Agricultural emissions of NMVOC and PM

Literature review and selection of emission factors

Marcel Bühler, Thomas Kupper

Final report

Zollikofen, June 27th, 2018

Commissioned by the Federal Office for the Environment (FOEN)

Bern University of Applied Sciences
School of Agricultural, Forest and Food Sciences HAFL

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Table of contents

List of abbreviations

AAP	Average annual animal population
BVOC	Biogenic volatile organic compounds
CAFO	Concentrated animal feeding operations
CAS Number	Chemical Abstracts Service Number
CH	Switzerland
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO_2	Carbon dioxide
DE	Germany
DK	Denmark
dm	Dry matter
EEA	European Environment Agency
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme
EMIS	Swiss Emission Information System
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FOEN	Federal Office for the Environment
FSO	Federal Statistical Office
GC-FID	Gas chromatography with flame ionisation detector
GC-MS	Gas chromatography mass spectrometry
IIASA	International Institute for Applied Systems Analysis
IIR	Informative Inventory Report
IPCC	Intergovernmental Panel on Climate Change
IUPAC	International Union of Pure and Applied Chemistry
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft eV
LIDAR	Light detection and ranging
LN	Agricultural area
LU	Livestock Unit. 1 LU = 500 kg live weight of an animal category
m/z-ratio	Mass-to-charge ratio used in mass spectrometry
MJ	Gross feed intake in mega joule
NAEMS	National Air Emissions Monitoring Study
NFR	Nomenclature for Reporting
NH_3	Ammonia
NL	Netherlands
NMHC	Non-methane hydrocarbons
NMVOC	Non-methane volatile organic compounds
OVOC	Oxygenated volatile organic compounds
PM	Particulate matter
PM10	Particles with a diameter of 10 µm or less
PM2.5	Particles with a diameter of 2.5 µm or less
PTR-MS	Proton-transfer-reaction mass spectrometry
PTR-TOF	Proton-transfer-reaction time-of-flight mass spectrometry
RAINS	Regional Air Pollution INformation and Simulation
TEOM	Tapered element oscillating microbalance
TSP	Total suspended particles
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VFA	Volatile fatty acids
VOC	Volatile organic compounds
VS	Volatile Solids
YC	Young cattle

Summary

This report provides information and suggestions to choose emission factors for Switzerland's air pollution emission inventory and Informative Inventory Report (IIR) for the source categories 3B Manure management and 3D Crop production and agricultural soils for the pollutants particulate matter (PM) and non-methane volatile organic compounds (NMVOC).

The last so-called in-depth stage 3 review of Switzerland's air pollution emission inventory (NFR tables) and IIR in 2016 made several suggestions concerning the EFs of PM and NMVOC from 3B Manure management and 3D Crop production and agricultural soils. This was the case since Switzerland did not report any NMVOC emissions from manure management and PM emissions from crop production and agricultural soils. Furthermore, Switzerland was not able to provide any source for their country specific emission factors. This report should help to overcome the mentioned shortcomings.

3B Manure management: a literature study showed that several sources are available for PM emission factors. For almost all livestock categories, an EF could be found. It seems that even more grey literature is available that we were not able to include in our study. The general problem is that these EFs differ widely between studies and countries and it is difficult to assess which of them are most representative for Switzerland. If for all livestock categories the default Tier 1 EFs from the EMEP/EEA Guidebook (2016) are used, 39%, 56% and 89% of TSP, PM10 and PM2.5 emissions, respectively, originate from cattle (in the reference year 2015) which is believed to be rather high as compared to the inventories of other countries. Therefore, we were charged to evaluate the possibility to establish country specific emission factors for dairy and non-dairy cattle based on PM10 measurements carried out in Switzerland by Schrade (2009). In the course of this work it could be shown that the emission factors used in the EMEP/EEA Guidebook (2016) for dairy and non-dairy cattle included questionable assumptions. Thus, country specific EFs were derived with fraction ratios for the different PM size fractions found in the reviewed literature. It was possible to provide EFs for dairy and non-dairy cattle in tied- and loose housings, which can then be aggregated according to the distribution of the housing systems in the corresponding years. For the reference year 2015, new country specific EFs for dairy cattle result which are a factor of 2.5, 3.5 and 9.5 smaller for TSP, PM10 and PM2.5, respectively, than the Tier 1 EFs in Table 3.5 of the EMEP/EEA Guidebook (2016). Compared to the currently used EFs for dairy cattle in the emission inventory, the new country specific EFs are 0.7, 2.2 and 1.4 times smaller for TSP, PM10 and PM2.5, respectively. With the updated EFs, 26%, 28% and 51% of the TSP, PM10 and PM2.5 emissions, respectively, in 2015 originate from cattle. Moreover, the provided Tier 1 TSP EF for fattening pigs and the PM10 and PM2.5 EFs for goats in the EMEP/EEA Guidebook (2016) were not verifiably. The EFs given in the EMEP/EEA Guidebook (2016) for these livestock categories do not coincide with the referenced literature sources. Therefore, the EFs from the original source for fattening pigs as well as for goats, which are also applied for sheep, lamas/camels and deer were used. For all other livestock categories and PM size fractions, we suggest to use the default Tier 1 EFs provided in the EMEP/EEA Guidebook (2016).

A literature study was also conducted for NMVOC emissions from manure management where the data base is very scarce and the EFs differ widely. One problem is that most of the studies rather focused on single compounds than on total NMVOC emissions. The review of some of the studies used for the EFs in the EMEP/EEA Guidebook (2016) showed several inconsistencies that can have significant effects on the EFs. It remains unknown, how the emissions from the United States Environmental Protection Agency (EPA) 2012 studies were adapted to European agricultural feeding conditions and how the corresponding EFs were built. We observed that the emissions for dairy and non-dairy cattle from the Tier 2 methodology in the EMEP/EEA Guidebook (2016) are twice as high as the emissions calculated with the Tier 1 methodology. This is a questionable result as both methodologies are based on the same EPA studies. Further investigation on emissions from silage-feeding revealed that Tier 2 methodology provides possibly more reasonable emissions from silage-feeding than the Tier 1 methodology. On the other hand, the Tier 2 methodology uses an approach to calculate NMVOC emissions based on the ratio between NH_3 and NMVOC but that should not be

used as it leads to a clear overestimation of the emissions. Therefore, both methodologies include questionable or erroneous assumptions and we cannot recommend a methodology which is best to use. The current available literature is too scarce to determine valid EFs for all livestock categories. Hence, it is suggested to postpone the derivation of NMVOC EFs and the reporting of NMVOC emissions from source category 3B Manure management until more reliable data is published or to launch measurements as a base for country specific emission factors.

3D Crop production and agricultural soils: less literature is available for this source category than for 3B Manure management within sector 3 Agriculture. For particulate matter, several studies are available reporting EFs from different soil operations. However, only a few studies could be found concerning PM emissions from crop harvesting. According to the EMEP/EEA Guidebook (2016), emissions are defined as the particles leaving the field boarder. This makes it more difficult to determine emissions as assumptions need to be established regarding the fractions of the particles deposited within the field. We suggest to use the Tier 2 methodology in the EMEP/EEA Guidebook (2016). However, it is important to state that the EFs have a large uncertainty and the resulting emissions are uncertain due to the lack of emission measurements from several crop types.

For NMVOC emissions from crop production and agricultural soils, the data base is most scarce. The emission factors in the EMEP/EEA Guidebook (2016) are based on studies from 1993 and 1995. More recent studies are available but similar to older studies they are based on short term measurements. For more reliable data long term measurements over the entire growing period including the harvest for several different crops are necessary. Despite the large uncertainty entailed with the EFs, we nevertheless, suggest to use the Tier 2 methodology in the EMEP/EEA Guidebook (2016) and using country specific data for dry matter content and growing period.

Conclusion: overall, it can be stated that this report leads to an improvement of the Swiss air pollution emission inventory and suggests at the same time that the EMEP/EEA Guidebook (2016) should consider revising the pollutants particulate matter and NMVOC in the source categories 3B Manure management and 3D Crop production and agricultural soils .

1 Introduction and aims

Within the framework of the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), Switzerland is committed to report the current emissions. This includes, among others, non-methane volatile organic compounds (NMVOC) and particulate matter (PM). The EMEP/EEA air pollutant emission inventory Guidebook 2016 provides a basis for the reporting. In the scope of the 2016 review, the EMEP emission centre CEIP made several suggestions for the improvement of the inventory of the agricultural sector (United Nations, 2016).

Based on this review and the current situation, the Federal Office for the Environment requested a thorough evaluation on emissions of NMVOC and PM from the agricultural sector and a report of the outcomes thereof. The goal of this task is to determine appropriate emission factors as a basis for updated and reliable emission calculations. This has to be done for the source categories 3B Manure management and 3D Crop production and agricultural soils of the EMEP/EEA Guidebook (2016) for the pollutants NMVOC, TSP (total suspended particles), PM10 and PM2.5.

2 Literature review on particulate matter

The reviewed studies were categorised according to the livestock categories provided in the ammonia emission inventory based on the model Agrammon (www.agrammon.ch) published in Kupper et al. (2018). They were subsequently aggregated to the nomenclature for reporting (NFR) source categories used in the EMEP/EEA Guidebook (2016) and in EMIS (Swiss Emission Information System). All studies included in the present report are listed in the references. In addition, Annex 1 comprises studies on PM emissions which could be relevant as well but were not considered owing to the restricted time of the present mandate.

2.1 3B Manure Management

The following numbers of studies on PM emission measurements from housings were included: thirteen for cattle, ten for swine, eighteen for poultry, three for goats and one for rabbits.

