

3.B - Manure Management

Short description

NFR-Code	Name of Category	Method	AD	EF	Key Category ¹	State of reporting
3.B	Manure Management	see sub-category details				
consisting of / including source categories						
3.B.1.a & 3.B.1.b	Cattle	T3 (NH ₃), T2 (NO _x , TSP, PM ₁₀ , PM _{2.5} , NMVOC)	NS, RS	CS (NH ₃ , NO _x), D (TSP, PM ₁₀ , PM _{2.5} , NMVOC)	L & T: NH ₃ (for 3.B.1.b), NMVOC	L: NH ₃ (for 3.B.1.a)
3.B.2, 3.B.4.d, 3.B.4.e	Sheep, Goats, Horses	T2 (NH ₃ , NO _x , TSP, PM ₁₀ , PM _{2.5}), T1 (NMVOC)	NS, RS	CS (NH ₃ , NO _x), D (TSP, PM ₁₀ , PM _{2.5} , NMVOC)	no key category	
3.B.3	Swine	T3 (NH ₃), T2 (NO _x , TSP, PM ₁₀ , PM _{2.5}), T1 (NMVOC)	NS, RS	CS (NH ₃ , NO _x), D (TSP, PM ₁₀ , PM _{2.5} , NMVOC)	L & T: NH ₃ , TSP	
3.B.4.a	Buffalo					NO, from 1990 until 1995, since 1996 IE, considered in 3.B.1.b
3.B.4.f	Mules and asses					IE, considered in 3.B.4.e
3.B.4.g i-iv	Poultry	T2 (NH ₃ , NO _x , TSP, PM ₁₀ , PM _{2.5}), T1 (NMVOC)	NS, RS	CS (NH ₃ , NO _x), D (TSP, PM ₁₀ , PM _{2.5} , NMVOC)	L: TSP (for 3.B.4.g i)	T: NH ₃ (for 3.B.4.g iii)
3.B.4.h	Other animals					NE

Legend 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 - 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, surveys

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

Country specifics

	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
mules and asses														
horses	499.5	634.1	499.5	508.4	461.8	461.6	461.5	461.3	454.9	448.4	442.0	435.5	429.1	422.6
sheep	3,266.1	2,990.7	2,743.3	2,643.1	2,245.0	1,979.7	1,965.9	1,877.2	1,892.4	1,866.9	1,851.0	1,863.2	1,846.0	1,813.6
goats	90.0	100.0	140.0	170.0	149.9	143.4	136.8	130.2	133.1	135.9	138.8	141.7	144.6	147.4
swine	26,502.5	20,387.3	21,767.7	22,742.8	22,244.4	22,787.9	23,648.3	23,391.2	23,666.9	22,978.5	22,761.2	22,920.8	22,019.2	21,596.4
laying hens	53,450.5	45,317.3	44,225.6	38,203.6	35,279.0	39,514.9	43,750.8	47,986.7	49,303.0	50,619.3	51,935.5	52,524.4	53,561.4	53,901.4
broilers	35,393.0	42,025.8	50,359.9	56,762.5	67,531.1	77,402.6	87,274.1	97,145.6	96,027.5	94,909.4	93,791.3	93,791.3	93,791.3	93,791.3
turkeys	5,029.2	6,742.0	8,893.1	10,611.1	11,344.0	11,981.2	12,618.5	13,255.7	12,957.1	12,658.5	12,359.9	12,359.9	12,359.9	12,359.9
pullets	17,210.8	14,592.0	14,240.5	12,301.4	11,303.3	12,749.3	14,195.2	15,641.2	14,734.7	13,828.3	12,921.8	12,921.8	12,921.8	12,921.8
ducks	2,013.7	1,933.7	2,055.7	2,352.2	3,164.3	3,029.5	2,894.6	2,759.7	2,585.3	2,410.8	2,236.4	2,236.4	2,236.4	2,236.4
geese	781.5	617.0	404.8	329.5	278.1	366.8	455.5	544.2	472.5	400.8	329.0	329.0	329.0	329.0
other animals: no data available a)														

a) Animal numbers of other animals are not available. Emissions of other animals were approximated with estimated population figures for a single year (see Rösemann et. al., 2017, Chapter 9, ³⁾ and submitted to the TERT of the NECD-Review. The TERT confirmed that emissions are below the threshold of significance. For GHG emission reporting the UNFCCC has acknowledged that the emissions from Germany's other animals are negligible. To ensure consistency between UNFCCC and UNECE/NEC reporting, no air pollutants from other animals are reported.

Additional data

Emission calculations in accordance with a Tier 2 or Tier 3 method require data on animal performance (animal weight, weight gain, milk yield, milk protein content, milk fat content, numbers of births, numbers of eggs and weights of eggs) and on the relevant feeding details (phase feeding, feed components, protein and energy content, digestibility and feed efficiency). To subdivide officially recorded total numbers of turkeys into roosters and hens, the respective population percentages need to be known. Details on data requirements for the modelling of emissions from livestock husbandry in the German inventory can be found in Rösemann et al. (2021), Chapters 4 to 8.

Most of the data mentioned above is not available from official statistics and was obtained from literature, from publications by agricultural association, from regulations for agricultural consulting in Germany and from expert judgments. For 1991, 1995 and 1999, frequency distributions of feeding strategies, husbandry systems (shares of pasturing/stabling; shares of various housing methods), storage types as well as techniques of farm manure spreading were obtained with the help of the RAUMIS agricultural sector model (Regionalisiertes Agrar- und UmweltInformationssystem für Deutschland/ Regionalised agricultural and environmental information system for Germany). RAUMIS has been developed and is operated by the Institute of Rural Studies of the Thünen Institute (Federal Research Institute for Rural Areas, Forestry and Fisheries). For an introduction to RAUMIS see Weingarten (1995) ⁴⁾; a detailed description is provided in Henrichsmeyer et al. (1996) ⁵⁾.

