# 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 |

| Key Category | $SO_2$ | $NO_x$ | $NH_3$ | NMVOC | CO | BC | Pb | Hg | Cd | Diox | PAH | HCB | TSP | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.B.1.a | - | -/- | L/T | L/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.1.b | - | -/- | L/T | L/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.2 | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.3 | - | -/- | L/T | -/- | - | - | - | - | - | - | - | - | L/- | -/- | -/- |
| 3.B.4.d | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.4.e | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.4.g.i | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | L/- | -/- | -/- |
| 3.B.4.g.ii | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.4.g.iii | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |
| 3.B.4.g.iv | - | -/- | -/- | -/- | - | - | - | - | - | - | - | - | -/- | -/- | -/- |

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

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

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

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

## Country specifics

In 2019, $NH_3$ emissions from category 3.B (manure management) derived up to 43.6 % from total agricultural emissions, which is equal to ~ 243.3 kt $NH_3$. Within those emissions 47.2 % originate from

cattle manure (~ 114.9 kt), 36.4 % from pig manure (ca. 88.5 kt), and 13.3 % from poultry manure (~ 32.4 kt). Calculations take into account the impact of anaerobic digestion of manure on the emissions.

$NO_x$ emissions from category 3.B (manure management) contribute only 1.2 % (~ 1.4 kt) to the total agricultural $NO_x$ emissions. They are calculated proportionally to $N_2O$ emissions, see Rösemann et al. (2021) [1)].

NMVOC emissions from category 3.B (manure management) contributed 97.2 % (295.8 kt) from total agricultural NMVOC emissions (304.4 kt).

In 2019, manure management contributed, respectively, 71.1 % (42.9 kt), 42.7 % (13.0 kt) and 84.8 % (3.7 kt) to the total agricultural TSP, $PM_{10}$ and $PM_{2.5}$ emissions (TSP: 60.3 kt, $PM_{10}$: 30.4 kt, $PM_{2.5}$: 4.4 kt, respectively).

## Activity data for all pollutants

The Federal Statistical Agency and the Statistical Agencies of the federal states carry out surveys in order to collect, along with other data, the head counts of animals. The results of these surveys are used for emission calculations, for details see Rösemann et al, 2021, Chapter 3.4.2.

The animal population figures used in the inventory are presented in Table 1. Buffaloes are included in the cattle population figures, mules and asses are included in the horse population figures (IE), see Rösemann et al. (2021), Chapters 4.1 and 7.1. In the first years after the German reunification in 1990 animal livestock decreased markedly. The head counts for cattle continued to decrease significantly until 2006/2007, followed by a more or less stable period until 2014. Since 2015 a slight decrease occurred. In 2019, dairy cattle numbers are 63.1 % of 1990 numbers, while the total population of other cattle is at 58.1 % of 1990. Swine numbers decreased until 1995 and then increased slightly. Since 2014 a slight decrease occurred (2019: 81.5 % of 1990). The 2019 numbers of horses, sheep and goats are, respectively, at 84.6 %, 55.5 % and 163.8 % of 1990.

Figures for broilers and turkeys are showing a massive increase since 1990. In total, 2019 poultry population figures are at 154.1 % of 1990. A detailed description of the animal figures used can be found in the National Inventory Report 2021 [2)], Chapter 5.1.3.2.3.

*Table 1: Population of animals*

| **Population of animals (in 1000)** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1990** | **1995** | **2000** | **2005** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| dairy cattle | 6,354.6 | 5,229.4 | 4,569.8 | 4,236.4 | 4,183.1 | 4,190.1 | 4,190.5 | 4,267.6 | 4,295.7 | 4,284.6 | 4,217.7 | 4,199.0 | 4,100.9 | 4,011.7 |
| other cattle | 13,133.4 | 10,660.5 | 9,968.9 | 8,800.4 | 8,628.7 | 8,340.4 | 8,319.1 | 8,418.4 | 8,446.5 | 8,350.8 | 8,248.9 | 8,082.2 | 7,848.2 | 7,627.9 |
| buffalo | NO | NO | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE |
| mules and asses | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE | IE |
| 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 UmweltInformationsystem 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.

# $NH_3$ and $NO_x$

## Method

### N in manure management

#### N excretion

In order to determine $NH_3$ and $NO_x$ emissions from manure management of a specific animal category, the individual N excretion rate must be known as well as, for $NH_3$, 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, 2019[6]. 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*

