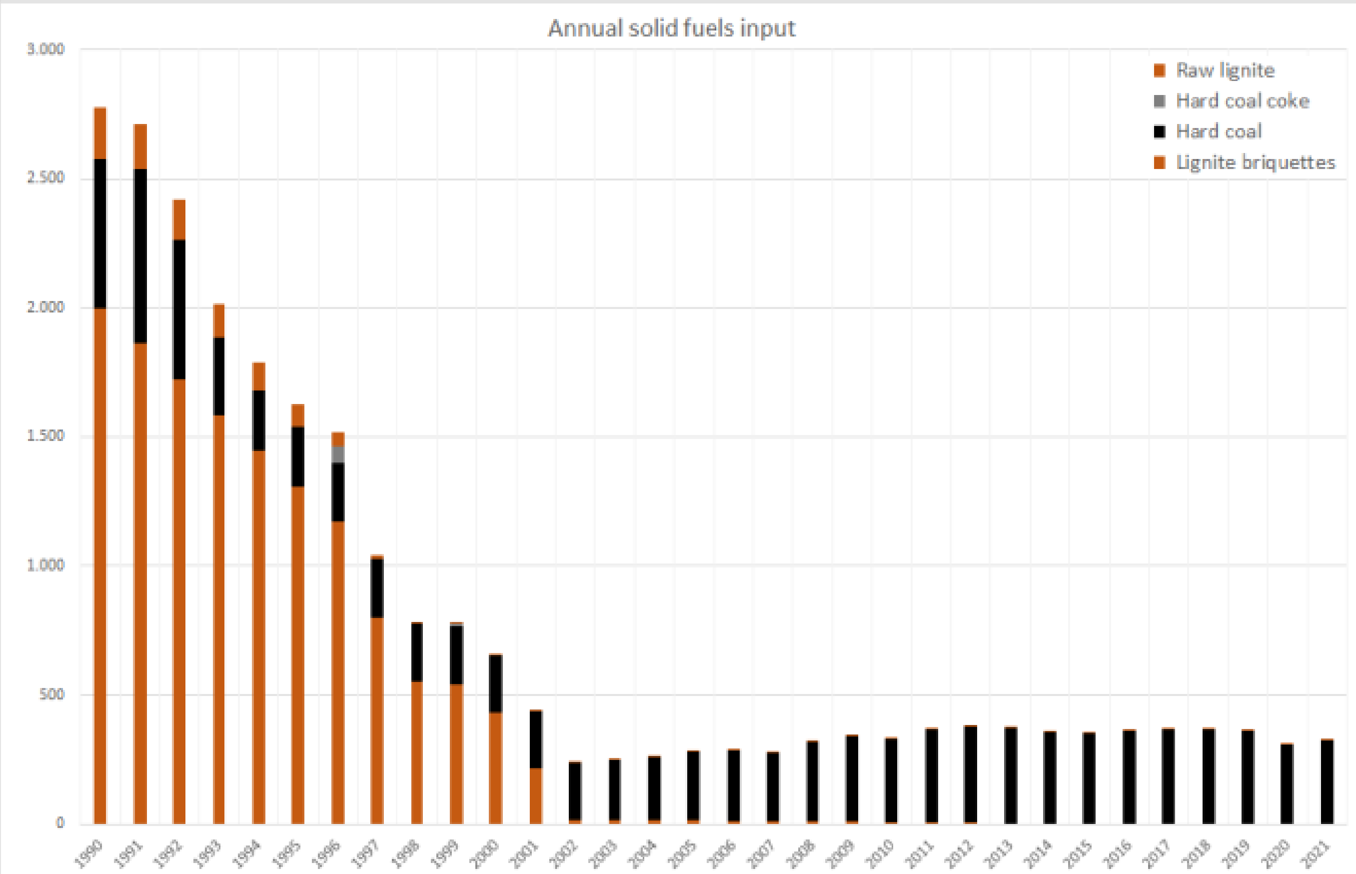
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Diesel Oil	38,458	31,054	25,410	18,142	14,626	13,321	13,775	11,344	9,425	10,747	10,782	11,072	
Biodiesel	0	0	0	401	957	727	729	606	548	612	896	769	
Liquids TOTAL	**38,458**	**31,054**	**25,410**	**18,543**	**15,583**	**14,048**	**14,504**	**11,950**	**9,973**	**11,359**	**11,678**	**11,841**	
Lignite Briquettes	0	0	0	0	0	0	0	0	0	0	0	0	
Raw Lignite	200	86	1.33	0.79	0.79	0.66	0.63	0.46	0.46	0.43	0.22	0.35	
Hard Coal	576	232	223	267	324	351	361	367	365	362	306	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	
Solids TOTAL	**2,776**	**1,627**	**655**	**283**	**332**	**352**	**363**	**368**	**367**	**363**	**308**	**327**	
Σ 1.A.3.c	**41,234**	**32,681**	**26,065**	**18,826**	**15,915**	**14,400**	**14,867**	**12,318**	**10,340**	**11,722**	**11,985**	**12,168**	