RAUMIS did not model complete time series but only selected years. RAUMIS data for the years 1991, 1995, and 1999 are used in the inventory for years 1990 - 1993, 1994 - 1997, and 1998 - 1999, respectively. For the year 2010, respective data are used that were derived from the 2010 official agricultural census and the simultaneous survey of agricultural production methods (Landwirtschaftliche Zählung 2010, Statistisches Bundesamt/ Federal Statistical Office) as well as the 2011 survey on manure application practices (Erhebung über Wirtschaftsdüngerausbringung, Statistisches Bundesamt/ Federal Statistical Office).

For the year 2015, data on techniques of farm manure spreading from the 2016 official agricultural census (Agrarstrukturerhebung 2016, Statistisches Bundesamt / Federal Statistical Office) are used. The gaps between the latest RAUMIS model data (1999) and the first official data (2010) were closed by linear interpolation on district level. For 2011 to 2019 the 2010 data was kept, with the exception of data on techniques of farm manure spreading. For the latter the data was linearly interpolated between 2010 and 2015, and for 2016 to 2019 the 2015 data was kept. In addition it was taken into account that, as of 2012, slurry spread on bare soil has to be incorporated within four hours. For a description of the RAUMIS data, the data from official surveys and additional data from other sources see Rösemann et al. (2021), Chapter 3.4. Time series of frequency distributions of housing systems, storage systems and application techniques as well as the corresponding emission factors are provided in NIR 2021, Chapter 19.3.2.

NH₃ and NO_x

Methodology

N in manure management N excretion

In order to determine NH₃ and NO_x emissions from manure management of a specific animal category, the individual N excretion rate must be known as well as, for NH₃, the TAN content of the N excretions. Default excretion rates are provided by IPCC Guidelines and default TAN contents can be found in the EMEP Guidebook, 2019⁶⁾. However, the German agricultural emission inventory uses N mass balances to calculate the N excretions and the TAN contents of almost all animal categories to be reported. N mass balance calculations (see below) consider N intake with feed, N retention due to growth, N contained in milk and eggs, and N in offspring. Table 2 presents national means of N excretions and TAN contents. For methodological details and mass balance input data see Rösemann et al. (2021), Chapter 3.3.4.3 as well as Chapters 4 to 8.

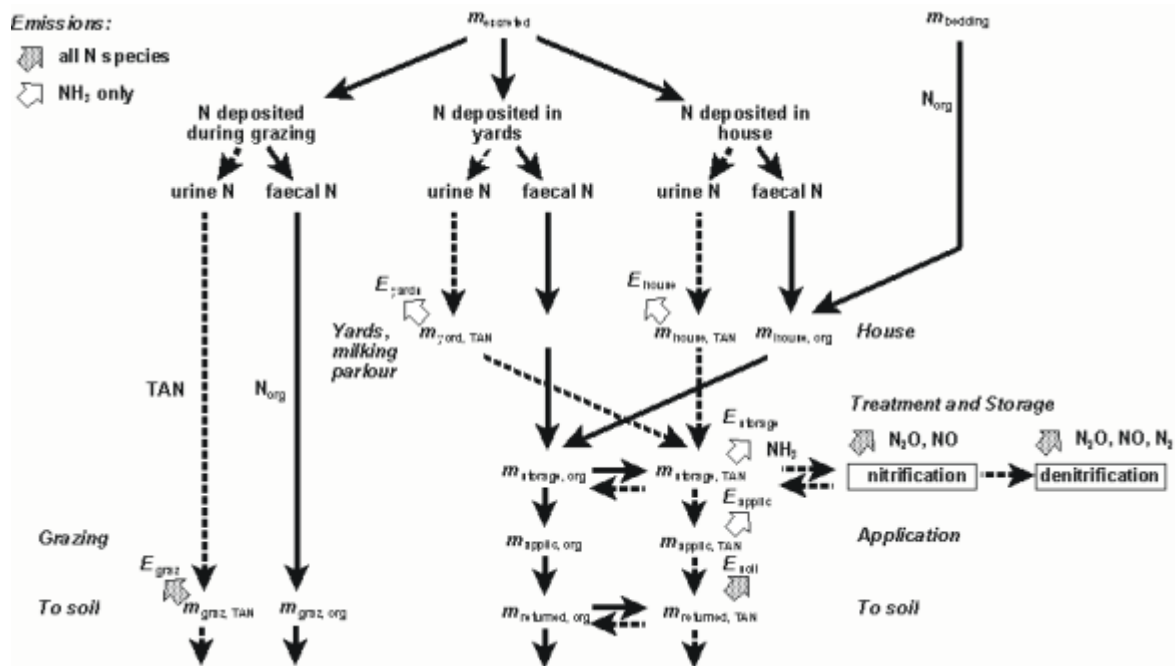
Table 2: National means of N excretions and TAN contents

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
mean N excretions in kg per animal place														
dairy cattle	92.0	97.9	103.8	108.9	110.3	111.0	111.3	110.7	111.8	113.1	114.5	114.3	116.8	120.0
other cattle	38.1	40.4	41.9	41.8	42.6	42.4	42.4	42.5	42.5	42.8	42.7	42.9	43.1	43.5
horses	48.2	48.1	49.0	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8
sheep	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
goats	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
swine	12.1	12.6	12.7	12.8	12.9	12.9	12.9	13.0	13.0	13.0	13.1	13.2	13.3	13.3
laying hens	0.82	0.79	0.78	0.80	0.87	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.89
broilers	0.48	0.44	0.49	0.52	0.57	0.54	0.49	0.45	0.48	0.50	0.50	0.51	0.52	0.51
turkeys	2.0	2.0	2.0	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
pullets	0.33	0.29	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
ducks	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
geese	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
mean TAN contents in %														
dairy cattle	58.0	55.0	52.9	51.3	49.9	49.6	49.3	49.2	48.7	48.6	48.3	48.2	47.6	47.2
other cattle	65.0	64.7	64.5	64.5	64.8	64.8	64.9	64.9	65.0	65.0	64.9	64.9	64.9	64.9
horses	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
sheep	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
goats	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
swine	74.3	74.1	73.8	73.7	73.3	73.2	73.0	73.0	72.9	72.9	72.8	72.7	72.7	72.7
laying hens	70.3	69.6	69.1	69.4	70.0	70.0	70.0	70.1	70.2	70.1	70.1	70.1	70.1	70.1
broilers	60.8	60.1	58.0	55.1	52.8	52.8	52.8	52.8	52.8	52.8	52.8	52.8	52.8	52.8
turkeys	63.9	63.9	62.2	63.0	62.1	62.3	62.9	62.6	62.6	62.6	62.6	62.6	62.6	62.6
pullets	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8	67.8
ducks	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9	49.9
geese	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0