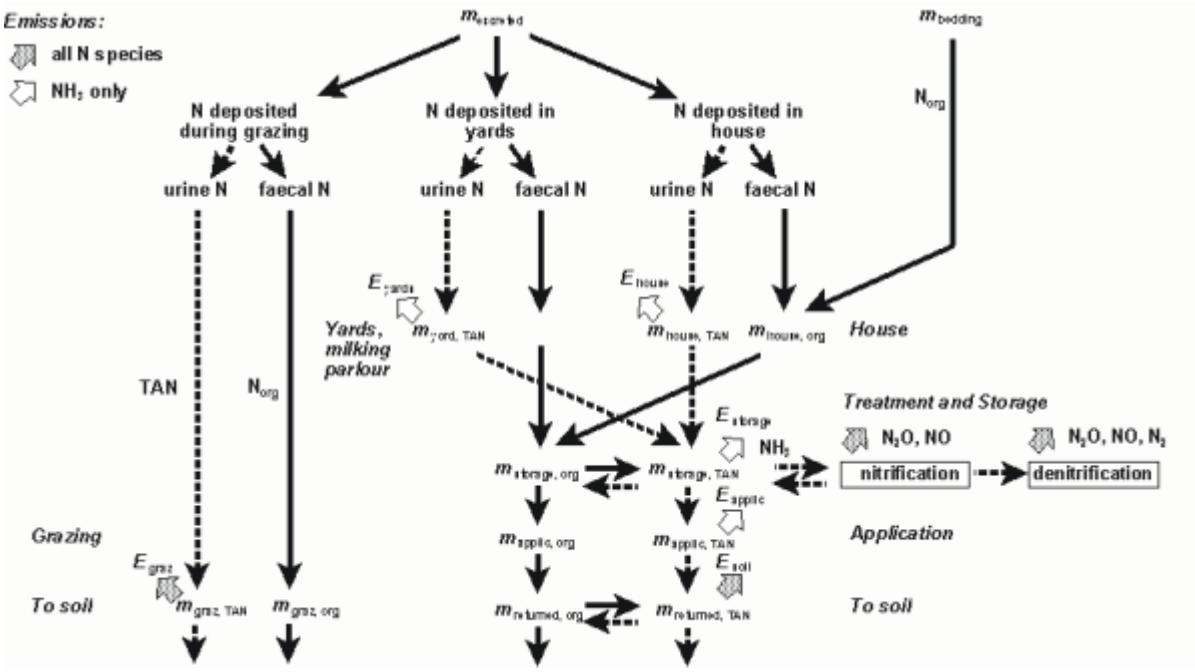
| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **mean N excretions in kg per animal place** | | | | | | | | | | | | | | |
| **dairy cattle** | 92.0 | 97.9 | 103.8 | 108.9 | 110.3 | 111.0 | 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 |

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **mean N excretions in kg per animal place** | | | | | | | | | | | | | | |
| **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 $NH_3$, $N_2O$, $NO_x$ and $N_2$ from German animal husbandry is based on the so-called N mass flow approach (e. g. Dämmgen and Hutchings, 2008 [7)]). 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 $NH_3$ 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 Norg 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 Norg 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, 2005 [10)]). 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 (Norg + 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 N2 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.

$NH_3$ and NO emissions occur from pre-storage of solid manure, from non-gastight storage of digestates and from landspreading of digestates ($NH_3$ 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 $NH_3$ 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 $NH_3$, $N_2O$, $NO_x$ and $N_2$ describing the emissions from the various housing and storage systems.

The detailed $NH_3$ 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 $NH_3$ emission factors are country specific but some are taken from EMEP (2019). No specific $NH_3$ 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 $NH_3$ emission factors for manure management (housing and storage). The overall German $NH_3$ IEF for manure application is reported in section 3.D.a.2.a.

The detailed emission factors for $N_2O$, $NO_x$ and $N_2$ relate to the amount of N available which is N excreted plus, in case of solid manure systems, N input with bedding material. The $N_2O$ emission factors are taken from IPCC (2006). The emission factors for $NO_x$ and $N_2$ are approximated as being proportional to the $N_2O$ emission factors, i. e. the NO-N and $N_2$ emission factors are, respectively, one-tenth and three times the value of the $N_2O$-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 $N_2O$ 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 NOx. 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 $NH_3$ 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 $NH_3$ & $NO_x$ from manure management*

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IEF in kg $NH_3$ 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 |

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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 |
| **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 $NH_3$ emissions from manure management. The time series of the total $NH_3$ 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 $NH_3$ 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 $NH_3$ and $NO_x$ from 3B with the respective data of last year's submission. The total emissions of $NH_3$ 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 $NH_3$ 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 $NH_3$ 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 $NH_3$ emissions of other animals increased for all years of the time series due to the update of the $NH_3$ 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 $NH_3$ 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 | |

| NOₓ 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.

# NMVOC

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 – $x_{graz}$ with $x_{graz}$ the proportion of the year spent on pasture, see NIR 2021, Chapter 19.3.2,
- $FRAC_{silage}$: 1 as proposed by EMEP (2019)-3B-29, since silage feeding for cattle is considered dominant in Germany
- $FRAC_{silage\ store}$: 0.25 as proposed by EMEP (2019)-3B-30 for European conditions
- $EF_{NMVOC,\ silage_feeding}$, $EF_{NMVOC,\ house}$, $EF_{NMVOC,\ graz}$ are taken from EMEP (2019)-3B-32, table 3.11 as 0.0002002, 0.0000353 and 0.0000069 kg NMVOC/MJ feed intake, respectively,
- $EF_{NH_3,storage}$, $EF_{NH_3,building}$ and $EF_{NH_3,application<sub> are taken from the NH<sub>3}$ 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 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 $PM_{10}$ 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

EMEP (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 2013[11)] 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 $PM_{10}$, 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, $PM_{10}$ 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, $PM_{10}$ & $PM_{2.5}$ 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 $PM_{10}$ 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 |
| **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 |

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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, $PM_{10}$ & $PM_{2.5}$) 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 | |
| **$PM_{10}$** | **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 |
| **$PM_{10}$** | **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