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	21,484	21,365	19,580	18,058	16,917	
Electric	361,515	337,853	361,633	356,605	344,546	323,387	295,798	295,798	296,280	288,336	281,130	262,268	
Σ 1.A.3.c	**460.326**	**396.658**	**398.870**	**383.145**	**371.248**	**344.785**	**317.282**	**317.282**	**317.645**	**307.916**	**299.188**	**279.184**	





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. (2022a) [6] 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 [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**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
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	0.54	0.54
NMVOC	109	100	90.2	64.8	52.0	54.1	44.7	42.2	41.6	39.2	39.0	37.8	36.8	36.3	37.7	36.8
NO_x	1170	1207	1225	1111	970	989	919	899	885	826	802	776	749	707	741	744
SO_x	196	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	0.33	0.33
BC[3]	28.8	28.3	23.8	15.2	11.5	12.0	10.4	9.5	9.3	8.67	8.52	8.05	7.70	7.40	7.90	7.90
PM	44.4	43.6	36.6	23.4	17.7	18.4	16.0	14.7	14.3	13.3	13.1	12.4	11.8	11.4	12.2	12.2
CO	287	292	255	162	121	121	105	101	99.6	95.8	94.6	93.6	90.9	89.8	90.3	89.6

[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.

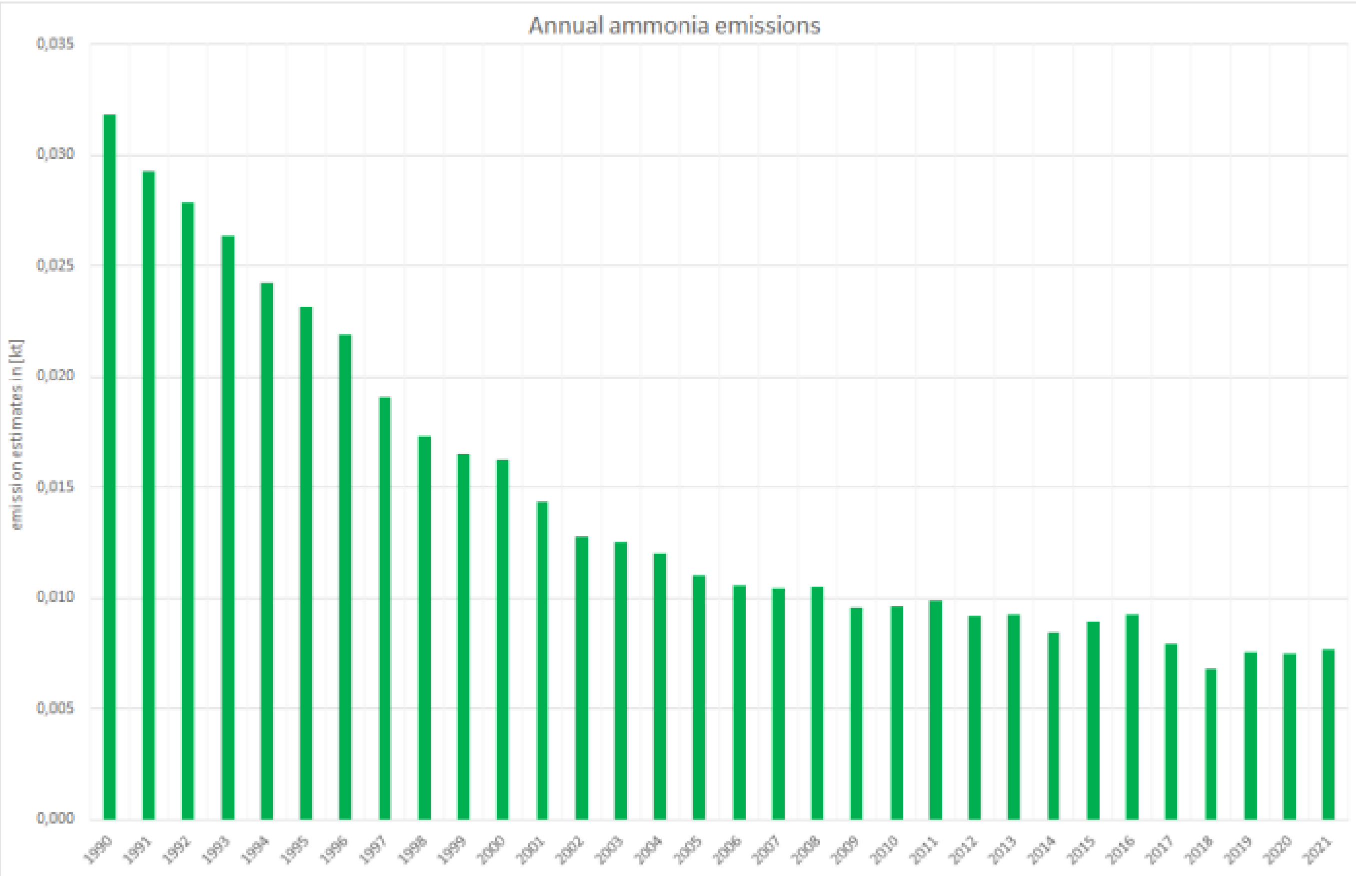
Discussion of emission trends

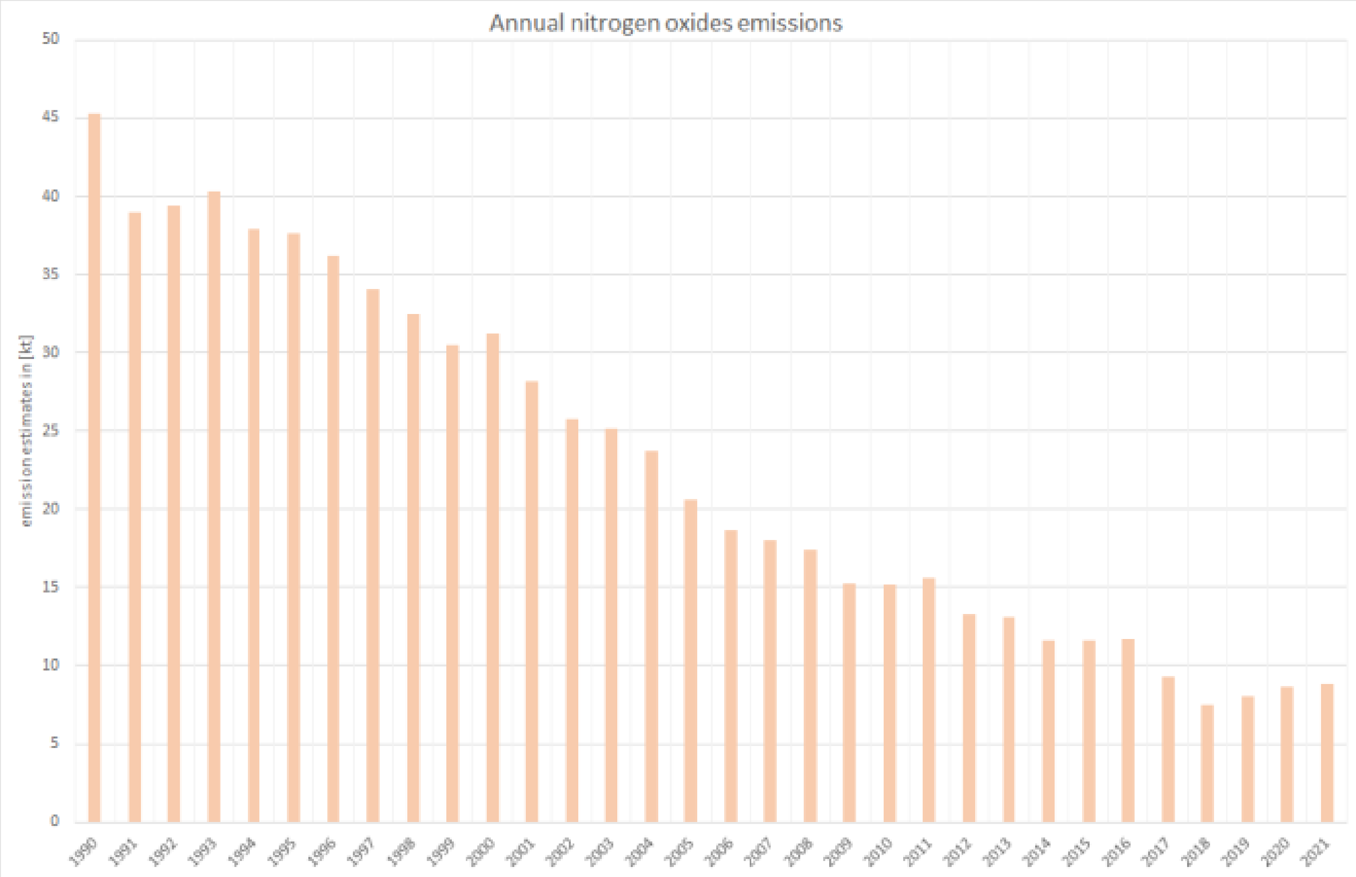
Table 6: Outcome of Key Category Analysis