N mass flow and emission assessment

The calculation of the emissions of NH₃, N₂O, NO_x and N₂ from German animal husbandry is based on the so-called N mass flow approach (e. g. Dämmgen and Hutchings, 2008⁷⁾). This approach differentiates between N excreted with faeces (organic nitrogen Norg, i. e. undigested feed N) and urine (total ammoniacal nitrogen TAN, i. e. fraction of feed N metabolized). The N flow within the manure management system is treated as depicted in the figure below. This method reconciles the requirements of both the Atmospheric Emission Inventory Guidebook for NH₃ emissions (EMEP, 2019), and the IPCC guidelines for greenhouse gas emissions (IPCC (2006)⁸⁾. Reidy et al. (2008),⁹⁾ showed for several European countries (Germany, the Netherlands, Switzerland, United Kingdom) that their N-flow based inventory models yielded, in spite of national peculiarities, comparable results as long as standardised data sets for the input variables were used.

Not explicitly shown in the N mass flow scheme is air scrubbing in housing and anaerobic digestion of manure. These issues are separately described further below. Note that emissions from grazing and application are reported in sector 3.D.



General scheme of N flows in animal husbandry

m : mass from which emissions may occur. Narrow broken arrows: TAN (total ammoniacal nitrogen); narrow continuous arrows: organic N. The horizontal arrows denote the process of immobilisation in systems with bedding occurring in the house, and the process of mineralisation during storage, which occurs in any case. Broad arrows denote N-emissions assigned to manure management (E_{yard} NH_3 emissions from yards; E_{house} NH_3 emissions from house; $E_{storage}$ NH_3 , N_2O , NO_x and N_2 emissions from storage; E_{applic} NH_3 emissions during and after spreading; E_{graz} NH_3 , N_2O , NO_x and N_2 emissions during and after grazing; E_{soil} N_2O , NO_x and N_2 emissions from soil resulting from manure input).

The figure allows tracing of the pathways of the two N fractions after excretion. The various locations where excretion may take place are considered. The partial mass flows down to the input to soil are depicted. During storage N_{org} can be transformed into TAN and vice versa. Both, the way and the amount of such transformations may be influenced by manure treatment processes like, e. g., anaerobic digestion where a considerable fraction of N_{org} is mineralized to TAN. For details see Rösemann et al. (2021), Chapters 3.3.4.3 and 3.3.4.4. Wherever NH_3 is emitted, its formation is related to the amount of the TAN present. For poultry the excretion of uric acid nitrogen (UAN) should be used instead of TAN (see Dämmgen and Erisman, 2005¹⁰). In line with EMEP (2019), it is assumed that UAN excreted can be considered TAN. N_2O emissions are related to the total amount of N available ($N_{org} + TAN$). NO_x emissions (i. e. NO emissions) are calculated proportionally to the N_2O emissions, see section 'Emission factors'. Note that the N_2O , NO_x and N_2 emissions from the various storage systems include the respective emissions from the related housing systems.

Air scrubber systems in swine and poultry housings

For pig and poultry production the inventory considers the effect of air scrubbing. Data on frequencies of air scrubbing facilities and the removal efficiency are provided by KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft / Association for Technology and Structures in Agriculture). The average removal efficiency of NH_3 is 80 % for swine and 70 % for poultry, while for TSP and PM_{10} the rates are set to 90 % and for $PM_{2.5}$ to 70 % for both animal categories. For swine two types of air scrubbers are distinguished: certified systems that remove both NH_3 and particles, and non-certified systems that remove only particles.

According to the KTBL data, 7.3 % of all pig places were equipped with certified systems in 2019, another 0.7 % were equipped with non-certified systems. For poultry 0.6 % of all laying hen places and 1.5 % of all broiler places were equipped with air scrubbers that remove both NH_3 and particles. The amounts of NH_3 -N removed by air scrubbing are completely added to the pools of total N and TAN for landspreading. For details see Rösemann et al. (2021), Chapter 3.3.4.3.3.

Anaerobic digestion of manure

According to IPCC (2006), anaerobic digestion of manure is treated like a particular storage type that, however, comprises three sub-compartments (pre-storage, fermenter and storage of digestates). For details see Rösemann et al. (2021), Chapters 3.3.4.4 and 3.4.4.2. The resulting digestates are considered as liquid. Two different types of digestates storage systems are considered: gastight storage and open tank. For the open tank formation of a natural crust because of the usual co-fermentation of energy crops is taken into account. Furthermore, the modelling of anaerobic digestion and spreading of

the digestates takes into account that the amount of TAN in the digestates is higher than in untreated slurry and that the frequencies of spreading techniques differ from those for untreated slurry.

NH₃ and NO emissions occur from pre-storage of solid manure, from non-gastight storage of digestates and from landspreading of digestates (NH₃ emissions and NO emissions from landspreading of digested manure are reported in 3.Da.2.a). There are no such emissions from pre-storage of slurry, from the fermenter and from gastight storage of digestates. Note that NH₃ and NO emissions calculated with respect to the digestion of animal manures do not comprise the contributions by co-digested energy crops. The latter are dealt with separately in 3.D.a.2.c and 3.I.