In the reviewed literature, the emissions are reported per animal, per livestock unit (LU) or per animal place. Whenever feasible, the data was transformed to kg per animal per year [kg animal^{-1} a^{-1}]. If the average live weight or any kind of live weight information was missing in the literature the transformation of the EFs from LU into animal was not possible. The emissions given in terms of unit per animal place were assumed to be equal to the emission per animal for livestock categories with one production cycle per year like dairy cows, goats and laying hens. This does not apply to livestock categories with several production cycles per year such as fattening pigs, broilers and turkeys. In case of missing information on the duration of the production cycle and the empty period the transformation from animal place to animal was not possible.

Further, we would like to mention that in the following sections of this chapter the emission factors of some studies are given in tables and others just in running text. If studies are given in tables it is done for practical or comprehensibility reasons and does not indicate that they are more important than others. This is especially the case for data from Takai et al. (1998) and Vonk et al. (2016).

2.1.1 Dairy cattle

Here we present the current state of the reviewed literature for dairy cattle and discuss the recommendation from a scientific point of view to derive country specific EFs instead of using default Tier 1 EFs provided by the EMEP/EEA Guidebook (2016). The procedure is explained below for the livestock category dairy cattle.

For dairy cattle, eleven different studies reporting emission factors from seven different countries could be found. In a comprehensive study, Takai et al. (1998) examined emissions from dairy cattle kept either in tied housings or loose housings with production of slurry or slurry and solid manure, respectively, in UK, the Netherlands, Denmark and Germany. Koerkamp and Uenk (1997) presented early results from the study of Takai et al. (1998) for the Netherlands. Schmidt et al. (2002) measured emissions of TSP, PM10 and PM2.5 from a naturally ventilated dairy house with 500 cows in the US. Goodrich et al. (2002) reported TSP and PM10 emissions from a loose housing with an open lot in Texas. One year later, Goodrich et al. (2003) measured again in the same housing, but this time only TSP emissions. Schrade (2009) measured PM10 emissions from loose housings in Switzerland yielding several EFs which are published later in Schrade et al. (2010) and Schrade et al. (2017). Joo et al. (2013) published TSP, PM10 and PM2.5 emissions measured in Washington State in the US. Mosquera et al. (2010) measured all size fractions in four loose housings in the Netherlands. Winkel et al. (2015) presented recalculations of published data and Vonk et al. (2016) published a report based on the measurements conducted by Mosquera et al. (2010) including some transformations for other housing systems and other cattle categories. Hinz et al. (2007) conducted TSP and PM10 emission measurements in a Polish tied housing. Henseler-Passmann (2010) measured PM10 emissions in loose housings either with production of slurry or deep litter. Heidenreich et al. (2008) conducted TSP and PM10 emission measurements in a slurry production system and in a system with production of slurry and solid manure. The EFs of all mentioned studies are listed in Table 1.

From the above mentioned studies reporting emissions from dairy cattle (Vonk et al., 2016; Schmidt et al., 2002; Goodrich et al., 2003; Goodrich et al., 2002; Joo et al., 2013; Takai et al., 1998; Koerkamp and Uenk, 1997; Schrade, 2009; Winkel et al., 2015; Mosquera et al., 2010; Schrade et al., 2017; Hinz et al., 2007; Heidenreich et al., 2008; Henseler-Passmann, 2010), we selected the ones which were conducted in housing systems and under climatic conditions being comparable to Switzerland. The EFs are classified according to the housing systems used by Kupper et al. (2018). In the following sections, the explanation for exclusion and inclusion of reported data is given.

Literature data excluded: Schmidt et al. (2002) conducted measurements during the hot summer and warm winter in Texas and more important, the values of the published EFs are questionable: the mass fraction of PM10 and PM2.5 are equal in winter and in summer, and the EF for PM2.5 is larger than the one for PM10. Moreover, no information is provided on the housing system. We assume that it was a loose housing system with production of slurry, which is typical in the US for concentrated animal feeding operations (CAFO). Goodrich et al. (2002) was excluded because the data was collected only during the summer in Texas which is much warmer than in Switzerland. In addition, contamination from unpaved roads in the surrounding area could have distorted the measurements. A study from the same author conducted in 2003 was excluded as well since it contains only summer values and is also derived from a dairy farm with more than 2000 animals (Goodrich et al., 2003). The results from Joo et al. (2013) were excluded because of the temperature prevailing at the study site. Washington State has humid winters and dry summers compared to moderately humid winters and summers in Switzerland. Washington State has larger temperature fluctuations within the year and about half the precipitation as compared to Switzerland. The study from Koerkamp and Uenk (1997) was excluded since it presents preliminary results from Takai et al. (1998). As mentioned above it contains only results from the Netherlands and furthermore, only EFs for respirable dust are provided. Inhalable dust is only stated in concentration value and no EF is given. Also, the provided EFs by Koerkamp and Uenk (1997) differ from those provided by Takai et al. (1998) which is not comprehensible and additionally, the publication was not peer-reviewed. However, Koerkamp and Uenk (1997) provide somewhat more information on the examined housing systems. Taking this into account we concluded that the term “litter” used in Takai et al. (1998) is equal to “tied housing” and “calves” are actually fattening calves. Henseler-Passmann (2010) was excluded as the EFs are based on measurements where the animals might have been partially grazed. With the available data it was not possible to conclude if the animals were sometimes on the pasture during the measurements or the EFs were corrected afterwards for the time the animals were grazed. Without this information it is not possible to compare these EFs with others. Furthermore, the original source of this study (PhD thesis) was not available and data was adopted from Schrade et al. (2017).

Literature data included: Still, the selected studies (marked with X in Table 1) are partly imperfect. All of them contain gaps and inconsistencies. First, Takai et al. (1998) measured only inhalable and respirable dust. Inhalable dust, which are particles that can be inhaled through the nose and mouth is approximately equal to PM100 or TSP. Respirable dust, which are particles that can penetrate into the larynx is either equal to PM4 (EN481:1993 and ISO 7708:1995) or PM5 (Convention of Johannesburg) (Cambra-Lopez et al., 2010). Here, respirable dust is defined according to the Convention of Johannesburg. Second, the measurements in the UK and Germany were conducted during winter only. Third, the EFs were calculated by multiplying daily average exhaust rates estimated with a CO_2 mass balance method by Seedorf et al. (1998) with the measured concentrations near the exhaust. It remains unclear, whether the concentration measurements and the exhaust rates estimations were conducted on the same day. Since the emission rates are heavily influenced by the exhaust rate the actual EFs might differ considerably from the given ones. Finally, the dust measurements were not inlet or background corrected as concentration measurements were conducted only inside the housings. Strong points of this study are that the measurements were conducted during night and daytime so that influences by animal activity and feeding times are accounted for. Furthermore, for the Netherlands and Denmark, the measurements were done during summer and winter.

Table 1 Overview of the literature that provides EFs for dairy cattle. The studies marked with an X in the last column could be representative for Swiss livestock housing systems

Manure	Source	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]	Marked
EMEP/EEA Guidebook, 2016, Tier 1 (Table 3.5 and A1.6)					
all systems	Takai et al., 1998	1.38	0.63	0.41	
slurry	Takai et al., 1998	1.81	0.83	0.54	
solid	Takai et al., 1998	0.94	0.43	0.28	
Tied housings					
slurry	Vonk et al., 2016	-	0.081	0.022	X
slurry and solid	Hinz et al., 2007	0.184	0.070	-	X
slurry and solid	Takai et al., 1998	1.016*	-	-	X
slurry and solid	Koerkamp and Uenk, 1997	-	-	-	
Loose housings, cubicles, slurry					
slurry	Winkel et al., 2015	2.321	0.075	0.014	X
slurry	Joo et al., 2013	18.469	4.909	1.022	
slurry	Mosquera et al., 2010	3.900	0.148	0.041	X
slurry	Henseler-Passmann, 2010 in Schrade et al., 2017	-	0.076*	-	
slurry	Schrade, 2009; Schrade et al., 2017	-	0.234	-	X
slurry	Heidenreich et al., 2008 in Schrade et al., 2017	0.630	0.210	-	X
slurry	Goodrich et al., 2003	3.960	-	-	
slurry	Goodrich et al., 2002	2.957	0.730	-	
slurry	Schmidt et al., 2002	4.515*	0.379*	2.033*	
slurry	Takai et al., 1998	1.964*	-	-	X
slurry	Koerkamp and Uenk, 1997	-	-	-	
Loose housings, cubicles, slurry and solid manure					
slurry and solid	Heidenreich et al., 2008 in Schrade et al., 2017	1.340	0.360	-	X
Loose housings, deep litter					
deep litter	Henseler-Passmann, 2010 in Schrade et al., 2017	-	0.702*	-	

*EFs were provided as per LU. An average live weight of 650 kg per dairy cattle was used.

The measurements conducted by Schrade (2009) and later published in Schrade et al. (2010) and Schrade et al. (2017) are the only results from Switzerland. The measurements were conducted during all seasons for periods of 72 h which is long enough to avoid distortions due to the influence of animal activity and diurnal fluctuations. In addition, they are background corrected. Nonetheless, the studies include exclusively values for PM10. The original EF is given in per livestock unit (LU) and per animal. The transformation was based on the reported live weight of the animals.

Mosquera et al. (2010) provide measurement results for all PM size fractions of interest (TSP, PM10, PM2.5). Emissions at four different farms of the same housing system were determined in order to take into account variations between different farms. The challenges related to daily and seasonal variations of dust emissions were met by measurements conducted every second month for 24 hours. Usually, the cattle had three hours grazing time but for the study period, they were kept all day inside the housing. The emission factors were calculated from the concentration measurements and the average daily ventilation rate. The only drawback is that background measurements of TSP are lacking and therefore, the resulting data are not inlet corrected. Hence, we might assume that the emission factor for TSP is too high. This might also be the reason why the EF for TSP is included in running text only and not presented in any table or in the summary or conclusion. The EFs from Mosquera et al. (2010) are actually given as emission per animal place instead of per animal. However, for dairy cattle these terms can be used interchangeably.

