

# 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				
Key Category	SO <sub>2</sub>	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	BC	Pb	Hg	Cd	Diox	PAH	HCB	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>
1.A.3.c	-/-	-/T	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-	L/-	L/-	L/-

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

Methods	
<b>D</b>	Default
<b>RA</b>	Reference Approach
<b>T1</b>	Tier 1 / Simple Methodology *
<b>T2</b>	Tier 2*
<b>T3</b>	Tier 3 / Detailed Methodology *
<b>C</b>	CORINAIR
<b>CS</b>	Country Specific
<b>M</b>	Model

\* as described in the EMEP/CORINAIR Emission Inventory Guidebook - 2007, in the group specific chapters.

AD - Data Source for Activity Data	
<b>NS</b>	National Statistics
<b>RS</b>	Regional Statistics
<b>IS</b>	International Statistics
<b>PS</b>	Plant Specific data
<b>AS</b>	Associations, business organisations
<b>Q</b>	specific questionnaires, surveys
EF - Emission Factors	
<b>D</b>	Default (EMEP Guidebook)
<b>C</b>	Confidential
<b>CS</b>	Country Specific
<b>PS</b>	Plant Specific data

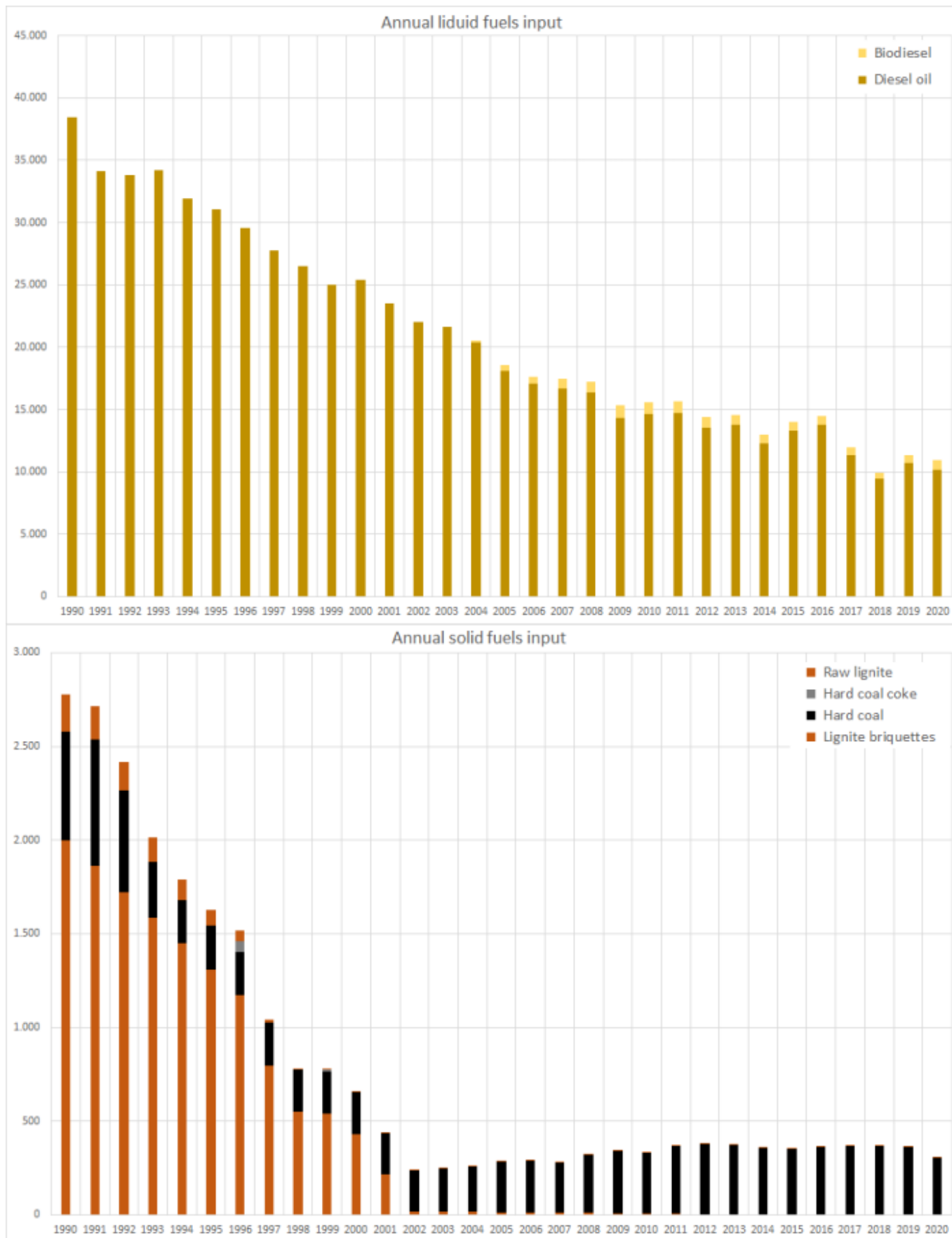
Germany's railway sector is undergoing a long-term modernisation process, aimed at making electricity the main energy source for rail transports. Use of electricity, instead of diesel fuel, to power locomotives has been continually increased, and electricity now provides 80% of all railway traction power. 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, 2021) <sup>1)</sup>. This data is based upon sales data of the Association of the German Petroleum Industry (MWV) <sup>2)</sup>. 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.