Emission Factors

Application of the N mass flow approach requires detailed emission factors for NH₃, N₂O, NO_x and N₂ describing the emissions from the various housing and storage systems.

The detailed NH₃ emission factors are, in general, related to the amount of TAN available at the various stages of the N flow chain. The emission factors for laying hens, broilers, pullets, ducks and turkeys are related to N. Most NH₃ emission factors are country specific but some are taken from EMEP (2019). No specific NH₃ emission factors are known for the application of digested manure. However, due to co-fermentation of energy crops, the viscosity of digested manure resembles that of untreated cattle slurry. Hence, the emission factors for untreated cattle slurry are adopted for the application of digested manure. For the detailed emission factors of livestock husbandry see Rösemann et al. (2021), Chapters 4 to 8; for emission factors of digested manure see Rösemann et al. (2021), Chapter 3.4.4.2.4. Table 3 provides, by animal category, the implied NH₃ emission factors for manure management (housing and storage). The overall German NH₃ IEF for manure application is reported in section 3.D.a.2.a.

The detailed emission factors for N₂O, NO_x and N₂ relate to the amount of N available which is N excreted plus, in case of solid manure systems, N input with bedding material. The N₂O emission factors are taken from IPCC (2006). The emission factors for NO_x and N₂ are approximated as being proportional to the N₂O emission factors, i. e. the NO-N and N₂ emission factors are, respectively, one-tenth and three times the value of the N₂O-N emission factor, see Rösemann et al. (2021), chapter 3.3.4.3.5. This proportionality is also applied to anaerobic digestion of manure, where N₂O emissions occur from pre-storage of solid manure and non-gastight storage of digestates with the emission factors being those used for normal storage of solid manure and the storage of untreated slurry with natural crust provided by IPCC (2006). Note that the inventory model calculates NO rather than NO_x. The conversion of NO emissions into NO_x emissions is achieved by multiplying the NO emissions with the NO_x/NO molar weight ratio of 46/30. This relationship also holds for NO and NO_x emission factors.

All NO_x emissions from the agricultural sector are excluded from emission accounting by [adjustment](#) as they are not considered in the NEC and Gothenburg commitments.

Table 3 shows the implied emission factors of NH₃ and NO_x for the various animal categories. These emission factors normalize emissions from an animal category as the ratio of the total emission to the respective number of animals.

Table 3: IEF for NH₃ & NO_x from manure management

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
IEF in kg NH₃ per animal place														
dairy cattle	9.8	10.4	11.1	12.1	12.6	12.5	12.4	12.3	12.2	12.3	12.4	12.3	12.4	12.6
other cattle	7.0	7.4	7.7	8.2	8.4	8.4	8.3	8.3	8.3	8.4	8.4	8.4	8.4	8.5
horses	13.5	13.5	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7
sheep	0.83	0.82	0.84	0.83	0.84	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.82	0.83
goats	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62
swine	4.42	4.41	4.37	4.32	4.19	4.15	4.12	4.12	4.11	4.09	4.10	4.10	4.11	4.10
laying hens	0.214	0.203	0.203	0.200	0.142	0.144	0.144	0.145	0.145	0.145	0.146	0.146	0.147	0.147
broilers	0.143	0.131	0.141	0.144	0.148	0.140	0.126	0.116	0.122	0.126	0.128	0.130	0.133	0.131
turkeys	0.788	0.788	0.792	0.869	0.831	0.835	0.888	0.858	0.857	0.856	0.857	0.857	0.859	0.859
pullets	0.108	0.096	0.088	0.087	0.082	0.081	0.081	0.079	0.079	0.079	0.079	0.080	0.080	0.080
ducks	0.193	0.193	0.193	0.192	0.190	0.189	0.188	0.187	0.186	0.186	0.186	0.186	0.186	0.186
geese	0.301	0.301	0.301	0.300	0.298	0.298	0.298	0.297	0.297	0.297	0.297	0.297	0.297	0.297
IEF in kg NO_x per animal place														
dairy cattle	0.106	0.114	0.125	0.130	0.125	0.122	0.118	0.115	0.115	0.116	0.117	0.117	0.119	0.122

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
other cattle	0.053	0.058	0.060	0.064	0.065	0.064	0.064	0.063	0.063	0.063	0.063	0.063	0.063	0.064
horses	0.084	0.084	0.086	0.086	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.086	0.086	0.086
sheep	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
goats	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
swine	0.010	0.012	0.012	0.014	0.016	0.016	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
laying hens	0.00027	0.00026	0.00026	0.00029	0.00035	0.00035	0.00034	0.00034	0.00033	0.00034	0.00034	0.00033	0.00033	0.00033
broilers	0.00016	0.00015	0.00016	0.00019	0.00022	0.00021	0.00018	0.00017	0.00018	0.00019	0.00019	0.00019	0.00019	0.00019
turkeys	0.00067	0.00067	0.00070	0.00083	0.00090	0.00090	0.00091	0.00089	0.00089	0.00089	0.00088	0.00088	0.00087	0.00087
pullets	0.00011	0.00010	0.00009	0.00010	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011
ducks	0.00024	0.00024	0.00024	0.00025	0.00027	0.00027	0.00026	0.00027	0.00026	0.00027	0.00027	0.00026	0.00026	0.00026
geese	0.00018	0.00018	0.00019	0.00021	0.00023	0.00023	0.00021	0.00022	0.00021	0.00022	0.00022	0.00021	0.00021	0.00021

Trend discussion for Key Sources

Dairy cattle, other cattle and swine are key sources of NH₃ emissions from manure management. The time series of the total NH₃ emissions from all three categories are predominantly driven by the development of the animal numbers, see Table 1. This also holds for the negative trend of total emissions in the last few years. However, the effect of decreasing animal numbers is partly compensated by the continuously increasing animal performance. This leads to increasing N excretions per animal, see Table 2, which, in principle, is reflected by increasing implied emission factors, see Table 3. For swine, as of 2012, the IEF is almost constant over time due to the use of air scrubbing systems that, to a high degree, remove NH₃ from the housings.