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

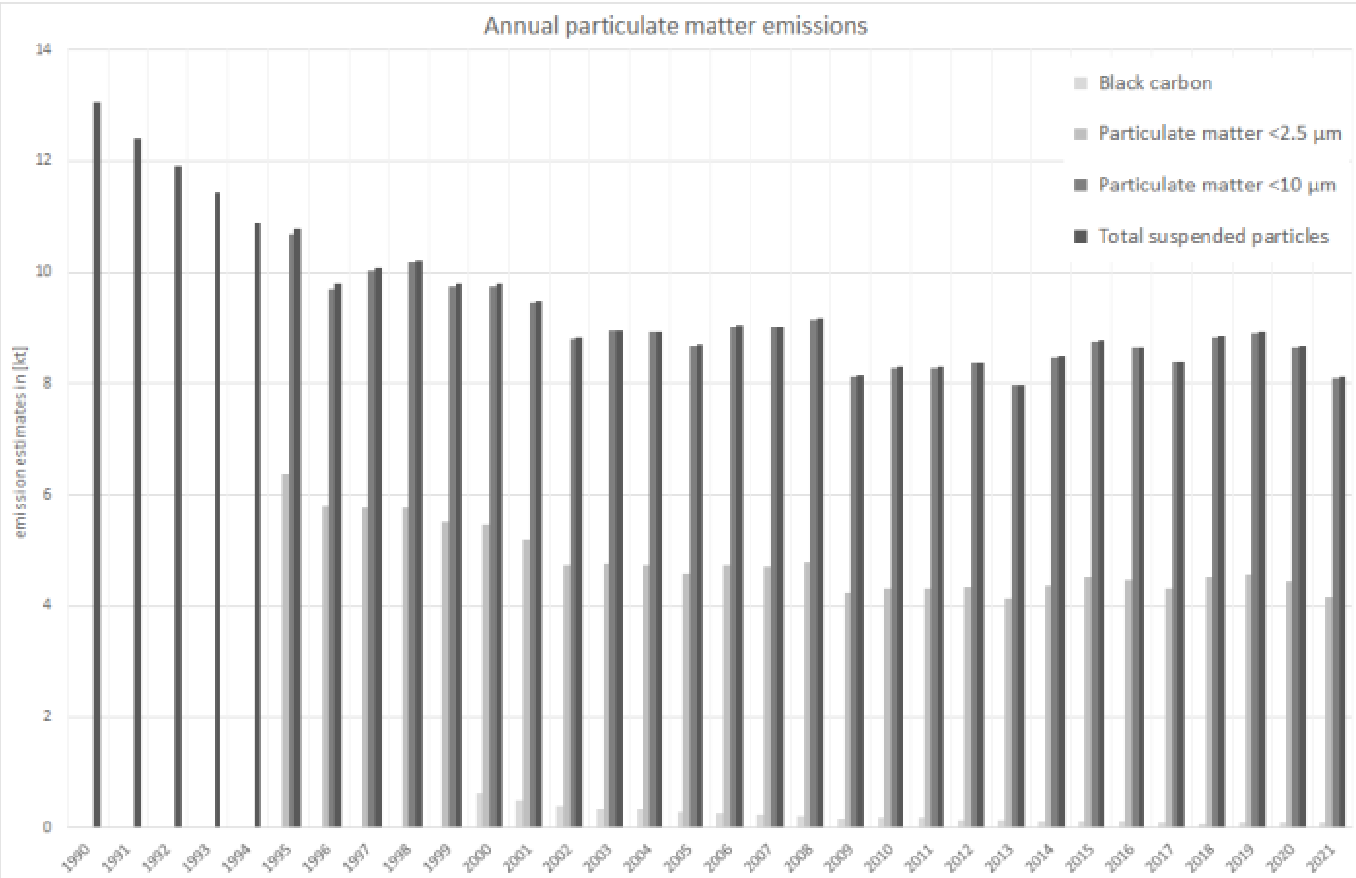
Basically, for all unregulated pollutants, emission trends directly follow the trend in over-all fuel consumption.