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. (2021a) <sup>6)</sup> 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 <sup>7)</sup>. On the other hand, constant default values from (EMEP/EEA, 2019) <sup>8)</sup> are used for all reported PAHs and heavy metals and from Rentz et al. (2008) <sup>9)</sup> 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<sub>10</sub> 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<sub>10</sub>) were calculated from the emission estimates extrapolated backwards from 2013 to 1990 and the transport performance data available from TREMOD.

Regarding PM<sub>2.5</sub> and TSP, due to lack of better information, a fractional distribution of 0.5 : 1 : 1 (PM<sub>2.5</sub> : PM<sub>10</sub> : TSP) is assumed for now. Emission factors for emissions 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<sup>1</sup>, in kg/TJ

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
<b>NH<sub>3</sub></b>	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
<b>NM VOC</b>	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
<b>NO<sub>x</sub></b>	1,170	1,207	1,225	1,111	970	989	919	899	887	826	801	775	747	699	737
<b>SO<sub>x</sub></b>	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
<b>BC<sup>3</sup></b>	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
<b>PM</b>	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
<b>CO</b>	287	292	255	162	121	121	105	101	98.8	94.6	93.3	92.6	88.5	87.0	87.2

<sup>1</sup> due to lack of better information: similar EF are applied for fossil diesel oil and biodiesel

<sup>2</sup> EF(PM<sub>2.5</sub>) also applied for PM<sub>10</sub> and TSP (assumption: >99% of TSP consists of PM<sub>2.5</sub>)

<sup>3</sup> EFs calculated via f-BCs as provided in <sup>10)</sup>: 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

	<b>NH<sub>3</sub></b>	<b>NM VOC</b>	<b>NO<sub>x</sub></b>	<b>SO<sub>x</sub></b>	<b>PM<sub>2.5</sub></b>	<b>PM<sub>10</sub></b>	<b>TSP</b>	<b>BC</b>	<b>CO</b>
<b>Hard coal</b>	4.00	15.0	120	650	222	250	278	14.2	500
<b>Hard coal coke</b>	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

	<b>PM<sub>2.5</sub></b>	<b>PM<sub>10</sub></b>	<b>TSP</b>	<b>BC</b>	<b>Pb</b>	<b>Cd</b>	<b>Hg</b>	<b>As</b>	<b>Cr</b>	<b>Cu</b>	<b>Ni</b>	<b>Se</b>	<b>Zn</b>
<b>Contact line</b> <sup>1</sup>	0.00016	0.00032	0.00032	NA	NA	NA	NA	NA	NA	0.00033	NA	NA	NA
<b>Tyres on rails</b> <sup>2</sup>	0.009	0.018	0.018	NA	NA								
<b>Braking system</b> <sup>3</sup>	0.004	0.008	0.008	NA	NA	NA	NA	NA	0.00008	NA	0.00016	NA	NA
<b>Current collector</b> <sup>4</sup>	NE	NE	NE	NE	NA								

<sup>1</sup> assumption: 100 per cent copper

<sup>2</sup> assumption: 100 per cent steel

<sup>3</sup> assumption: steel alloy containing Chromium and Nickel

<sup>4</sup> 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. <sup>1)</sup>



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.