For NO_x there are no key categories.

Recalculations

All time series of the emission inventory have completely been recalculated since 1990. Tables REC-1 and REC-2 compare the recalculated time series for NH₃ and NO_x from 3B with the respective data of last year's submission. The total emissions of NH₃ and NO_x are significantly lower than those of submission 2020. This is predominantly due to the update of the models of dairy cows, calves, heifers and male beef cattle, see main page of the agricultural sector ([Chapter 5 - NFR 3 - Agriculture \(OVERVIEW\)](#)), list of **recalculation reasons, No. 1 through 4, and 12**.

The NH₃ and NO_x emissions from pig changed only slightly; the reasons are given in the list of **recalculation reasons (No. 6 through 8, and 12)**.

The NH₃ emissions from poultry are higher than those reported in submission 2020 for all years of the time series, while NO_x emissions differ only slightly. The underlying changes in poultry emission calculations are provided in the **recalculation reasons, No. 9 through 11, and 12**.

The overall NH₃ emissions of other animals increased for all years of the time series due to the update of the NH₃ emission factor for sheep manure storage, see **recalculations reasons No. 9 Chapter 5 - NFR 3 - Agriculture (OVERVIEW)**. Further details on recalculations are described in Rösemann et al. (2021), Chapter 3.5.2..

Tables REC-1 and REC-2: Comparison of the NH₃ and NO_x emissions of the submissions (SUB) 2020 and 2021

NH₃ emissions from manure management, in Gg															
	SUB	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	2021	303.26	256.08	256.91	257.32	252.88	253.17	257.21	258.42	260.03	256.36	253.73	252.85	247.20	243.31
	2020	325.60	275.30	276.21	276.48	271.11	271.43	275.70	277.31	279.59	276.30	273.98	272.83	267.01	
Dairy cattle	2021	62.19	54.13	50.81	51.28	52.71	52.44	51.86	52.30	52.48	52.72	52.10	51.64	50.74	50.40
	2020	75.05	65.57	61.87	62.48	64.19	64.22	63.79	64.44	65.29	65.88	65.43	64.96	64.24	
Other cattle	2021	91.39	78.88	76.79	71.73	72.48	69.75	69.39	70.26	70.48	69.85	68.90	67.62	65.85	64.47
	2020	101.28	87.37	86.15	81.09	80.84	77.90	77.51	78.51	78.74	78.14	77.24	75.69	73.74	
Swine	2021	117.12	89.92	95.08	98.23	93.21	94.56	97.47	96.29	97.28	94.06	93.26	93.92	90.54	88.50
	2020	117.12	89.92	95.08	98.23	93.21	94.58	97.51	96.36	97.37	94.17	93.40	94.09	90.63	
poultry	2021	22.96	21.99	24.87	26.65	26.06	28.23	30.34	31.50	31.80	31.84	31.68	31.95	32.45	32.43
	2020	22.71	21.41	23.86	25.36	24.55	26.63	28.81	30.02	30.27	30.31	30.21	30.46	30.87	

Other animals	2021	9.59	11.16	9.37	9.43	8.43	8.18	8.16	8.07	8.00	7.89	7.79	7.72	7.62	7.51
	2020	9.44	11.02	9.25	9.31	8.33	8.09	8.07	7.98	7.91	7.80	7.71	7.64	7.53	
NO_x emissions from manure management, in Gg															
	SUB	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	2021	1.720	1.551	1.523	1.534	1.529	1.502	1.480	1.475	1.482	1.465	1.455	1.444	1.418	1.401
	2020	1.863	1.674	1.639	1.644	1.632	1.604	1.582	1.579	1.588	1.572	1.562	1.548	1.519	
Dairy cattle	2021	0.671	0.597	0.570	0.552	0.521	0.513	0.495	0.491	0.493	0.495	0.494	0.489	0.488	0.489
	2020	0.722	0.640	0.601	0.580	0.549	0.541	0.523	0.521	0.525	0.528	0.527	0.522	0.520	
Other cattle	2021	0.696	0.614	0.600	0.566	0.562	0.538	0.529	0.532	0.532	0.526	0.519	0.509	0.497	0.487
	2020	0.788	0.695	0.685	0.649	0.637	0.611	0.602	0.606	0.606	0.601	0.593	0.581	0.566	
Swine	2021	0.264	0.242	0.263	0.322	0.351	0.355	0.359	0.353	0.357	0.344	0.343	0.346	0.335	0.328
	2020	0.264	0.242	0.263	0.322	0.351	0.355	0.359	0.353	0.357	0.344	0.343	0.346	0.334	
poultry	2021	0.026	0.024	0.028	0.033	0.040	0.043	0.045	0.047	0.048	0.048	0.048	0.048	0.049	0.049
	2020	0.026	0.024	0.028	0.033	0.040	0.043	0.045	0.047	0.048	0.048	0.048	0.048	0.049	
Other animals	2021	0.063	0.073	0.062	0.062	0.055	0.053	0.053	0.053	0.052	0.051	0.051	0.050	0.050	0.049
	2020	0.063	0.073	0.062	0.062	0.055	0.053	0.053	0.053	0.052	0.051	0.051	0.050	0.050	

Planned improvements

No improvements are planned at present.

NM VOC

In 2019, NMVOC emissions from manure management amount to 295.8 which is 97.2 % of total NMVOC emissions from the agricultural sector. 84.8 % originate from cattle, 4.7 % from pigs, and 9.4 % from poultry. All NMVOC emissions from the agricultural sector are excluded from emission accounting by adjustment as they are not considered in the NEC and Gothenburg commitments (see Chapter 11 - [Adjustments and Emissions Reduction Commitments](#)).