Winkel et al. (2015) is actually a summary of several reports published by the Wageningen UR Livestock Research Institute including the findings from Mosquera et al. (2010) which are used for dairy cattle. However, different outdoor temperatures and humidity are reported and EFs differ from the original literature by a factor of two for all size fractions. E.g. the EFs from Mosquera et al. (2010) are twice as high as those given in Winkel et al. (2015). The fact that Winkel et al. (2015) is peer-reviewed would suggest to consider their EFs as correct. Further, for all the EFs from different livestock categories the authors provide an arithmetical and a geometrical mean. The geometrical mean is in fact a back transformed model prediction to eliminate unwanted variability. They use the geometrical mean as they claim it is more robust but leads to lower EFs, because the single measurements were positively skewed. In Table 1 the arithmetical mean is given, because some of the concentration measurements from dairy cattle for PM10 and PM2.5 were negative and therefore the model could not be applied. The geometrical mean for TSP would be 1.726 kg animal^{-1} a^{-1}. Nevertheless, Julio Mosquera assured us that his values are the correct ones and that the recalculations cannot explain these huge differences (personal communication with Mosquera (2017)). Therefore, the data published by Winkel et al. (2015) have to be considered with caution.

Vonk et al. (2016) is also a summary of several reports published by the Wageningen UR Livestock Research Institute. It is basically the supplementary information to the Dutch IIR for the PM emissions of source category 3B Manure management, plus some additional information. Vonk et al. (2016) list in their report EFs for PM10 and PM2.5 from dairy cattle in a tied housing system and a cubicle system with and without grazing. The EFs for the cubicle system were measured by Mosquera et al. (2010). The given EFs for grazing are derived from those without grazing and just corrected by the fraction of time the animals spend usually outside. For the EFs from tied housing given in Vonk et al. (2016), no original source could be found. From Mosquera and Hol (2011) we know that some of the EFs given in Mosquera and Hol (2011) and Vonk et al. (2016) were recalculated and derived from EFs presented in Mosquera et al. (2010), but no reliable information regarding the EFs of the tied housing system was found.

Due to time issues, Hinz et al. (2007) could not be fully examined and therefore no quality assessment is possible. We can only state that the PM10 measurements were conducted during November only and the TSP during July and November. For Heidenreich et al. (2008), we encountered the same problem, as we found this publication after the review process. We cannot make any statement on the quality of the data.

The default Tier 1 EF of the EMEP/EEA Guidebook (2016) are based on the EFs from Takai et al. (1998). Firstly, the authors of the Guidebook categorise slurry and solid manure, which are denoted as “cubicles” and “litter” in the underlying literature. Then, the average (50/50) of both EFs based on the solid/liquid distribution of the livestock manure management system were taken which amounts to 49/51 according to EU reporting to the UNFCCC in 2011. However, the average was calculated over all countries and the fact that for UK and Germany the measurements were exclusively conducted during winter was neglected. This average is the value for the default Tier 1 EF methodology. A Tier 2 EF methodology does not exist per se. However, one could use a country specific distribution of solid/liquid manure management system instead (Table A1.6 of the EMEP/EEA Guidebook (2016)). The EFs from Takai et al. (1998) are related to 500 kg live weight. To transform these EFs to per animal, the Guidebook assumes an average weight of 600 kg per dairy cattle. In Switzerland the average weight of dairy cattle is determined as 650 kg (Flisch et al., 2009). As described above, Takai et al. (1998) provide TSP values only and therefore, fraction values based on Seedorf and Hartung (2001) were used in the Guidebook in order to determine the EFs of PM10 and PM2.5 (Table A1.5 of the EMEP/EEA Guidebook (2016)).

If some size fractions are missing a viable strategy is to calculate the different PM fractions as a proportion of TSP. However, in order to extract comparable results from actual measurements a proper definition of TSP and the measuring procedure is required (EMEP/EEA Guidebook, 2016). A series of fraction values found in the literature is given in Table 2. They are either directly adopted or calculated based on the provided EFs in the underlying literature. The Guidebook uses the fraction value for PM10 provided by Seedorf and Hartung (2001), which measured all size fraction in a cubicle house with dairy cows and calves, kept on a slatted floor and a solid floor with straw, obtained within a 24-hour monitoring campaign. The fraction value for PM2.5 was determined later and personally communicated by Seedorf and Hartung (2001) to the authors of the Guidebook. IIASA (2014) uses for its RAINS-model EFs from a Dutch emission inventory from where we derived the listed fraction values. The fraction values from Goodrich et al. (2003), Hinz et al. (2007), Heidenreich et al. (2008), Joo et al. (2013), Winkel et al. (2015) and Vonk et al. (2016) are derived from the reported EFs. Mosquera et al. (2010) provide two kind of fraction values. Fraction values of 0.17 and 0.07 for PM10 and PM2.5, respectively, are given in their report. But it is not clear how they were derived, because the fraction values that we calculated from the provided EFs of TSP, PM10 and PM2.5 are 0.02 and 0.01, respectively.

Table 2 Fraction values of the different PM fractions compared to TSP or PM10 for dairy cattle. They were either directly provided in the underlying literature or calculated out of the provided EFs. Values marked with two stars (**) were used later on in the model (see Chapter 3)

Animal	TSP	PM10	PM2.5	Source
dairy cattle	100%	46%	30%	Seedorf and Hartung, 2001 cited in EMEP/EEA Guidebook (2016)
dairy cattle	100%	3%	0.6%	Winkel et al., 2015
cow	100%	40%	12%	IIASA, 2014
dairy cattle	100%	27% **	5.5%	Joo et al., 2013
dairy cattle	100%	4%	1.1%	Mosquera et al., 2010
dairy cattle	100%	17%	7%	Mosquera et al., 2010 (expert judgement)
dairy cattle	100%	27% **	-	Heidenreich et al., 2008
dairy cattle	100%	33% **	-	Heidenreich et al., 2008
dairy cattle	100%	38% **	-	Hinz et al., 2007
dairy cattle	100%	25% **	-	Goodrich et al., 2002
dairy cattle	-	100%	28%	Vonk et al., 2016
dairy cattle	-	100%	65%	EMEP/EEA Guidebook, 2016
dairy cattle	-	100%	19%	Winkel et al., 2015
cow	-	100%	30%	IIASA, 2014
dairy cattle	-	100%	21% **	Joo et al., 2013
dairy cattle	-	100%	28% **	Mosquera et al., 2010
dairy cattle	-	100%	41%	Mosquera et al, 2010 (expert judgement)

The fraction values used by the Guidebook (Tables 3.5 and A1.5) are not beyond all doubt. They are not solely based on one single short term measurement (24 h), but they contradict somewhat with the measurements conducted by Takai et al. (1998) on which they were applied on, which is explained in the following. The calculated fraction value of the measured respirable dust (here PM5) on inhalable dust or TSP in Takai et al. (1998) is on average 0.29 (see Table 3). The fraction values within one country are about the same for the two housing systems, contrasting to their wide variation between the countries, which is in the order of one magnitude (see Table 3). Hypothetically, we can suggest excluding the measurements from the UK, as it is the only country with higher PM emissions from the litter system and it is suggested that housing systems with litter produce less PM emission due to the sticking of particles to the humid bedding (EMEP/EEA Guidebook, 2016). Without the UK values, the overall average of the fraction value of respirable dust on inhalable dust would be 0.14, which is about half the number given in Table 3. In respirable dust, respectively PM5, PM2.5 is already included and therefore, the PM5 fraction value should be larger than the fraction value of 0.30 for PM2.5 provided by Seedorf and Hartung (2001), otherwise they contradict each other.

Table 3 Fraction values from EFs of respirable dust (PM5) on inhalable dust (TSP) derived from Takai et al. (1998)

System	UK	NL	DK	DE	average
litter	0.59	0.22	0.11	0.08	0.25
cubicle	0.86	0.25	0.11	0.09	0.33
average	0.72	0.23	0.11	0.08	0.29

The listed fraction values in the upper part of Table 2 for PM10 and PM2.5 on TSP range from 0.03 to 0.46 and from 0.006 to 0.30, respectively, where for both fractions, the values used in the EMEP/EEA Guidebook (2016) are the highest. Further information concerning fraction values is given in the lower part of Table 2 where the fraction values of PM2.5 on PM10 are listed. The values range from 0.19 to 0.65, wherein the EMEP/EEA Guidebook (2016) reports the highest value. Thus, there is a wide range of fraction values dedicated to calculate missing EFs for PM differing between countries and studies.

Based on the considerations presented above the question remains, which EFs are most appropriate for Switzerland. In principle there are four different options:

1. Use of the EF for PM10 from Schrade et al. (2017) based on the work of Schrade (2009) and application of fraction values to calculate EFs for TSP and PM2.5. Therefore, one of the given fraction values in Table 2 or a combination of several fraction values must be chosen.
2. Use of the EFs from a study that measured all size fractions (i.e. Winkel et al., 2015; IIASA, 2014; Joo et al., 2013; Mosquera et al., 2010).
3. Use of an EF for each size fraction from different studies or an average EF from several studies for each PM fraction individually.
4. Use of the default Tier 1 EFs provided by the EMEP/EEA Guidebook (2016) (Table 3.5).