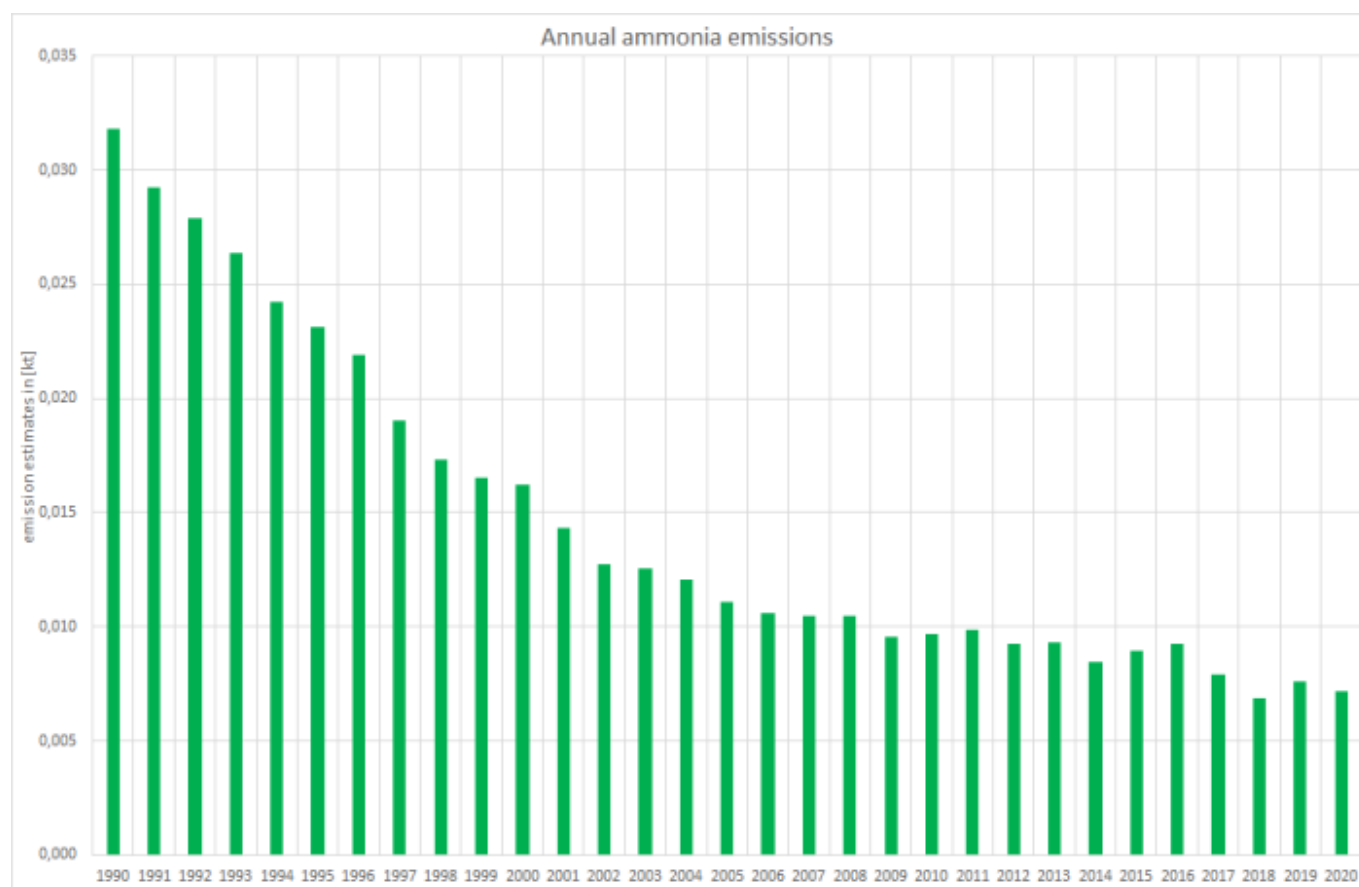
## Discussion of emission trends

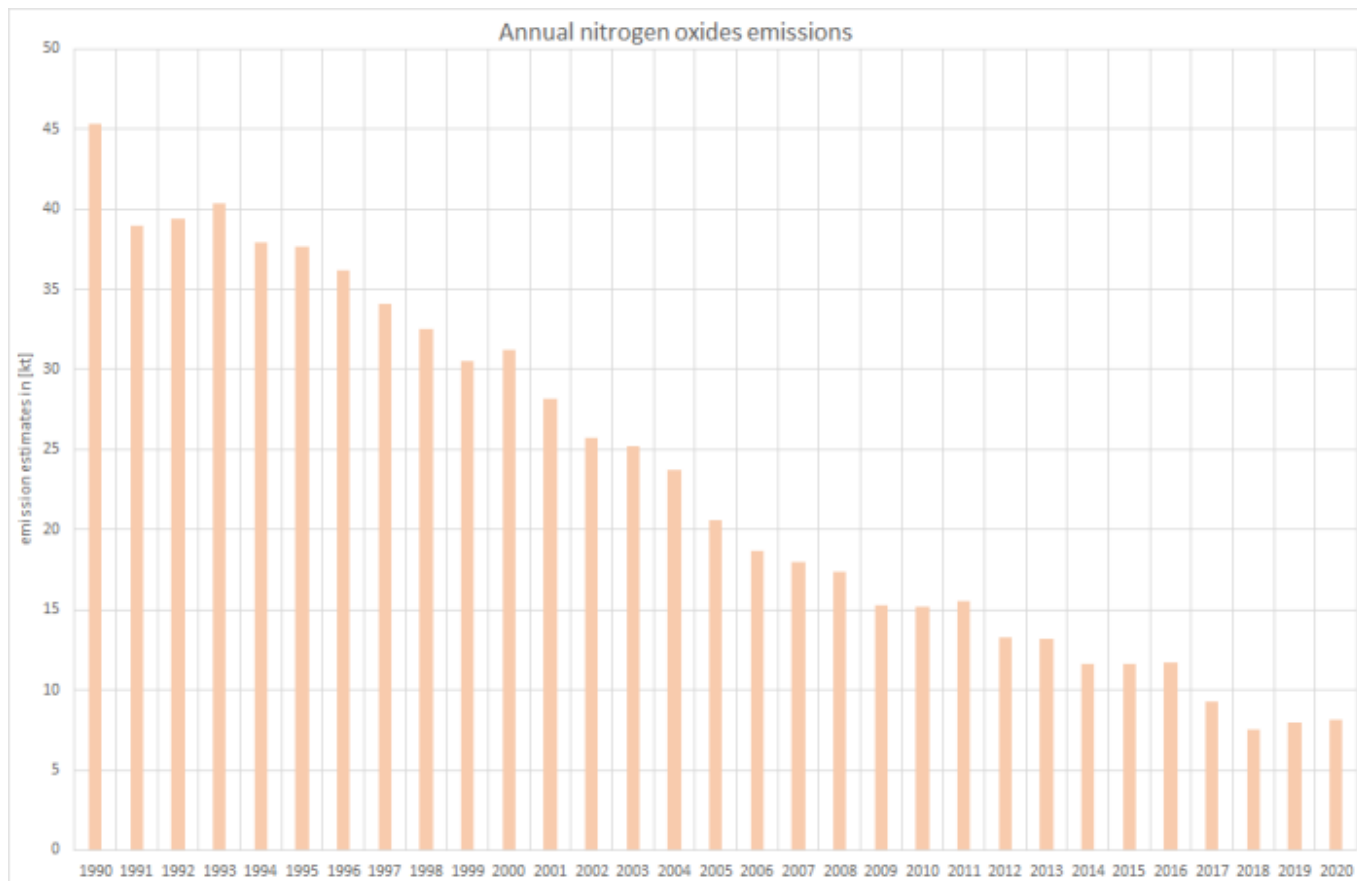
Table: Outcome of Key Category Analysis

for:	<b>NO<sub>x</sub></b>	<b>TSP</b>	<b>PM<sub>10</sub></b>	<b>PM<sub>2.5</sub></b>