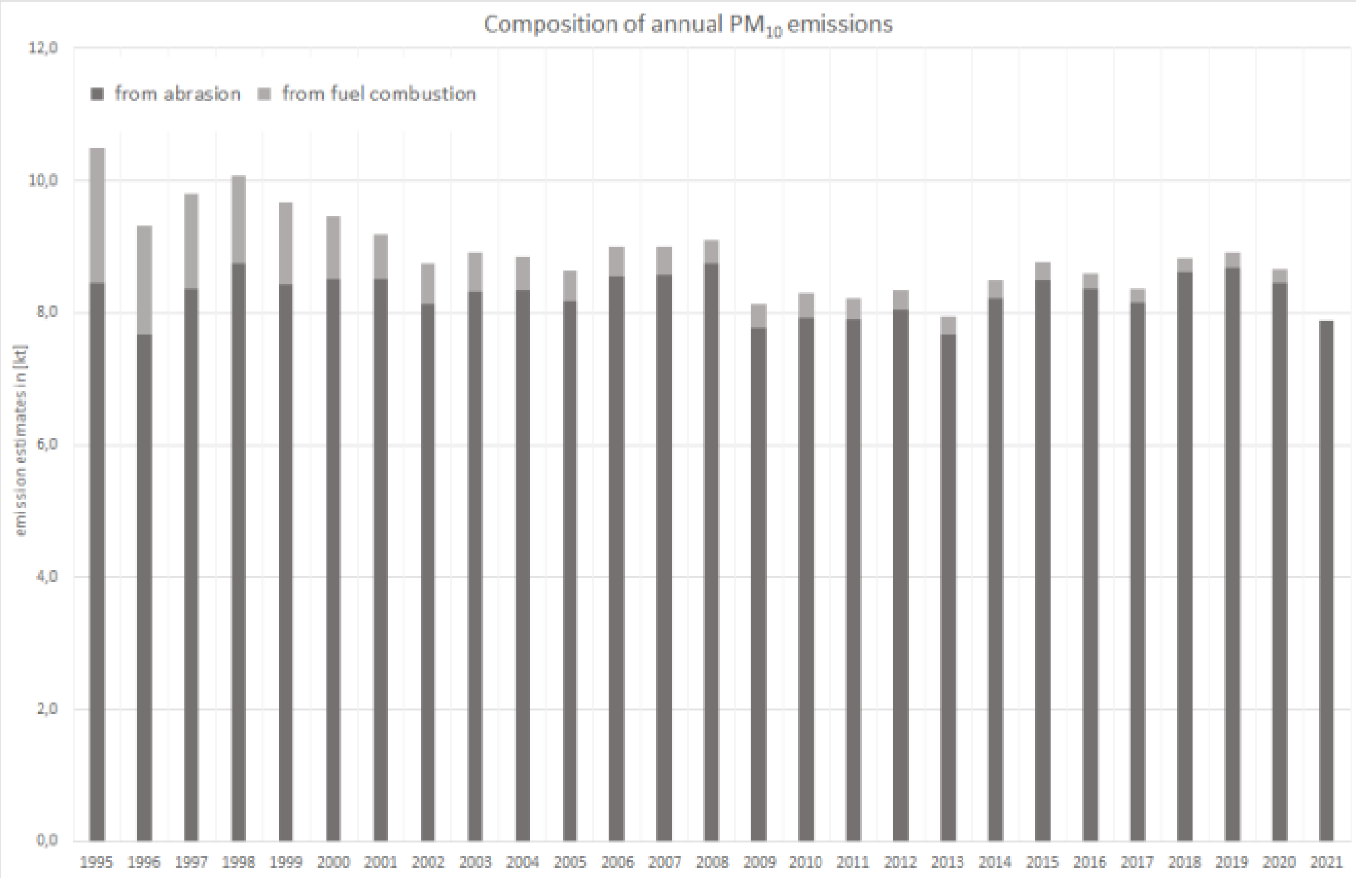
Here, as emission factors for solid fuels tend to be much higher than those for diesel oil, emission trends are disproportionately effected by the amount of solid fuels used. Therefore, for the **main pollutants**, **carbon monoxide**, **particulate matter** and **PAHs**, emission trends show remarkable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