For option one, fraction values for TSP and PM2.5 must be chosen. They are either adopted from the same study, from different studies or aggregated from different studies. In anyway, this includes a subjective decision as we could come up with arguments to use almost any combination of fraction values. Option two, to use the EFs from a study which measured all size fractions is not suggested to do as they are either not applicable for Switzerland, include measuring problems or no explanation on the source (see paragraphs above). Option three, to choose EFs for the different size fractions from different sources or build an average EF from several sources, does not seem to be appropriate either. This would be a subjective decision again and another scientist commissioned with the same task would probably make a different choice. In our honest opinion, there is no best solution, as also option four, to use the EFs of the EMEP/EEA Guidebook (2016) are based on studies including measuring errors.

These problems are only arising if EFs for Switzerland for dairy cattle kept in a loose housing with production of slurry should be selected out of this literature review. There are even more problems, if EFs for dairy cattle in tied housing or loose housing with deep litter should be chosen where the EF data basis is even scarcer or the published EFs are rejected. Then, a conversion between different housing systems must be assumed.

2.1.2 Non-dairy cattle

Vonk et al. (2016) is the only study reporting EFs from suckling cows, calves from suckling cows, heifers younger than one year, heifers between one and two years and heifers older than two years (see Table 4). In this study, EFs for PM10 and PM2.5 in loose housings with production of slurry are available. However, these EFs are not based on measurements but are adapted from measurement data of dairy cattle from Mosquera et al. (2010).

Table 4 Emission factors for particulate matter from cattle categories from Vonk et al. (2016)

Livestock category	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]	Source
Suckling cows and calves from suckling cows	-	0.086	0.024	Vonk et al., 2016
Heifers >2 yr	-	0.118	0.033	
Heifers 1-2 yr	-	0.038	0.010	
Heifers <1yr	-	0.038	0.010	

Three studies are reporting EFs for beef cattle from four different countries kept in loose housings with production of slurry and loose housings with deep litter. From these three studies Takai et al. (1998) provide emission data related to LU, however without any further clarification related to the beef cattle itself (see Table 5). Therefore, it is not possible to transform them to emissions per animal. It also remains unknown if some of the measurements were actually conducted in tied housings instead of loose housings with deep litter as this was the case with dairy cattle. Since there are only a small proportion of beef animal kept in tied housings we assume that Takai et al. (1998) measured in loose housings with deep litter.

Table 5 Emission factors for particulate matter for beef cattle given in Takai et al. (1998)

Beef cattle, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
slurry	1.261	0.076	NL	Takai et al., 1998
slurry	0.683	0.013	DK	
slurry	1.025	0.018	DE	
deep litter	0.315	0.068	UK	
deep litter	1.183	0.016	DE	

Koerkamp and Uenk (1997) presented early results from the study of Takai et al. (1998) for the Netherlands. They reported an EF for respirable dust for beef cattle kept in loose housings with production of slurry of 0.208 kg animal^{-1} a^{-1}. Vonk et al. (2016) provided EFs of 0.170 kg animal^{-1} a^{-1} and 0.047 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively, which are transformed measurement data of Mosquera et al. (2010).

Three studies are reporting EFs for fattening calves from four different countries kept in loose housings with production of slurry and loose housings with deep litter. From these three studies Takai et al. (1998), provided the emission data per LU without providing further data of fattening calves. Hence, it is not possible to transform the reported EFs to emissions per animal (see Table 6). It also remains unknown if some of the measurements were done in tied housings instead of loose housings with deep litter as this was the case with dairy cattle. Since there are only a small proportion of fattening calves kept in tied housings we assume that Takai et al. (1998) measured in loose housings with deep litter.

Table 6 Emission factors for particulate matter for fattening calves given in Takai et al. (1998)

Fattening calves, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
slurry	0.552	0.045	NL	Takai et al., 1998
slurry	1.682	0.058	DE	
deep litter	0.561	0.074	UK	
deep litter	1.664	0.037	DK	
deep litter	1.244	0.105	DE	

Koerkamp and Uenk (1997) present early results from the study of Takai et al. (1998) for the Netherlands. They report an EF for respirable dust for fattening calves kept in loose housings with production of slurry of 0.046 kg $animal^{-1}$ a^{-1}. Vonk et al. (2016) provide EFs of 0.036 kg $animal^{-1}$ a^{-1} and 0.010 kg $animal^{-1}$ a^{-1} for PM10 and PM2.5, respectively, which are transformed measurement data of Mosquera et al. (2010). Furthermore, Vonk et al. (2016) list EFs for fattening calves in loose housings with production of slurry and an air scrubber installed of 0.025 kg $animal^{-1}$ a^{-1} and 0.007 kg $animal^{-1}$ a^{-1} for PM10 and PM2.5, respectively.

2.1.3 Swine

The livestock category swine is divided into the five subcategories dry sows, nursing sows, weaned piglets until 25 kg, fattening pigs and gilts and boars for service. For each subcategory emission factors could be found.

Table 7 Emission factors for particulate matter for dry sows in two different systems given in Takai et al. (1998)

Dry sows, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
conventional housings	1.060	0.114	UK	Takai et al., 1998
conventional housings	1.323	0.158	NL	
conventional housings	8.313	1.235	DK	
conventional housings	1.419	0.166	DE	
deep litter	1.261	0.429	UK	
deep litter	6.596	0.403	DE	

The findings from Takai et al. (1998) related to dry sows are given in Table 7. The eight to ten times higher emission factors in Denmark are not considered as an error but reasons for that are not specified in the literature. From the findings of Koerkamp and Uenk (1997) it is known that at least for the Netherlands in the Takai et al. (1998) study, next to dry sows also nursing sows were present during the measurements. Koerkamp and Uenk (1997) give an EF for respirable dust of 0.002 kg $animal^{-1}$ a^{-1}. Haeussermann et al. (2008) measured in a research farm with conventional housings with partly or fully slatted one-area pens. They provide an EF for PM10 of 0.256 kg LU^{-1} a^{-1}. With the average live weight given of 180 kg per sow it results in an EF of 0.092 kg $animal^{-1}$ a^{-1}. This EF is based on a 21 days measurement period in spring. Another study from Italy by Costa and Guarino (2009) conducted measurements spread over the year in conventional housings with fully slatted one-area pens. They report an EF of 0.449 kg LU^{-1} a^{-1} for PM10. Winkel et al. (2015) report EFs for dry sows in a group housing and in single housings. The EFs for single housings for TSP, PM10 and PM2.5 are 0.619 kg $animal^{-1}$ a^{-1}, 0.185 kg $animal^{-1}$ a^{-1} and 0.014 kg $animal^{-1}$ a^{-1} or 1.367 kg LU^{-1} a^{-1}, 0.409 kg LU^{-1} a^{-1} and 0.030 kg LU^{-1} a^{-1}, respectively. It is important to mention that the TSP values were not inlet corrected and consequently too high in value. The EFs for group housings in Winkel et al. (2015) are 0.159 kg $animal^{-1}$ a^{-1} and 0.012 kg $animal^{-1}$ a^{-1} or 0.421 kg LU^{-1} a^{-1} and 0.030 kg LU^{-1} a^{-1} for PM10 and PM2.5, respectively. These EFs are also used in the EMEP/EEA Guidebook (2016) (Tier 1 EF, Table 3.5) including the uncorrected TSP value. It can be assumed that the EFs for sows in single housings given by Vonk et al. (2016) are taken from Winkel et al. (2015), however, with a slight difference in the third decimal place for PM10 (0.180 instead of 0.185 kg $animal^{-1}$ a^{-1}). Both studies are a summary of previously conducted measurements of Dutch scientists and might include some transcription errors. Vonk et al. (2016) also report emission factors for boars of 0.186 kg animal^{-1} a^{-1} and 0.016 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively.

For the subcategory nursing sows, Vonk et al. (2016) list EFs of 0.410 kg animal^{-1} a^{-1} and 0.022 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively. On the other hand Costa and Guarino (2009) report an EF of 0.033 kg LU^{-1} a^{-1} for PM10 for the same livestock category.

The findings related to weaned piglets from Takai et al. (1998) are given in Table 8. On average they report an EF of 8.944 kg LU^{-1} a^{-1} and 0.661 kg LU^{-1} a^{-1} for TSP and respirable dust, respectively. Koerkamp and Uenk (1997) report an EF for respirable dust of 0.001 kg animal^{-1} a^{-1}. Haeussermann et al. (2008) measured in two research facilities with conventional housings and grooved plastic slats situated in northern Italy about 80 km apart from each other. They provide an EF for PM10 of 0.259 kg LU^{-1} a^{-1} and of 0.869 kg LU^{-1} a^{-1} from the first and the second farm, respectively. They explain the large difference in the emission factors by different farm management operations and seasonal differences, despite the fact that both measurements were conducted during autumn that lead to an exceptional low dust production for the first farm. Measurements of the first farm were run during 15 days in 2005 from September to November and for the second farm in 2006 continuously from September to October. In the first farm, the weaned piglets exhibited 36 kg live weight at the end which was higher by six kilograms as compared to the second farm. In another study from Italy by Costa and Guarino (2009) measurements spread over the year were conducted in conventional housings with fully slatted one-area pens. The animals had a final live weight of 35 kg per pig. They report an EF of 0.730 kg LU^{-1} a^{-1} for PM10. Winkel et al. (2015) report EFs for weaned piglets in conventional housing with fully slatted floors (9.8-21 kg live weight) and conventional housings with partly (50%) slatted floor (6-25 kg live weight). The EFs for fully slatted floors for PM10 and PM2.5 are 0.064 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1} or 2.383 kg LU^{-1} a^{-1} and 0.073 kg LU^{-1} a^{-1}, respectively. The EFs for conventional housings with partly (50%) slatted floors in Winkel et al. (2015) are 0.273 kg animal^{-1} a^{-1}, 0.079 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1} or 7.315 kg LU^{-1} a^{-1}, 2.278 kg LU^{-1} a^{-1} and 0.054 kg LU^{-1} a^{-1} for TSP, PM10 and PM 2.5, respectively. It is important to mention that the TSP value from the partly slatted stall was not inlet corrected and therefore too high. Furthermore, the TSP value measurement was conducted in a single house whereas the others are the mean of two houses and is also based on more measurements. This TSP EF is also used in the EMEP/EEA Guidebook (2016) (Tier 1 EF, Table 3.5). Vonk et al. (2016) give an EF for weaned piglets of 0.081 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively. It can be assumed that these EFs are based on the same measurements as the emission factors from Winkel et al. (2015) for fully slatted floors. Vonk et al. (2016) further provide emission factors for housings equipped with air scrubbers.