Method

The Tier 2 methodology provided by EMEP (2019)-3B-28 was used to assess the NMVOC emissions from manure management for dairy cattle and other cattle. For all other animals the Tier 1 methodology (EMEP (2019)-3B-17) was used.

Activity data

Animal numbers serve as activity data, see Table 1.

Emission factors

For the Tier 2 methodology applied to dairy cattle and other cattle the following data was used:

- gross feed intake in MJ per year, country specific data from the annual reporting of greenhouse gas emissions, see NIR 2021, Chapter 5.1.3.3,
- proportion x house of the year the animals spend in the livestock building: country specific data, being equal to 1 - xgraz with xgraz the proportion of the year spent on pasture, see NIR 2021, Chapter 19.3.2,
- FRACsilage 1 as proposed by EMEP (2019)-3B-29, since silage feeding for cattle is considered dominant in Germany
- FRACsilage store: 0.25 as proposed by EMEP (2019)-3B-30 for European conditions
- EFNMVOC silage_feeding, EFNMVOC, house, EFNMVOC, graz are taken from EMEP (2019)-3B-32, table 3.11 as 0.0002002, 0.0000353 and 0.0000069 kg NMVOC/MJ feed intake, respectively,
- EFNH3,storage, EFNH3,building, and EFNH3,application are taken from the NH3 reporting (see above and 3.D).

For all other animal categories the Tier 1 emission factors for NMVOC as provided in EMEP (2019)-3B-18, Table 3.4 [10] were used: For horses the emission factors for feeding with silage was chosen, for all other animals the emission factors for feeding without silage. Due to missing country-specific emission factors or emission factors that do not correspond to the inventory's animal categories, the emission factors provided in EMEP (2019)-3B-18, Table 3.4, were used to define specific emission factors for weaners, boars, lambs, ponies/light horses and pullets, see Rösemann et al. (2021), Chapter 3.3.4.2. The implied emission factors given in Table 4 relate the overall NMVOC emissions to the number of animals in each animal category. The IEFs for dairy cattle and other cattle are much higher than the EMEP Tier 1 EF, which are 17.937 kg NMVOC for dairy cattle and 8.902 kg NMVOC for other cattle. The only possible explanation for those huge differences is that

the EMEP Tier 2 and Tier 1 methods are not consistent.

The IEFs for the other categories provided in Table 4 correspond to the EMEP Tier 1 emission factors, except for horses, sheep, swine and other poultry. These categories comprise subcategories with different emission factors so that their overall IEFs in Table 4 represent subpopulation-weighted national mean values. Note that other poultry in Germany includes not only geese and ducks but also pullets. For pullets no default EF is given in the EMEP guidebook (EMEP, 2019), hence the EF of broilers has been adopted (because of similar housing). This assumption significantly lowers the overall IEF of other poultry in Table 4 (the IEFs are listed separately for each poultry category). The IEF of the sheep category is significantly lower than the EMEP Tier 1 emission factor, because for lambs the EF is assumed to be 40% lower compared to an adult sheep in accordance with the difference in N excretion between lambs and adult sheep.

Table 4: IEF for NMVOC from manure management

IEF in kg NMVOC per animal place														
	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
dairy cattle	30.940	32.695	35.473	36.706	37.234	37.578	37.560	37.351	37.721	37.914	38.366	38.378	39.213	40.093
other cattle	11.705	11.657	11.765	11.652	11.722	11.676	11.646	11.654	11.602	11.616	11.618	11.658	11.716	11.818
horses	6.497	6.491	6.688	6.660	6.644	6.643	6.642	6.641	6.644	6.646	6.648	6.651	6.653	6.656
sheep	0.131	0.131	0.132	0.132	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
goats	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542
swine	0.695	0.698	0.690	0.682	0.669	0.663	0.656	0.654	0.652	0.651	0.649	0.648	0.648	0.648
laying hens	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
broilers	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
turkeys	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489
pullets	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
ducks	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489
geese	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489

Trend discussion for Key Sources

Dairy cattle and other cattle are key sources of NMVOC emissions from manure management. The total NMVOC emissions from both animal categories strongly correlate with the animal numbers given in Table 1 (dairy cattle: $R^2 = 0.895$; other cattle: $R^2 = 0.995$).

Recalculations

All time series of the emission inventory have completely been recalculated since 1990. Table REC-3 compares the recalculated time series of the NMVOC emissions from 3.B with the respective data of last year's submission. The recalculated total emissions are lower by 4 to 11 %. This is due to improved methodology for the cattle sector (**recalculation reasons 1 through 4**, see [main page of the agricultural sector](#)). Emissions of other animals remained unchanged. Further details on recalculations are described in Rösemann et al. (2021), Chapter 3.5.2.

Table REC-3: Comparison of NMVOC emissions of the submissions (SUB) 2020 and 2021

NMVOC emissions from manure management, in Gg																
	SUB	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Total	2021	390.80	332.18	318.01	297.65	296.79	297.13	299.17	304.38	306.74	305.38	303.07	300.94	297.86	295.83	
	2020	439.44	365.76	344.98	320.23	317.25	317.26	318.95	324.80	326.92	325.45	322.84	320.20	316.49		
Dairy cattle	2021	196.61	170.97	162.10	155.50	155.75	157.45	157.39	159.40	162.04	162.45	161.82	161.15	160.81	160.84	
	2020	231.88	194.00	177.13	167.50	166.57	168.13	167.69	170.01	172.37	172.58	171.57	170.89	169.97		
Other cattle	2021	153.72	124.27	117.29	102.54	101.14	97.38	96.89	98.11	98.00	97.00	95.83	94.23	91.95	90.15	
	2020	167.09	134.83	129.24	113.12	110.78	106.84	106.37	107.92	107.84	106.95	105.84	103.75	101.42		
Other animals	2021	40.46	36.94	38.62	39.61	39.89	42.29	44.89	46.87	46.70	45.93	45.42	45.56	45.11	44.84	
	2020	40.46	36.94	38.62	39.61	39.89	42.29	44.89	46.87	46.70	45.93	45.42	45.56	45.11		

Planned improvements

No improvements are planned at present.