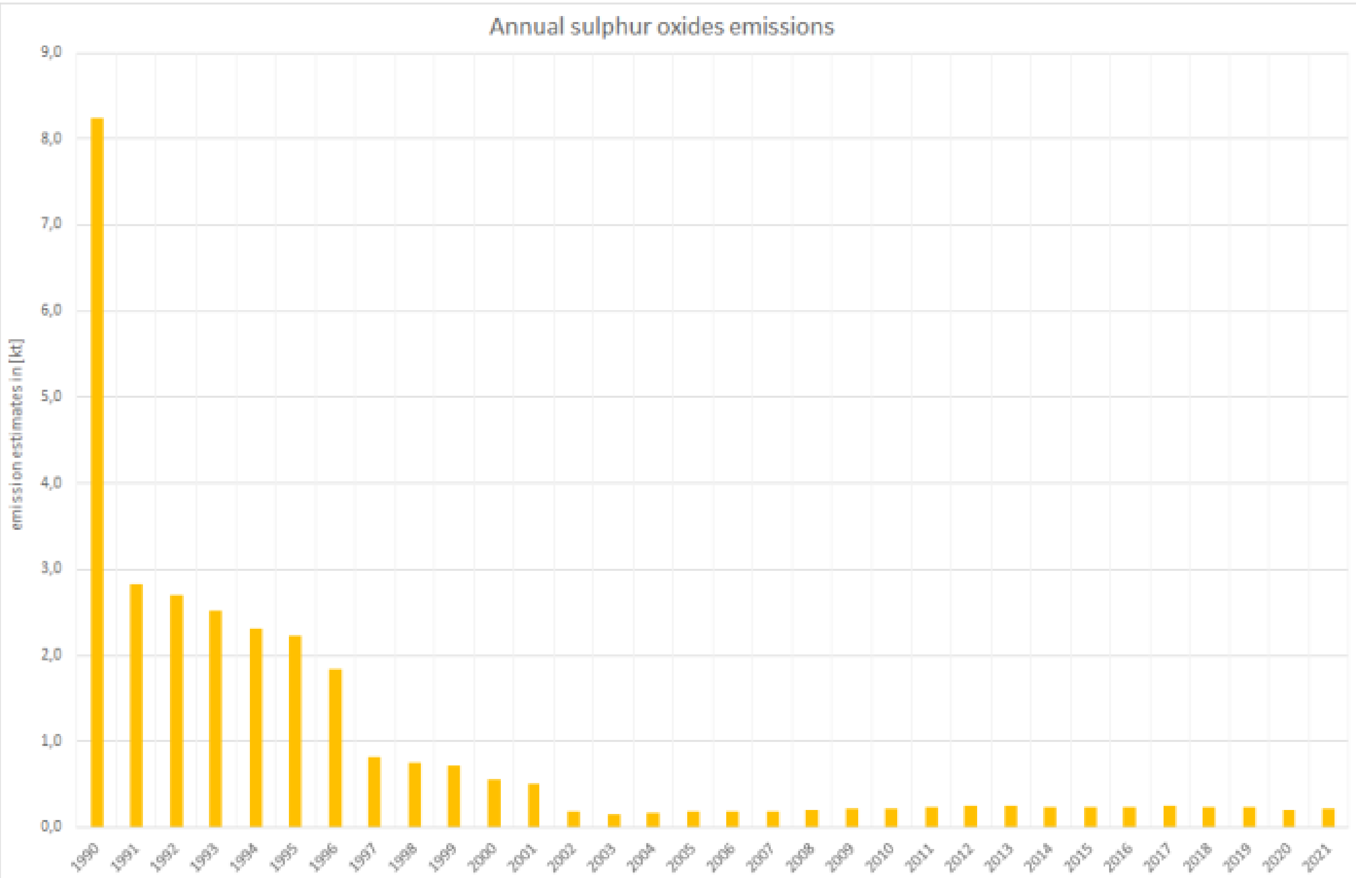


For all fractions of **particulate matter**, the majority of emissions generally result from abrasion and wear and the combustion of diesel fuels. Additional jumps in the over-all trend result from the use of lignite briquettes (1996-2001). Here, as the EF(BC) for fuel combustion are estimated via fractions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