Table 8 Emission factors for particulate matter for weaned piglets given in Takai et al. (1998)

Weaned piglets, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
conventional housings	6.018	0.526	UK	Takai et al., 1998
conventional housings	11.467	1.069	NL	
conventional housings	11.949	0.447	DK	
conventional housings	6.342	0.604	DE	

Most of the emission factors on swine found in the literature are from fattening pigs. Ten different studies could be identified. The findings from Takai et al. (1998) related to fattening pigs are given in Table 9. These measurements were not inlet corrected and therefore too high in value. They were carried out in conventional housings with slatted floor and in housings with deep litter. On average, an EF of 5.4 kg LU^{-1} a^{-1} and 0.58 kg LU^{-1} a^{-1} for TSP and respirable dust in conventional housings, respectively, is reported. The average EFs in deep litter are 6.4 kg LU^{-1} a^{-1} and 0.62 kg LU^{-1} a^{-1} for TSP and respirable dust, respectively. Koerkamp and Uenk (1997) report an EF for respirable dust of 0.003 kg animal^{-1} a^{-1}. Measurements in conventional housings with partly or fully slatted one-area pens were conducted by the following authors: Schmidt et al. (2002) provide an EF for PM10 of 1.104 kg LU^{-1} a^{-1} measured during summer and winter in the US. Koziel et al. (2004) conducted also measurements in the US and report an EF of 1.051 kg LU^{-1} a^{-1} for PM10. The EFs from both US studies were taken from Winkel et al. (2015), as the original studies were not available. Berry et al. (2005) did an extensive study on fattening pigs in different housing systems and with different feeding strategies in Switzerland. For conventional housing with partly slatted floor they report an EF for PM10 of 0.131 kg animal^{-1} a^{-1}. With the measured live weight this results in an EF of 1.104 kg LU^{-1} a^{-1} for PM10. For conventional housing with fully slatted floor and liquid feed the EF for PM10 is 0.145 kg animal^{-1} a^{-1} or 0.990 kg LU^{-1} a^{-1}. The measurements for fully slatted floors were not conducted during initial fattening. Berry et al. (2005) also measured in housings with multi-area pens and outside yards. The emission factors from this housings system are given in Table 10, divided in indoor and outdoor area. The EFs are means of summer and winter measurements and were conducted during final fattening. The EFs given in per LU were calculated with the provided live weight. The study also reports TSP values. However, the data is given in figures only. So, exact values for TSP are not available and therefore they are not reported here. Haeussermann et al. (2008) measured in research facilities in Germany and Italy with conventional housings and partly slatted floors during the growing-finishing period. From the German and Italian farm, they provide an EF for PM10 of 2.186 kg LU^{-1} a^{-1} and 0.745 kg LU^{-1} a^{-1}, respectively. They explain the large differences with seasonal variations and especially circa three times higher ventilation rates in Germany. In another study from Italy by Costa and Guarino (2009) measurements spread over the year were conducted in conventional housings with fully slatted one-area pens and liquid feed. They report an EF of 0.945 kg LU^{-1} a^{-1} for PM10.

Table 9 Emission factors for particulate matter for fattening pigs given in Takai et al. (1998)

Fattening pigs, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
conventional housings	7.840	1.165	UK	Takai et al., 1998
conventional housings	3.662	0.350	NL	
conventional housings	5.291	0.499	DK	
conventional housings	4.660	0.298	DE	
deep litter	4.914	0.639	UK	
deep litter	7.796	0.604	DK	

Van Ransbeeck et al. (2013) conducted measurements in conventional housings with one area pens and partly slatted floor in Belgium. The difference between the two measurements is that one is a low emission stable (best available technique) and the other is a conventional one. For the conventional stable, they report EFs for PM10 and PM2.5 of 0.100 kg animal^{-1} a^{-1} and 0.008 kg animal^{-1} a^{-1}, respectively. On the other hand, the EFs for the low emission stable are 0.085 kg animal^{-1} a^{-1} and 0.007 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively. In the derived EF values of both housing types an empty period of 10% over the year is accounted for which is not considered in other studies.

Winkel et al. (2015) report emission factors from two different housing systems. Both are conventional housings with partly slatted one-area pens, but one has slanted walls and a vacuum system for manure removal (low NH_3 emissions). For the housing with slanted walls emission factors are available for both dry and liquid feeding. The findings from Winkel et al. (2015) are given in Table 11 as well as an average value of the three listed EFs. The TSP emission factors were not inlet corrected and therefore assumingly too high in value. Likewise for sows and weaned piglets, the EMEP/EEA Guidebook (2016) also uses the TSP EF from Winkel et al. (2015). For unknown reasons, the Guidebook notes the TSP EF for fattening pigs as 1.05 kg animal^{-1} a^{-1} instead of 0.603 kg animal^{-1} a^{-1}. The 1.7 times higher emission factor leads to a disproportionately high TSP emission, which was visible in our calculations (see Supplementary_Information_Agricultural_emissions_of_NMVOC _and_PM.xlsx worksheet 3B Emissions_PM). The EFs in Vonk et al. (2016) are 0.156 kg animal^{-1} a^{-1} and 0.007 kg animal^{-1} a^{-1} for PM10 and PM2.5, respectively. Additionally, they provide emission factors for air scrubbers.

Table 10 EFs for fattening pigs in different housing areas with different floors from Berry et al. (2005)

Fattening pigs, system	Measuring location	EF PM10 [kg animal^{-1} a^{-1}]	EF PM10 [kg LU^{-1} a^{-1}]	Source
outside yards	Partly slatted, outdoor	0.247	1.596	Berry et al., 2005
	Solid, outdoor	0.198	1.180	
	Average outdoor	0.223	1.388	
housings with multi-area pens	Solid indoor 1	0.081	0.470	
	Solid indoor 2	0.083	0.440	
	Average indoor	0.082	0.455	
	Total average	0.152	0.921	

Table 11 EFs for fattening pigs in two slightly different systems with dry and liquid feed from Winkel et al. (2015). EFs are given in per animal and per livestock unit (LU)

Fattening pigs, system	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]	Source
Conventional	0.365	0.125	0.006	Winkel et al., 2015
Conventional – slanted walls, dry feed	0.840	0.197	0.008	
Conventional – slanted walls, liquid feed	-	0.129	0.005	
Conventional - average	0.603	0.150	0.006	
Fattening pigs, system	**EF TSP [kg LU^{-1} a^{-1}]**	**EF PM10 [kg LU^{-1} a^{-1}]**	**EF PM2.5 [kg LU^{-1} a^{-1}]**	**Source**
Conventional	3.215	1.034	0.048	Winkel et al., 2015
Conventional – slanted walls, dry feed	7.560	1.682	0.072	
Conventional – slanted walls, liquid feed	-	0.972	0.037	
Conventional – average	5.387	1.229	0.052	

2.1.4 Poultry

The livestock category poultry is divided into the five source categories laying hens, young hens, broilers, turkeys and other poultry. For each category emission factors could be found.

The findings related to laying hens from Takai et al. (1998) are listed in Table 12. They measured in each country during four times twelve hours and the measurements were conducted during summer and winter. Please note that these EFs were not inlet corrected and therefore too high in value. Additionally, It has to be noted that the data provided by Takai et al. (1998) did not allow to provide an EF per animal.

Table 12 EF for laying hens from the UK, the Netherlands and Denmark given in Takai et al. (1998)

Laying hens, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
Manure belt	15.514	4.091	UK	Takai et al., 1998
Manure belt	30.018	5.974	NL	
Manure belt	27.428	5.580	DK	