TSP, PM10 and PM2.5

In 2019, TSP emissions from manure management amount to 71.1 % of total emissions from the agricultural sector. Within the emissions from manure management 22.4 % originate from cattle, 39.3 % from pigs, and 37.7 % from poultry. 42.7 % of the PM₁₀ emissions from the agricultural sector are caused by manure management, where 34.0 % originate from cattle, 18.9 % from pigs, and 46.2 % from poultry. PM_{2.5} emissions from the agricultural sector mostly originate from manure management (84.8 %), of which are 77.5 % from cattle, 3.0 % from pigs, and 18.0 % from poultry.

Method

E MEP (2013)-3B-26 [9] provided a Tier 2 methodology. In the current Guidebook (EMEP, 2019), this methodology has been replaced by a Tier 1 methodology. However, EF for cattle derived with the EMEP 2013 Tier 2 methodology remained unchanged. So the EMEP 2013¹¹⁾ methodology was kept for cattle. For swine the EMEP 2013 methodology was formally kept but the EMEP 2019 Tier 1 EF was used both for slurry and solid based manure management systems. The same was done with the EMEP 2016 EFs for laying hens (used for cages and perchery). In case the EMEP 2019 EFs are just the rounded EMEP 2013 EFs, the unrounded EMEP 2013 EFs were kept. The inventory considers air scrubber systems in swine and poultry husbandry. For animal places equipped with air scrubbing the emission factors are reduced according to the removal efficiency of the air scrubber systems (90 % for TSP and PM₁₀, 70 % for PM_{2.5}). For details see Rösemann et al. (2021), Chapter 3.3.4.3.3.

Activity data

Animal numbers serve as activity data, see Table 1.

Emission factors

Tier 1 emission factors for TSP, PM₁₀ and PM_{2.5} from livestock husbandry are provided in EMEP (2019)-3B-19, Table 3.5 and 55, Table A1.7. For cattle the Tier 2 emission factors provided in EMEP (2013)-3B-29, Table 3-11 were used, because they differentiate between slurry and solid manure systems and were also used to develop the EMEP 2019 Tier 1 emissions factors.

The implied emission factors given in Table 5 relate the overall TSP and PM emissions to the number of animals in each animal category. The Guidebook does not indicate whether EFs have considered the condensable component (with or without).

Table 5: IEF for TSP, PM₁₀ & PM_{2.5} from manure management

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
IEF in kg TSP per animal place														
dairy cattle	1.2124	1.4016	1.4544	1.4743	1.4891	1.4873	1.4860	1.4841	1.4840	1.4828	1.4834	1.4828	1.4826	1.4826
other cattle	0.5194	0.5107	0.5018	0.4926	0.4823	0.4814	0.4817	0.4822	0.4813	0.4806	0.4807	0.4807	0.4810	0.4807
horses	0.3514	0.3512	0.3558	0.3552	0.3548	0.3548	0.3548	0.3548	0.3548	0.3549	0.3549	0.3550	0.3550	0.3551
sheep	0.0484	0.0478	0.0489	0.0486	0.0489	0.0485	0.0485	0.0485	0.0483	0.0482	0.0482	0.0482	0.0480	0.0482
goats	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914
swine	0.8260	0.8366	0.8320	0.8247	0.8104	0.8043	0.8086	0.8037	0.8002	0.7910	0.7918	0.7891	0.7865	0.7814
laying hens	0.1900	0.1900	0.1900	0.1900	0.1900	0.1900	0.1900	0.1900	0.1900	0.1899	0.1898	0.1897	0.1894	0.1890
broilers	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0399	0.0399	0.0397	0.0396	0.0395	0.0394
turkeys	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100
pullets	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400
ducks	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400
geese	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400
IEF in kg PM₁₀ per animal place														
dairy cattle	0.5557	0.6426	0.6668	0.6759	0.6827	0.6819	0.6813	0.6804	0.6803	0.6798	0.6801	0.6798	0.6797	0.6797
other cattle	0.2403	0.2363	0.2321	0.2278	0.2230	0.2226	0.2227	0.2229	0.2225	0.2222	0.2222	0.2222	0.2223	0.2222
horses	0.1619	0.1619	0.1639	0.1636	0.1634	0.1634	0.1634	0.1634	0.1634	0.1634	0.1635	0.1635	0.1635	0.1635
sheep	0.0194	0.0192	0.0196	0.0195	0.0196	0.0195	0.0194	0.0194	0.0194	0.0193	0.0193	0.0193	0.0192	0.0193
goats	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368	0.0368
swine	0.1241	0.1255	0.1244	0.1230	0.1199	0.1187	0.1185	0.1177	0.1170	0.1158	0.1156	0.1151	0.1147	0.1139
laying hens	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0399	0.0399	0.0398
broilers	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0199	0.0198	0.0198	0.0198	0.0197

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
turkeys	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100
pullets	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
ducks	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400	0.1400
geese	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400	0.2400
IEF in kg PM_{2.5} per animal place														
dairy cattle	0.3616	0.4181	0.4339	0.4398	0.4442	0.4437	0.4433	0.4427	0.4427	0.4423	0.4425	0.4423	0.4422	0.4422
other cattle	0.1574	0.1548	0.1521	0.1493	0.1463	0.1460	0.1461	0.1462	0.1460	0.1458	0.1458	0.1458	0.1459	0.1458
horses	0.1027	0.1026	0.1039	0.1038	0.1036	0.1036	0.1036	0.1036	0.1036	0.1037	0.1037	0.1037	0.1037	0.1037
sheep	0.0059	0.0059	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0059	0.0059	0.0059	0.0059	0.0059	0.0059
goats	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112
swine	0.0056	0.0057	0.0056	0.0056	0.0054	0.0054	0.0053	0.0053	0.0053	0.0052	0.0052	0.0052	0.0052	0.0052
laying hens	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030
broilers	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
turkeys	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
pullets	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
ducks	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180
geese	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320