by:	Trend	Level	L/-	L/-

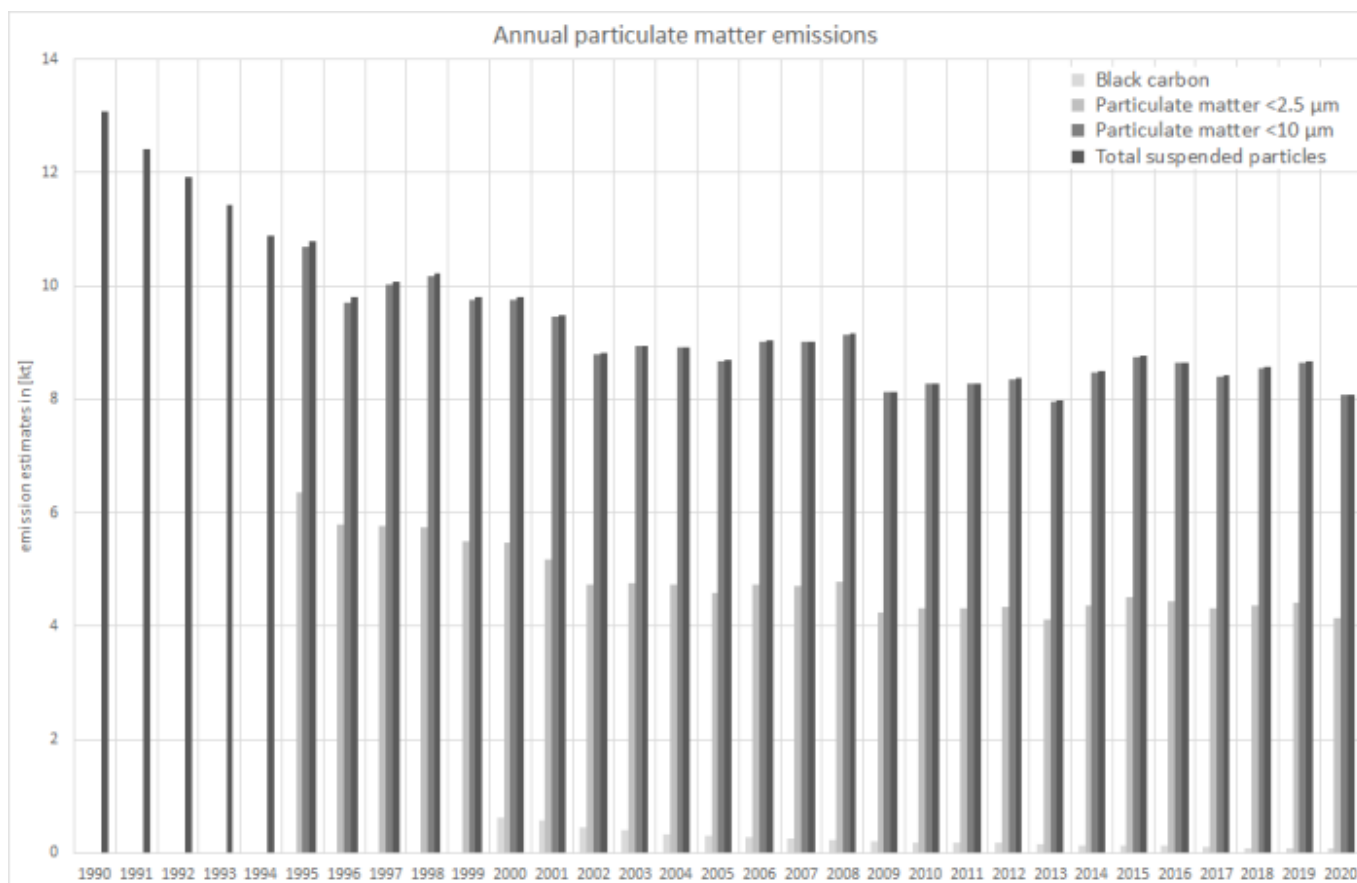
Basically, for all unregulated pollutants, emission trends directly follow the trend in over-all fuel consumption.