The only measurements found that were conducted with laying hens with access to a free range are from Demmers et al. (2010). They report PM10 and PM2.5 EFs of 0.051 kg animal^{-1} a^{-1} and 0.013 kg animal^{-1} a^{-1}, respectively. The measurements were taken during two hours at two to three days during summer and winter. Aarnink et al. (2009) conducted measurements in two different aviary systems with manure belt. The Meller system exhibited PM10 and PM2.5 EFs of 0.065 kg animal^{-1} a^{-1} and 0.007 kg animal^{-1} a^{-1}, respectively, whereas the Big Dutchman yielded PM10 and PM2.5 EFs of 0.094 kg animal^{-1} a^{-1} and 0.004 kg animal^{-1} a^{-1}, respectively. In both systems, also oil spraying was used as dust reduction method which led to significant reduction of PM emissions (see supplementary file Supplementary_Information_Agricultural_emissions_of_NMVOC_and_PM.xlsx, sheet PM - poultry). Measurements conducted in Italy by Costa et al. (2012) result in a PM10 EF of 0.011 kg animal^{-1} a^{-1} whereas the ones by Valli et al. (2013) provide an PM10 EF of 0.046 kg animal^{-1} a^{-1} or 14.892 kg LU^{-1} a^{-1}. Hayes et al. (2013) report EFs for PM10 and PM2.5 from a Big Dutchman system in the US with about 48'000 animals per house of 0.040 kg animal^{-1} a^{-1} and 0.003 kg animal^{-1} a^{-1} or 10.768 kg LU^{-1} a^{-1} and 0.767 kg LU^{-1} a^{-1}, respectively. Another study using manure belts by Shepherd et al. (2015) provides EFs for PM10 and PM2.5 of 0.037 kg animal^{-1} a^{-1} and 0.003 kg animal^{-1} a^{-1} or 11.698 kg LU^{-1} a^{-1} and 1.031 kg LU^{-1} a^{-1}, respectively. These measurements were conducted during summer and winter, each time during a cycle of 20-78 weeks old hens with about 50'000 animals. Winkel et al. (2015) provide EFs for laying hens with a manure belt and deep pit system. For the system with manure belt, the EFs for PM10 and PM2.5 are 0.061 kg animal^{-1} a^{-1} and 0.003 kg animal^{-1} a^{-1} or 17.327 kg LU^{-1} a^{-1} and 0.946 kg LU^{-1} a^{-1}, respectively. For deep pit the EFs for TSP, PM10 and PM2.5 are 0.186 kg animal^{-1} a^{-1}, 0.076 kg animal^{-1} a^{-1} and 0.003 kg animal^{-1} a^{-1} or 50.274 kg LU^{-1} a^{-1}, 20.525 kg LU^{-1} a^{-1} and 0.920 kg LU^{-1} a^{-1}, respectively. The TSP EF is not inlet corrected and therefore might be too high in value. Vonk et al. (2016) provide EFs for PM10 and PM2.5 in deep litter and manure belt. For deep litter, the EFs for PM10 and PM2.5 are 0.087 kg animal^{-1} a^{-1} and 0.004 kg animal^{-1} a^{-1}, respectively. In the manure belt system, the EFs for PM10 and PM2.5 are 0.061 kg animal^{-1} a^{-1} and 0.003 kg animal^{-1} a^{-1}, respectively. Further, they list EFs of systems with biological and chemical air scrubbers, which are not very common in Switzerland yet and thus, not shown here.

For young hens, two sets of EFs from Vonk et al. (2016) are available. With a manure belt system, the EFs for PM10 and PM2.5 are 0.027 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1}, respectively. With a deep litter system, the EFs for PM10 and PM2.5 are 0.035 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1}, respectively. Vonk et al. (2016) also provide EFs in a manure belt system with biological and chemical air scrubbers, which are not shown here.

All the studies found for broilers were conducted in systems with deep litter. The oldest findings are from Takai et al. (1998) and presented in Table 13. The underlying PM concentration measurements were not inlet corrected and therefore these EFs are too high in value.

Table 13 EF for broilers from different countries measured by Takai et al. (1998)

Broilers, system	EF TSP [kg LU^{-1} a^{-1}]	EF Resp. dust [kg LU^{-1} a^{-1}]	Country	Source
Deep litter	54.470	6.185	UK	Takai et al., 1998
Deep litter	43.660	6.351	NL	
Deep litter	16.259	2.146	DK	
Deep litter	24.572	3.451	DE	

Lacey et al. (2003) found EFs for TSP and PM2.5 of 0.184 kg animal^{-1} a^{-1} and 0.010 kg animal^{-1} a^{-1} or 89.440 kg LU^{-1} a^{-1} and 4.695 kg LU^{-1} a^{-1}, respectively. However, these results should be used with caution. They assumed a linear increase in emissions during the lifespan of a flock. However, several studies show (Aarnink et al., 2009; Roumeliotis et al., 2010; Winkel et al., 2015) that the emission increase during a lifespan is in fact exponential, and therefore assuming a linear increase leads to an overestimation of the emissions. Another study that assumed linear regression was conducted by Calvet et al. (2009). Further, their lightning scheme is not comparable to commercial conditions and the number of animals (i.e. 158) was very low. The reported PM10 EF is 0.018 kg animal^{-1} a^{-1}. Roumeliotis and van Heyst (2007) present emission factors from Canada. The reported PM10 and PM2.5 EFS are 0.004 kg animal^{-1} a^{-1} and 0.001 kg animal^{-1} a^{-1}. These are yearly data and it remains unknown if the empty periods were included or not. However, the measurements were taken over three flocks and continuous measurements were locked every five minutes. The same study was evaluated again and three years later the EFs were published in per livestock unit instead of per animal (Roumeliotis et al., 2010), which resulted in EFs for PM10 and PM2.5 of 2.143 kg LU^{-1} a^{-1} and 0.511 kg LU^{-1} a^{-1}, respectively. Aarnink et al. (2009) only give a range of EFs as the study was about emission reduction methods in broiler houses. In Australia, Modini et al. (2010) measured at the exhaust of a tunnel ventilated building, however they did not make any background measurements. Therefore, it can be assumed that the reported EFs are too high in value. The EFs for PM10 and PM2.5 are 8.594 kg LU^{-1} a^{-1} and 1.892 kg LU^{-1} a^{-1}, respectively. Demmers et al. (2010) conducted measurements in Italy and corrected their data for the average bird live weight over the entire life cycle. The sampling was stopped before the end of the flock to avoid thinning events due to early removal of animals which have reached the slaughter weight. The EFs of PM10 and PM2.5 are 0.012 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1}, respectively. The emission factors from Lin et al. (2012) are given in emissions per animal and per livestock unit. For PM10 and PM2.5, EFs are 0.016 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1} or 11.896 kg LU^{-1} a^{-1} and 0.620 kg LU^{-1} a^{-1}, respectively. Winkel et al. (2015) provide EFs from two slightly different housing systems. The TSP, PM10 and PM2.5 EFs from the traditional housing system with full deep litter are 0.043 kg $animal^{-1}$ a^{-1}, 0.020 kg $animal^{-1}$ a^{-1} and 0.001 kg $animal^{-1}$ a^{-1} or 22.250 kg LU^{-1} a^{-1}, 10.424 kg LU^{-1} a^{-1} and 0.523 kg LU^{-1} a^{-1}, respectively. The TSP measurements were not inlet corrected. The other system had two-third elevated slatted floor with manure pit and laying nests. These are mostly broiler parents. The PM10 and PM2.5 EFs are 0.041 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1} or 5.878 kg LU^{-1} a^{-1} and 0.335 kg LU^{-1} a^{-1}, respectively. Vonk et al. (2016) provide EFs for PM10 and PM2.5, which are 0.027 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1}, respectively. Furthermore, they give EFs for broiler parents under 18 weeks for PM10 and for PM2.5 which amount to 0.017 kg $animal^{-1}$ a^{-1} and 0.001 kg $animal^{-1}$ a^{-1}. For broiler parents of 18 weeks and older the listed EFs are 0.0491 kg $animal^{-1}$ a^{-1} and 0.004 kg $animal^{-1}$ a^{-1} for PM10 and PM2.5, respectively. For all three sets of EFs, Vonk et al. (2016) list EFs with biological and chemical air scrubbers, which are not shown here.

For Turkeys, only four sources were found. Schmidt et al. (2002) (cited in Winkel et al. (2015)) measured in a naturally ventilated barn and report an EF for PM10 of 6.369 kg LU^{-1} a^{-1}. The original paper was not available and therefore no further assessment is possible. Li et al. (2008) provide an EF for PM10 of 0.092 kg $animal^{-1}$ a^{-1} or 7.410 kg LU^{-1} a^{-1}. More information is available for Winkel et al. (2015). They report EFs for PM10 and PM2.5 of 0.105 kg $animal^{-1}$ a^{-1} and 0.021 kg $animal^{-1}$ a^{-1} or 5.466 kg LU^{-1} a^{-1} and 1.139 kg LU^{-1} a^{-1}, respectively. Vonk et al. (2016) provide EFs for turkeys for slaughter, turkey parents under and over seven months (Table 14).

Table 14 Particulate matter EFs for Turkeys given in Vonk et al. (2016)

Livestock category	EF PM10 [kg $animal^{-1}$ a^{-1}]	EF PM2.5 [kg $animal^{-1}$ a^{-1}]	Source
Turkeys for slaughter	0.095	0.045	
Turkey parents <7 months	0.177	0.083	Vonk et al., 2016
Turkey parents >7 months	0.241	0.113	

For ducks only EFs from Vonk et al. (2016) could be found. The reported EFs are 0.087 kg $animal^{-1}$ a^{-1} for PM10 and 0.004 kg $animal^{-1}$ a^{-1} for PM2.5.

2.1.5 Other animals

Emission factors are available for horses, goats and rabbits. Seedorf and Hartung (2001) report EFs for horses of 0.164 kg LU^{-1} a^{-1} and 0.017 kg LU^{-1} a^{-1} for TSP and respirable dust, respectively. The original source was not available and was adopted from the EMEP/EEA Guidebook (2016) (Tier 1, Table 3.5). For goats, Vonk et al. (2016) give EFs for PM10 and PM2.5 of 0.019 kg $animal^{-1}$ a^{-1} and 0.006 kg $animal^{-1}$ a^{-1}, respectively. Further, they provide also EFs for rabbits, which are 0.011 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1} for PM10 and PM2.5, respectively. The EMEP/EEA Guidebook (2016) (Tier 1, Table 3.5) provides EFs for goats and sheep of 0.14 kg $animal^{-1}$ a^{-1}, 0.06 kg $animal^{-1}$ a^{-1} and 0.02 kg $animal^{-1}$ a^{-1} for TSP, PM10 and PM2.5, respectively. These EFs are indicated to be based on Mosquera and Hol (2011) but they report EFs for PM10 and PM2.5 of 0.019 kg animal a^{-1} and 0.0053 kg animal a^{-1}, respectively, for goats older than one year, which are also used in Vonk et al. (2016). Aarnink et al. (2014) conducted measurements for goats as well and combined them with own older measurements (0.067 kg animal a^{-1}, 0.022 kg animal a^{-1} 0.001 kg animal a^{-1} for TSP, PM10 and PM2.5, respectively (Aarnink et al., 2012)), yielding EFs of 0.137 kg $animal^{-1}$ a^{-1}, 0.047 kg $animal^{-1}$ a^{-1} and 0.002 kg $animal^{-1}$ a^{-1} for TSP, PM10 and PM2.5, respectively. This is in our opinion the best available source. Since the EFs for goats from the EMEP/EEA Guidebook (2016) were already used in the version of 2013 they must be based on another source than Mosquera and Hol (2011), Aarnink et al. (2012) or Aarnink et al. (2014). Hence the original source is unknown and especially the PM2.5 EF is significantly higher and leads to unrealistic emissions.