Trend discussion for Key Sources

Swine and laying hens are key sources of TSP emissions from manure management. The total TSP emissions from swine mainly follow the animal numbers given in Table 1. However, due to air scrubbing and different emission factors of the different housing systems of the four swine subcategories (sows with piglets, weaners, fattening pigs, boars) and the varying population shares in those housing systems the R^2 of the linear regression is lower than 1 (0.79). For laying hens and broilers, due to the low prevalence of air scrubbing systems, TSP emissions almost perfectly correlate with the animal numbers provided in Table 1 ($R^2 = 1$).

Recalculations

Table REC-4 shows the effects of recalculations on emissions of particulate matter. Changes in the years 1990 through 1999 are a consequence of the update of the dairy cow model (**recalculation reason 1**, see [main page of the agricultural sector](#)). This update includes a modified calculation of the share of year spent on pasture, resulting in longer grazing periods and therefore lower emissions of particulate matter from manure management in the years 1990 through 1999. Differences of TSP and PM emissions in the years as of 2005 are due to updated activity data of air scrubbing systems for sows, weaners, fattening pigs and broilers, see **recalculation reasons 8 and 10** on [the main page of the agricultural sector](#). Further details on recalculations are described in Rösemann et al. (2021), Chapter 3.5.2.

Table REC-4: Comparison of particle emissions (TSP, PM₁₀ & PM_{2.5}) of the submissions (SUB) 2020 and 2021

TSP, PM10, PM2.5 emissions from manure management, in Gg															
	SUB	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TSP	2021	50.04	42.24	42.44	41.26	40.32	41.79	43.90	45.06	45.33	44.58	44.35	44.40	43.55	42.90
TSP	2020	50.26	42.41	42.44	41.26	40.32	41.79	43.91	45.07	45.36	44.61	44.39	44.44	43.62	
PM₁₀	2021	14.34	12.71	12.63	12.29	12.32	12.75	13.31	13.80	13.77	13.56	13.39	13.36	13.17	13.00
PM₁₀	2020	14.44	12.78	12.63	12.29	12.32	12.75	13.31	13.80	13.78	13.57	13.40	13.38	13.19	
PM_{2.5}	2021	5.01	4.47	4.18	3.89	3.86	3.86	3.91	4.01	4.01	3.97	3.91	3.88	3.80	3.72
PM_{2.5}	2020	5.08	4.52	4.18	3.89	3.86	3.86	3.91	4.01	4.01	3.97	3.91	3.88	3.80	

Planned improvements

No improvements are planned at present.

Uncertainty

Details will be described in [chapter 1.7](#).

1)

Rösemann C., Haenel H-D., Vos C., Dämmgen U., Döring U., Wulf S., Eurich-Menden B., Freibauer A., Döhler H., Schreiner C., Osterburg B. & Fuß, R. (2021): Calculations of gaseous and particulate emissions from German Agriculture 1990 –2019. Report on methods and data (RMD), Submission 2021. Thünen Report (in preparation).

<https://www.thuenen.de/de/ak/arbeitsbereiche/emissionsinventare>

²⁾
NIR, National Inventory Report 2021 for the German Greenhouse Gas Inventory 1990-2019. Available in April 2021

³⁾
Rösemann C, Haenel H-D, Dämmgen U, Freibauer A, Döring, U, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, and Osterburg B, 2017, Calculations of gaseous and particulate emissions from German Agriculture 1990 – 2015. Report on methods and data (RMD), Submission 2017. Thünen Report 46, 423 p.

⁴⁾
Weingarten, 1995: Das „Regionalisierte Agrar- und Umweltinformationssystem für die Bundesrepublik Deutschland“ (RAUMIS). Berichte über die Landwirtschaft Band 73, 272-302.

⁵⁾
Henrichsmeyer, W.; Cypris, Ch.; Löhe, W.; Meuth, M.; Isermeyer F; Heinrich, I.; Schefski, A.; Neander, E.; Fasterding, F.; Neumann, M.; Nieberg, H., 1996: Entwicklung des gesamtdeutschen Agrarsektormodells RAUMIS96. Endbericht zum Kooperationsprojekt. Forschungsbericht für das BMELF (94 HS 021), Bonn, Braunschweig.

⁶⁾
EMEP/EEA air pollutant emission inventory guidebook – 2019, EEA Report No 13/2019,
<https://www.eea.europa.eu/publications/emep-eea-guidebook-2019>.

⁷⁾
Dämmgen U., Hutchings N.J. (2008): Emissions of gaseous nitrogen species from manure management - a new approach. Environmental Pollution 154, 488-497.

⁸⁾
IPCC – Intergovernmental Panel on Climate Change (2006): IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture, Forestry and Other Land Use.

⁹⁾
Reidy B. et al. (2008): Reidy B., Dämmgen U., Döhler H., Eurich-Menden B., Hutchings N.J., Luesink H.H., Menzi H., Misselbrook T.H., Monteny G.-J., Webb J. (2008): Comparison of models used for the calculation of national NH₃ emission inventories from agriculture: liquid manure systems. Atmospheric Environment 42, 3452-3467.

¹⁰⁾
Dämmgen U., Erisman J.W. (2005): Emission, transmission, deposition and environmental effects of ammonia from agricultural sources. In: Kuczyński T., Dämmgen U., Webb J., Myczko (eds) Emissions from European Agriculture. Wageningen Academic Publishers, Wageningen. pp 97-112.

¹¹⁾
EMEP (2013): EMEP/EEA air pollutant emission inventory guidebook – 2013