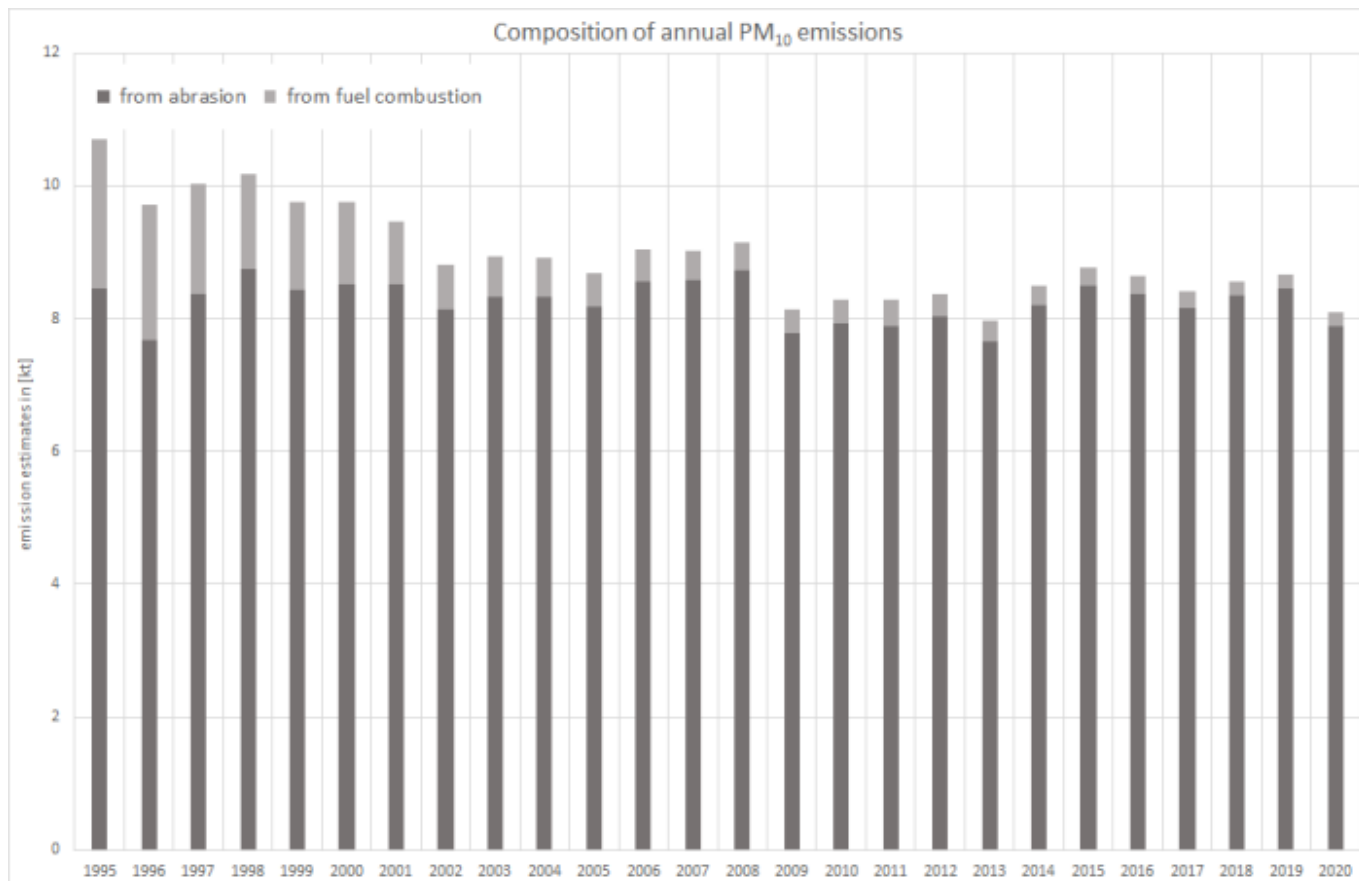
Here, as emission factors for solid fuels tend to be much higher than those for diesel oil, emission trends are disproportionately effected by the amount of solid fuels used. Therefore, for the **main pollutants, carbon monoxide, particulate matter** and **PAHs**, emission trends show remarkable jumps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