2.2 3D Crop production and agricultural soils

Only a few studies reporting emission factors from crop harvesting are available. There are many studies reporting EFs from cotton and almond harvests, but this is not relevant for Switzerland. More studies are available for operations regarding soil cultivation. Hence, this section is split into operations on soil and operations on crops. Almost all the studies are reporting EFs for PM10 only.

2.2.1 Operations on crops

Batel (1976) cited in van der Hoek and Hinz (2007) report a range of PM10 EFs from combine harvesting between 4.1 and 6.9 kg ha^{-1}. WRAP Fugitive Dust Handbook (2006) cited in van der Hoek and Hinz (2007) provide an EF range for PM10 for combine harvesting of 3.3-5.8 kg ha^{-1}. In Table 15 the emission factors from van der Hoek and Hinz (2007) are given. They measured emissions from different operations in Germany. The default Tier 1 and Tier 2 EFs in the EMEP/EEA Guidebook (2016) (Table 3.1, 3.5-3.8) are based on these EFs.

Table 15 PM10 emission factors from van der Hoek and Hinz (2007)

Crop	EF Soil cultivation [kg ha^{-1}]	EF Harvesting [kg ha^{-1}]	EF Cleaning [kg ha^{-1}]	EF Drying [kg ha^{-1}]
Wheat	0.25	2.7	0.19	0.56
Rye	0.25	2.0	0.16	0.37
Barley	0.25	2.3	0.16	0.43
Oat	0.25	3.4	0.25	0.66

Qiu and Pattey (2008) conducted PM10 measurements from the spring wheat harvest with a tracer ratio technique and dispersion modelling yielding an EF of 0.71 kg ha^{-1}. The EFs regarding operations on crops and soil from the EMEP/EEA Guidebook (2016) are given in Table 16 and Table 17.

Table 16 Tier 2 EFs in the EMEP/EEA Guidebook (2016) for agricultural crop operations for PM10 under wet climate conditions

Crop	EF Soil cultivation [kg ha^{-1}]	EF Harvesting [kg ha^{-1}]	EF Cleaning [kg ha^{-1}]	EF Drying [kg ha^{-1}]
Wheat	0.25	0.49	0.19	0.56
Rye	0.25	0.37	0.16	0.37
Barley	0.25	0.41	0.16	0.43
Oat	0.25	0.62	0.25	0.66
Other arable	0.25	-	-	-
Grass	0.25	0.25	0	0

Table 17 Tier 2 EFs in the EMEP/EEA Guidebook (2016) for agricultural crop operations for PM2.5 under wet climate conditions

Crop	EF Soil cultivation [kg ha^{-1}]	EF Harvesting [kg ha^{-1}]	EF Cleaning [kg ha^{-1}]	EF Drying [kg ha^{-1}]
Wheat	0.015	0.02	0.009	0.168
Rye	0.015	0.015	0.008	0.111
Barley	0.015	0.016	0.008	0.129
Oat	0.015	0.025	0.0125	0.198
Other arable	0.015	-	-	-
Grass	0.015	0.01	0	0

It can be seen that the EMEP/EEA Guidebook (2016) publishes EFs from harvesting which are lower by 82% compared to the referenced study of van der Hoek and Hinz (2007). But no information is provided on the chosen emission values (incl. request to the lead author). The source for the EFs of grass remains unknown. Further, the EMEP/EEA Guidebook (2016) provides EFs for PM2.5, which are also indicated to be based on van der Hoek and Hinz (2007). However, in van der Hoek and Hinz (2007) no information regarding PM2.5 emissions are given. Calculations show that the EFs for soil cultivation, harvesting, cleaning and drying from PM10 to PM2.5 were reduced by 94%, 96%, 95% and 70%, respectively in the EMEP/EEA Guidebook (2016). There is one study providing EFs from herbicide application on silage winter wheat (Moore et al., 2015). The EFs are an average derived from measurements by LIDAR, filter sampling and optical particle counters. The EFs for TSP, PM10 and PM2.5 are 0.83 kg ha^{-1}, 0.35 kg ha^{-1} and 0.15 kg ha^{-1}, respectively. Pesticide applications are not yet considered in the EMEP/EEA Guidebook (2016).

2.2.2 Operations on soil

MAFF (2000) cited in van der Hoek and Hinz (2007) give EFs for PM10 from soil cultivation of 0.06-0.3 kg ha^{-1}. It is not further specified what kind of soil operation they measured. Klimont et al. (2002) cited in van der Hoek and Hinz (2007) report an EF of PM10 for soil cultivation of 0.1 kg ha^{-1}. These measurements were conducted in Austria and are used for the 'Regional Air Pollution INformation and Simulation' (RAINS)-model. Also, only an EF for soil cultivation with no additional information is given in Hinz et al. (2002) cited in van der Hoek and Hinz (2007). They provide an EF range between 0.28-0.48 kg ha^{-1} for PM10. The WRAP Fugitive Dust Handbook (2006) also provides an EF range for soil cultivation for PM10 of 4.2-5.2 kg ha^{-1}. The US value is higher by one order of magnitude due to dry and hot conditions. Van der Hoek and Hinz (2007) report an average EF of 0.25 kg ha^{-1} for PM10, which is based on MAFF (2000), Klimont et al. (2002) and Hinz et al. (2002). There are studies, mostly from the US, giving EFs from specific soil operations like fertiliser injection, break down in-field borders, planting, strip-tilling, listing, rolling, optimizer, land plane, chisel, disking, cultivating and ploughing. For simplification, the average of these operations was taken and displayed in the following. Oettl et al. (2005) and Hinz and Funk (2007) cited both in van der Hoek and Hinz (2007) provide an average EF for PM10 of 1.31 kg ha^{-1} and 3.64 kg ha^{-1} for moist soil and dry soil conditions, respectively, during ploughing. For PM2.5 the average EFs are 0.13 kg ha^{-1} for moist condition and 0.44 kg ha^{-1} for dry soil condition during ploughing. Zavyalov et al. (2010) conducted LIDAR measurements in US California. As there was only a small difference between the upwind and downwind PM2.5 concentrations, they did not report any EFs. The average PM10 EF from different soil operations however, is 0.57 kg ha^{-1}. An average EF for PM10 of 1.11 kg ha^{-1} is given in Wang et al. (2010). They measured in New Mexico with filter sampling. Two studies are available from Moore et al. In 2013, they made LIDAR measurements yielding EFs for TSP, PM10 and PM2.5 of 1.52 kg ha^{-1}, 0.57 kg ha^{-1} and 0.29 kg ha^{-1}, respectively. In 2015, they conducted measurements with LIDAR, optical particle counter and filter sampling. The average EFs from the three measuring methods and from all soil operations are 46.87 kg ha^{-1}, 8.46 kg ha^{-1} and 0.55 kg ha^{-1} for TSP, PM10 and PM2.5, respectively. In general, the results of this campaign do not agree well with data from previous studies. The LIDAR system did not collect data below a height of 10 m, which resulted in a loss of emissions. Vice versa, point sensors have limitations above 10 m. Further, a significant portion of the filter based samples were rendered unusable for emission calculations due to sampling irregularities and errors (Moore et al., 2015).

3 PM emission factors for dairy cattle and other cattle based on the measurements by Schrade (2009)

A task given in the present project was to define emission factors for dairy cattle based on the PM10 EF from Schrade (2009). Deriving EFs for all five housing systems (i.e. tied housings with production of slurry, tied housings with production of slurry and solid manure, loose housings in cubicles with production of slurry, loose housings in cubicles with production of slurry and solid manure and loose housings with deep litter) used in Kupper et al. (2018) needs too many assumptions. Therefore, the goal was to define two different sets of emission factors; one for tied housings and one for loose housings, which then could be aggregated according to the distribution of the two systems. The derivation of the EFs was done in three steps based on already existing EFs and expert judgements:

1. Derivation of a fraction value for the conversion of the EF of PM10 for loose housings from Schrade (2009) to PM2.5.
2. Derivation of a fraction value for the conversion of the EF of PM10 for loose housings from from Schrade (2009) to TSP.
3. Estimate of missing EFs for tied housings based on the defined EFs for loose housings.

For this task the selected studies did not have to be conducted in housing systems and under climatic conditions being comparable to Switzerland as only the fraction value between the size fractions was of importance. According to the Federal Office for the Environment (FOEN), PM10 and PM2.5 are the important size fractions for reporting policies. Further, the fraction values of PM2.5 on PM10 show a lower variability than the fraction values based on TSP (see Chapter 2 , Table 2). Hence, we started with the derivation of a fraction value for the conversion from PM10 to PM2.5. Not considered of the listed fraction values were the ones from the EMEP/EEA Guidebook based on Seedorf and Hartung (2001), IIASA (2014), Winkel et al. (2015) and Vonk et al. (2016) as well as those based on expert judgement from Mosquera et al. (2010). The measurements from Seedorf and Hartung (2001) were conducted only at one day and as shown above contradict the measurements they were applied on (Section 2.1.1). As no original source was available and we did not know how and how long the measurements were run, the fraction values from IIASA (2014) were excluded as well. The expert judgement from Mosquera et al. (2010) was excluded as no information is provided on the basis of the values. As described above (section 2.1.1) the EFs from Winkel et al. (2015) are based on the measurements from Mosquera et al. (2010) and differ for unknown reasons. Therefore, these EFs should be excluded to avoid double count or misleading data. Vonk et al. (2016) was excluded as it is a transformation of the Mosquera et al. (2010) values without a change of the fraction values between the size fractions and should therefore also be excluded to avoid double counting. Out of the remaining fraction values (Mosquera et al., 2010, measured PM10 and PM2.5 emissions) and Joo et al. (2013) a mean value of 0.24 is calculated for the share of PM2.5 on PM10.