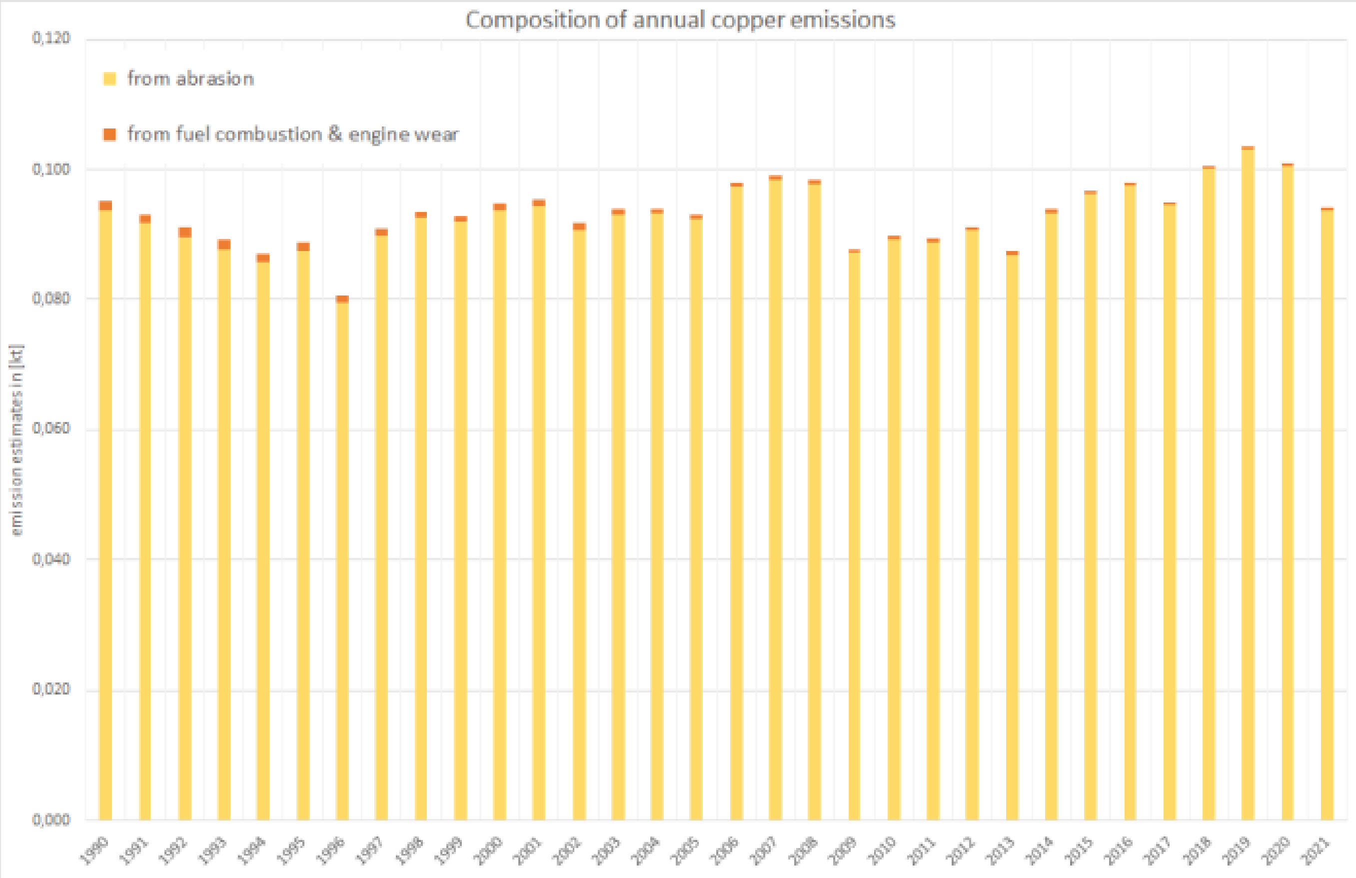




Due to fuel-sulphur legislation, the trend of **sulphur dioxide** emissions follows not only the trend in fuel consumption but also reflects the impact of regulated fuel-qualities. For the years as of 2005, sulphur emissions from diesel combustion have decreased so strongly, that the over-all trend shows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

Given the revised NEB 2020, both the **activity data** for diesel oil and the annual amounts of blended biodiesel were revised accordingly.