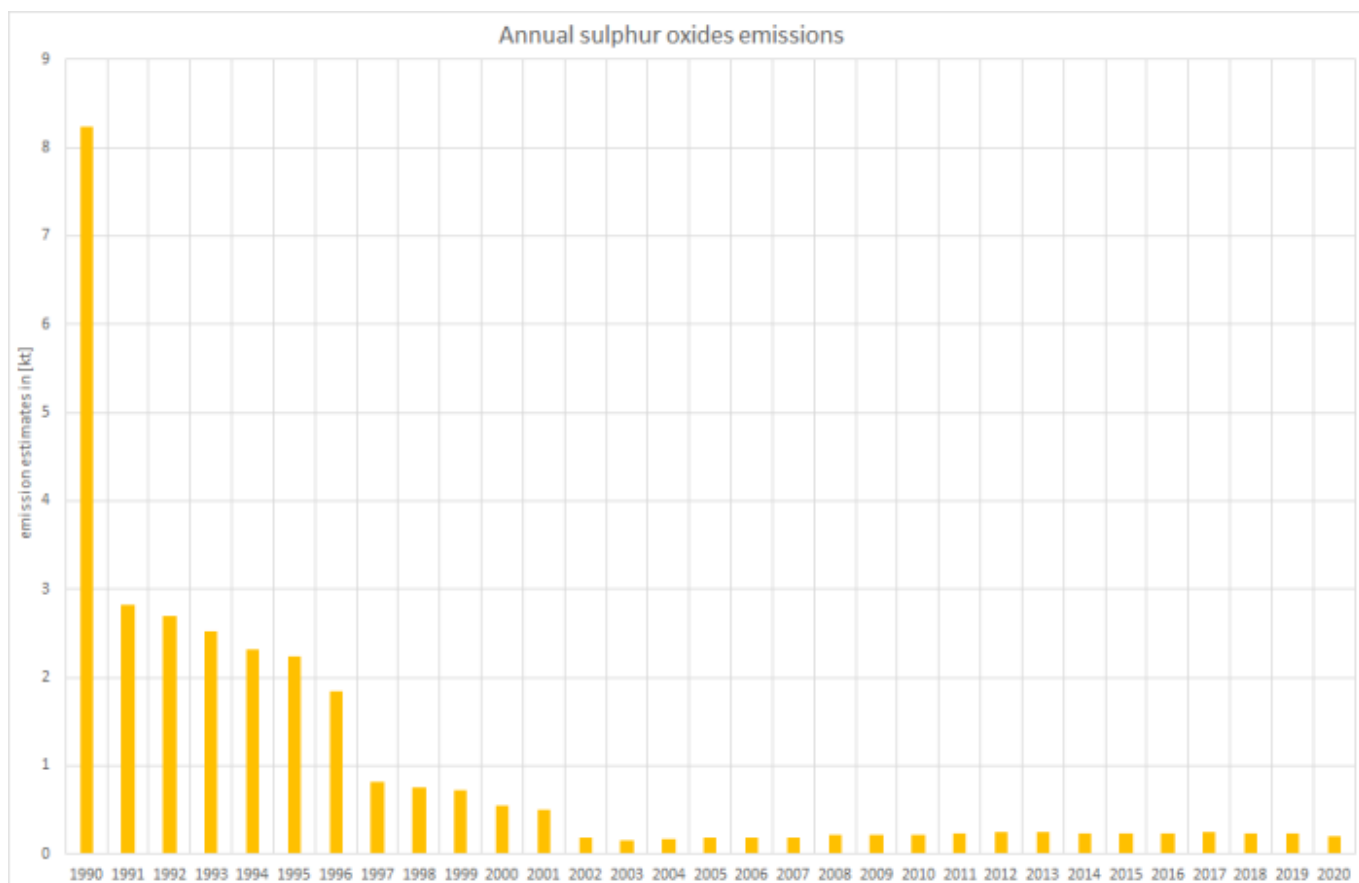


For all fractions of **particulate matter**, the majority of emissions generally result from abrasion and wear and the combustion of diesel fuels. Additional jumps in the over-all trend result from the use of lignite briquettes (1996-2001). Here, as the EF(BC) for fuel combustion are estimated via fractions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





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.