Table 5: Revised fuel consumption data 2020, in terajoule

	DIESEL OIL	BIODIESEL	SOLID FUELS	Σ
current submission	10,782	896	308	11,985
previous submission	10,145	843	308	11,295
absolute change	637	52.9	0	690
relative change	6.28%	6.27%	0.00%	6.11%

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

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

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Non-methane volatile organic compounds - NMVOC															
current submission	109	100	90.2	64.8	52.0	54.1	44.7	42.2	41.6	39.2	39.0	37.8	36.8	36.3	37.7
previous submission	109	100	90.2	64.8	52.0	54.1	44.7	41.9	41.2	38.5	38.2	37.2	35.2	34.2	35.6
absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.49	0.68	0.78	0.58	1.55	2.11	2.15

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.82%	1.18%	1.76%	2.03%	1.56%	4.42%	6.19%	6.04%
Nitrogen oxides - NO_x															
current submission	1.170	1.207	1.225	1.111	970	989	919	899	885	826	802	776	749	707	741
previous submission	1.170	1.207	1.225	1.111	970	989	919	899	887	826	801	775	747	699	737
absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.34	-1.32	-0.12	0.99	0.60	2.82	7.51	4.15
relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.04%	-0.15%	-0.01%	0.12%	0.08%	0.38%	1.07%	0.56%
Black carbon - BC															
current submission	28.8	28.3	23.8	15.2	11.5	12.0	10.4	9.5	9.3	8.67	8.52	8.05	7.70	7.40	7.90
previous submission	28.8	28.9	24.2	16.1	11.4	11.5	12.0	10.4	9.5	9.29	8.65	8.48	8.05	7.60	7.18
absolute change	0.00	-0.62	-0.44	-0.91	0.09	0.49	-1.62	-0.83	-0.20	-0.61	-0.12	-0.44	-0.35	-0.20	0.72
relative change	0.00%	-2.15%	-1.80%	-5.65%	0.78%	4.27%	-13.5%	-8.04%	-2.12%	-6.61%	-1.40%	-5.13%	-4.37%	-2.57%	10.04%
Particulate matter - PM ($PM_{2.5}$ = PM_{10} = TSP)															
current submission	44.4	43.6	36.6	23.4	17.7	18.4	16.0	14.7	14.3	13.3	13.1	12.4	11.8	11.4	12.2
previous submission	44.4	43.6	36.6	23.4	17.7	18.4	16.0	14.6	14.3	13.3	13.1	12.4	11.7	11.0	11.8
absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.04	0.06	0.00	0.15	0.34	0.35
relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.33%	0.23%	0.32%	0.46%	0.00%	1.29%	3.10%	2.96%
Carbon monoxide - CO															
current submission	287	292	255	162	121	121	105	101	100	95.8	94.6	93.6	90.9	89.8	90.3
previous submission	287	292	255	162	121	121	105	101	99	94.6	93.3	92.6	88.5	87.0	87.2
absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.78	1.16	1.34	1.08	2.43	2.80	3.04
relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.52%	0.79%	1.23%	1.43%	1.17%	2.75%	3.22%	3.49%

Furthermore, 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, in [Mio km]

	2015	2016	2017	2018	2019	2020
current submission	344.785	317.282	317.282	317.645	307.916	299.188
previous submission	344.785	317.282	317.645	307.916	299.188	279.184
absolute change	0,00	0,00	-363	9.729	8.728	20.003
relative change	0,00%	0,00%	-0,11%	3,16%	2,92%	7,16%

Abrasive particulate matter and heavy metal emissions were revised accordingly.

For **pollutant-specific information on recalculated emission estimates for Base Year and 2020**, 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.

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[1] AGEB, 2022: Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen (Hrsg.), AGEB): Energiebilanz für die Bundesrepublik Deutschland; https://ag-energiebilanzen.de/daten-und-fakten/bilanzen-1990-bis-2020/?wpv-jahresbereich-bilanz=2011-2020, (Aufruf: 23.11.2022), Köln & Berlin, 2022

[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], [12] Knörr et al. (2021a): Knörr, W., Heidt, C., Gores, S., & Bergk, F.: Fortschreibung des Daten- und Rechenmodells: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2035, sowie TREMOD, im Auftrag des Umweltbundesamtes, Heidelberg [u.a.]: Ifeu Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg & Berlin, 2022.

[7] (bibcite 4)

[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.