Composition of annual copper emissions

from abrasion

from fuel combustion & engine wear

emission estimates in [kt]

Year	from abrasion [kt]	from fuel combustion & engine wear [kt]	Total [kt]
1990	0.094	0.002	0.096
1991	0.092	0.002	0.094
1992	0.090	0.002	0.092
1993	0.088	0.002	0.090
1994	0.086	0.002	0.088
1995	0.088	0.002	0.090
1996	0.080	0.002	0.082
1997	0.090	0.002	0.092
1998	0.092	0.002	0.094
1999	0.092	0.002	0.094
2000	0.094	0.002	0.096
2001	0.094	0.002	0.096
2002	0.091	0.002	0.093
2003	0.093	0.002	0.095
2004	0.093	0.002	0.095
2005	0.092	0.002	0.094
2006	0.097	0.002	0.099
2007	0.098	0.002	0.100
2008	0.098	0.002	0.100
2009	0.087	0.002	0.089
2010	0.089	0.002	0.091
2011	0.088	0.002	0.090
2012	0.090	0.002	0.092
2013	0.087	0.002	0.089
2014	0.093	0.002	0.095
2015	0.096	0.002	0.098
2016	0.097	0.002	0.099
2017	0.094	0.002	0.096
2018	0.097	0.002	0.099
2019	0.100	0.002	0.102
2020	0.093	0.002	0.095

Given the revised NEB 2019, both the **activity data** for diesel oil and the annual amounts of blended biodiesel were revised accordingly. In addition, the amounts of solid fuels used in steam locomotives has been revised widely based on a study carried out in 2021.

[illegible]



	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<b>SOLID FUELS</b>																		
<b>Submission 2022</b>	2,776	1,627	655	283	289	278	323	342	332	368	379	372	360	352	363	368	367	363
<b>Submission 2021</b>	576	336	682	256	263	256	301	322	315	346	357	353	342	340	341	341	341	341
<b>absolute change</b>	2,200	1,291	-26.9	27.1	25.6	22.5	21.6	20.7	16.8	22.3	21.6	19.1	18.2	11.7	22.1	27.6	26.0	22.6
<b>relative change</b>	382%	384%	-3.94%	10.6%	9.73%	8.82%	7.19%	6.44%	5.33%	6.45%	6.04%	5.41%	5.32%	3.43%	6.49%	8.10%	7.64%	6.62%
<b>over-all fuel consumption</b>																		
<b>Submission 2022</b>	41,234	32,681	26,065	18,826	17,893	17,762	17,529	15,675	15,915	16,073	14,783	14,947	13,395	14,400	14,867	12,318	10,340	11,722
<b>Submission 2021</b>	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	10,414
<b>absolute change</b>	2,200	1,291	-26.9	27.1	25.6	22.5	21.6	20.7	16.8	22.3	21.6	19.1	18.2	11.7	22.1	27.5	26.0	1,308
<b>relative change</b>	5.64%	4.11%	-0.10%	0.14%	0.14%	0.13%	0.12%	0.13%	0.11%	0.14%	0.15%	0.13%	0.14%	0.08%	0.15%	0.22%	0.25%	12.6%

Due to the routine revision of the TREMOD model <sup>12)</sup>, 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

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<b>Non-methane volatile organic compounds - NMVOC</b>																		
<b>Submission 2020</b>	109	100	90.2	64.8	61.8	57.3	55.6	51.2	52.0	54.1	44.7	41.9	41.2	38.5	38.2	37.2	35.2	34.2
<b>Submission 2019</b>	109	100	90.2	64.8	61.8	57.3	55.6	51.2	52.0	54.3	44.8	41.9	41.2	38.5	38.2	37.2	35.2	35.0
<b>absolute change</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.16	-0.10	-0.09	-0.04	-0.06	0.00	0.00	-0.01	-0.86
<b>relative change</b>	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.30%	-0.22%	-0.21%	-0.10%	-0.15%	0.00%	0.00%	-0.01%	-2.45%
<b>Nitrogen oxides - NO<sub>x</sub></b>																		
<b>Submission 2020</b>	1.170	1.207	1.225	1.111	1.058	1.028	1.010	991	970	989	919	899	887	826	801	775	747	699
<b>Submission 2019</b>	1.170	1.207	1.225	1.111	1.058	1.028	1.010	991	970	990	919	899	886	826	801	775	747	724
<b>absolute change</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.72	-0.12	0.09	0.11	0.01	0.00	0.00	-0.02	-24.43
<b>relative change</b>	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.07%	-0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	-3.38%
<b>Black carbon - BC</b>																		
<b>Submission 2020</b>	28.8	28.9	24.2	16.1	15.2	14.5	13.6	12.7	11.4	11.5	12.0	10.4	9.5	9.29	8.65	8.48	8.05	7.60
<b>Submission 2019</b>	28.8	28.3	23.8	15.2	14.5	13.6	12.7	11.4	11.5	12.0	10.4	9.5	9.3	8.65	8.48	8.05	7.60	7.27
<b>absolute change</b>	0.00	0.62	0.44	0.91	0.68	0.97	0.88	1.27	-0.09	-0.52	1.60	0.86	0.22	0.64	0.16	0.43	0.45	0.33
<b>relative change</b>	0.00%	2.20%	1.84%	5.99%	4.66%	7.18%	6.91%	11.13%	-0.78%	-4.31%	15.41%	9.01%	2.38%	7.39%	1.89%	5.40%	5.92%	4.55%
<b>Particulate matter - PM (PM<sub>2.5</sub> = PM<sub>10</sub> = TSP)</b>																		
<b>Submission 2020</b>	44.4	43.6	36.6	23.4	22.4	20.9	19.5	17.6	17.7	18.4	16.0	14.6	14.3	13.3	13.1	12.4	11.7	11.0
<b>Submission 2019</b>	44.4	43.6	36.6	23.4	22.4	20.9	19.5	17.6	17.7	18.5	16.0	14.6	14.3	13.3	13.1	12.4	11.7	11.2
<b>absolute change</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.04	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00	-0.14
<b>relative change</b>	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.22%	-0.14%	-0.09%	-0.02%	-0.03%	0.00%	0.00%	0.00%	-1.21%
<b>Carbon monoxide - CO</b>																		
<b>Submission 2020</b>	287	292	255	162	152	141	134	123	121	121	105	101	99	94.6	93.3	92.6	88.5	87.0
<b>Submission 2019</b>	287	292	255	162	152	141	134	123	121	121	105	101	99	94.7	93.3	92.6	88.5	88.2
<b>absolute change</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.26	-0.13	-0.14	-0.06	-0.10	0.00	0.00	-0.01	-1.18
<b>relative change</b>	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.22%	-0.13%	-0.14%	-0.06%	-0.11%	0.00%	0.00%	-0.02%	-1.34%

Furthermore, the use of wood in historic steam locomotives has been taken into account and resulting **emissions of HCB and PCBs are reported for the first time.**



For more information on recalculated emission estimates for Base Year and 2019, please see the pollutant-specific 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)<sup>13)</sup>.

## 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<sup>14)</sup> 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.

<sup>1)</sup> AGEb (2021): Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen (Hrsg.), AGEb): Energiebilanz für die Bundesrepublik Deutschland; URL: <https://ag-energiebilanzen.de/7-0-Bilanzen-1990-2019.html>, Köln & Berlin, 2021.

<sup>2)</sup> MWV (2021): Association of the German Petroleum Industry (Mineralölwirtschaftsverband, MWV): Annual Report 2018, page 65, Table 'Sektoraler Verbrauch von Dieselmotorkraftstoff 2012-2019'; URL: [https://www.mwv.de/wp-content/uploads/2020/09/MWV\\_Mineraloelwirtschaftsverband-e.V.-Jahresbericht-2020-Webversion.pdf](https://www.mwv.de/wp-content/uploads/2020/09/MWV_Mineraloelwirtschaftsverband-e.V.-Jahresbericht-2020-Webversion.pdf), Berlin, 2021.

<sup>3)</sup> Hedel, R., & Kunze, J. (2012): Recherche des jährlichen Kohleeinsatzes in historischen Schienenfahrzeugen seit 1990. Probst & Consorten Marketing-Beratung. Dresden, 2012.

<sup>4)</sup> 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.

<sup>5)</sup> 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.

<sup>6), 12)</sup> Knörr et al. (2021a): 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, 2021.

<sup>7)</sup> (bibtex 4)

<sup>8), 11), 14)</sup> 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.

<sup>9)</sup> 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>

<sup>10)</sup> (bibtex 6)

<sup>13)</sup> 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.

<sup>1)</sup>

During test-bench measurements, temperatures are likely to be significantly higher than under real-world conditions, thus reducing condensation. On the contrary, smaller dilution (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.