For the conversion from PM10 to TSP or vice versa the fraction values from Seedorf and Hartung (2001), IIASA (2014) and Winkel et al. (2015) were excluded for the same reasons as mentioned above. Mosquera et al. (2010) had to be excluded as the TSP values were not inlet corrected. Out of the remaining fraction values from Goodrich et al. (2002), Hinz et al. (2007), Heidenreich et al. (2008) and Joo et al. (2013) the average was taken resulting in a fraction value of 0.30 for the share of PM10 on TSP. The selected studies for the calculation of the fraction values are marked in Table 2 with two stars (**). The resulting EFs for dairy cattle in loose housings are given in Table 18.

Table 18 EF used in this study for dairy and non-dairy cattle in loose and tied housings derived from the PM10 measurements by Schrade (2009)

Livestock category and system	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]
Dairy cattle – loose housing	0.78	0.23	0.06
Non-dairy cattle – loose housing	0.34	0.10	0.02
Dairy cattle – tied housing	0.33	0.10	0.02
Non-dairy cattle – tied housing	0.14	0.04	0.01

The next step was to make a transformation from the resulting EFs for dairy cattle in loose housings with production of slurry to tied housings. Thus, we compared existing EFs from both housings system with each other (see Table 19). Vonk et al. (2016) did not conduct measurements in tied housing systems, but did a transformation based on expert judgement. However, we cannot find any source of the basis thereof. But according to Mosquera (2017) (personal communication) it is a fraction value widely used in the Netherlands. From the fraction values presented in Takai et al. (1998) the ones from UK were excluded as they show higher emissions for tied housings than loose housings. This is in contrast with all other studies that measured in both system and the general assumption that the emissions in tied housings are lower than in loose housings (EMEP/EEA Guidebook, 2016). The concentration measurements in tied housings from the UK were similar to the other countries (Takai et al., 1998), however, the ventilation rates in the UK in tied housings were higher by a factor of two compared with the other countries, whereas the ventilation rate for loose housings was similar to the ones measured in the Netherlands, Denmark and Germany. Therefore, the reason for the higher emissions in tied housings compared to loose housings in the UK are due to high ventilation rates in tied housings (Seedorf et al., 1998). Out of the remaining fraction values given in Table 19 the average was calculated. The resulting fraction value of the emissions from tied housings compared to loose housings of 0.43 is similar to the ratio measured for NH_3 emission of 0.37 by Klossner et al. (2014). With the calculated fraction value of 0.43 the emission factors for dairy cattle in tied-housings could be derived.

Table 19 Fraction values for the emissions from tied housings on loose housings derived from the literature

Fraction value for the emissions from tied housings on loose housings				
Country	**PM10**	**PM2.5**	**Average**	**Source**
NL	0.55	0.54	0.54	Vonk et al., 2016
Country	**Inhalable dust**	**Respirable dust**	**Average**	**Source**
UK*	6.76	4.67	5.71	Takai et al., 1998
NL	0.28	0.24	0.26	
DK	0.69	0.69	0.69	
DE	0.22	0.21	0.22	
mean value, used in this study			0.43	

For non-dairy cattle we have not done such an extensive analysis as for dairy cattle mainly because no measurements from Switzerland are available. However, as the EFs for non-dairy cattle in the EMEP/EEA Guidebook (2016) are also based on the measurements of Takai et al. (1998) and on fraction values from Seedorf and Hartung (2001) we did not use them for the same reasons as those for dairy cattle. Hence, we transformed our generated emission factors for dairy cattle based on Schrade (2009) to emission factors for non-dairy cattle. For simplification, we therefore used the fraction value between dairy cattle and non-dairy cattle of 0.43 adopted from the measurements of Takai et al. (1998). This fraction value was used for tied and loose housings. Further, we assigned the same set of emission factors derived for non-dairy cattle to all non-dairy cattle categories listed in Kupper et al. (2018) (heifers younger than one year, heifers between one and two years, heifers between two and three years, suckling cows, calves of suckling cows, beef cattle, fattening calves). The EFs for dairy and non-dairy cattle in both housing systems derived in this chapter from the measurements by Schrade (2009) are shown in Table 18. If the same distribution of tied housings and loose housings of 50:50 as in the EMEP/EEA Guidebook (2016) is assumed, the generated EFs for Switzerland (based on Schrade (2009)) for dairy and non-dairy cattle are a factor of 2.5 to 10 smaller than those listed in the Guidebook. A comparison of the emission factors is given in Table 20. Please note that the actual share of tied and loose housings in Switzerland is actually not 50:50 (e.g. 2015: 41.3:58.7) and varies from year to year. Therefore, also the EFs suggested to use in EMIS for dairy and non-dairy cattle do vary over time.

Table 20 Comparison of EFs given in the EMEP/EEA Guidebook (2016) with the EFs generated in this study based on Schrade (2009) assuming a share of 50% tied and loose housings

Livestock category	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]	Source
Dairy cattle	1.38	0.63	0.41	EMEP/EEA Guidebook (2016)
Dairy cattle	0.56	0.17	0.04	This Study
Non-dairy cattle	0.59	0.27	0.18	EMEP/EEA Guidebook (2016)
Non-dairy cattle	0.24	0.07	0.02	This study

4 Literature review on non-methane volatile organic compounds

The first issue of the present report was to provide a definition or selection of NMVOC which should be included in the literature study. After studying several papers on NMVOC emissions from agriculture we concluded that a reasonable selection of NMVOC is difficult to achieve for the following reasons:

First, we investigated papers related to source category 3B Manure management. According to the EMEP/EEA Guidebook (2016) there are NMVOC emissions from livestock housing, grazing animals, outside manure stores, manure application, silage stores and the feeding table if silage is used for feeding. Most of the publications are related to livestock housing and outside manure stores. Some studies conducted experiments on emissions from silage. Studies on grazing animals were not available. The study of Shaw et al. (2007) on which in the EMEP/EEA Guidebook (2016) the EFs for grazing are based (Tier 2 approach, Table 3.11) is in our opinion rather representative for a freestall than for grazing animals. Nevertheless, it can be assumed that the NMVOC emitted from animals on the field are similar to those emitted in livestock housings.

Measuring NMVOC is challenging. NMVOC can both be sampled and analysed on-line directly at the measuring site, or off-line using for example stainless steel canisters for sampling. The canisters are then transported to the laboratory where they are analysed. In the reviewed studies, the following devices were used:

- Gas chromatography (GC) systems (either GC-mass spectrometry (GC-MS) or GC-flame ionisation detector (GC-FID), which have a restricted time resolution and are difficult to operate when analysing more polar, surface sticky compounds.
- Proton-transfer reaction mass spectrometry (PTR-MS), which can measure only a few compounds (oxygenated VOC (OVOC) and certain unsaturated non-methane hydrocarbons (NMHC)) (ACTRiS, 2014).
- PTR-TOF can be considered as the best option but this technique is very expensive and only one study (Ruuskanen et al., 2011) was found which used it.

These challenges make it difficult to assign the right compounds to the measured m/z-ratio. Often, well-known standards are needed, or a data library is used for this procedure. However, it is not always possible to assign a component to a detected m/z-ratio. Therefore, in many cases, it can only be assumed that a certain NMVOC was detected, but without any mass quantification.

Moreover, only a few studies measured emissions. A part of these papers reported the data in a unit (e.g. mg m^{-3} d^{-1}, g m^{-2} d^{-1}) that hampered a transformation to the needed units for an inventory. Additionally, most of the studies focus on detection and concentration measurements.

Due to these challenges, at least half of the experiments were performed within a laboratory setup or at field scale using environmental chambers or wind tunnels. This makes the measuring easier even though it is not fully representative for field conditions.

Odour and odorous emissions from livestock buildings and outside manure stores directly affect the surrounding area of these facilities. As a consequence, most of the studies focus on the detection and the quantification of these odorous compounds. Therefore, rather compounds that are likely to exceed their odour detection threshold are included and not the main compounds emitted in terms of an NMVOC emission inventory.

Where emission rates were provided, the NMVOC were often pre-selected. This means according to the topic of interest one to about 20 NMVOC were selected. Sometimes, only the total NMVOC emission for the measured compounds was given and for the single compounds only concentration data was available. As mentioned above, the EMEP/EEA Guidebook (2016) itself does not include any suggestion or restriction regarding the selection of NMVOC. This situation makes it difficult to prepare a list of compounds which serves as a basis for the elaboration of an emission inventory.

Considering the insights listed above, we conclude that it is not meaningful to elaborate a list of individual NMVOC species which should be included in the literature review. For the literature review, we thus suggest including all the studies which measure NMVOC emissions from agriculture and report all the individual compounds studied or the sum of NMVOC. To summarise we can state that:

- The data base concerning NMVOC emissions from agricultural activities is in general scarce.
- Due to technical limitations of the measuring devices a pre-selection of NMVOC had to be done in the studies.
- Most of the studies carry out qualitative measurements of NMVOC (i.e. detection, no-detection) or determinate their concentrations. Only a few studies quantify emissions.
- More laboratory studies than field studies are available.
- The focus was rather on odour and odorous emissions than total NMVOC emissions.
- Even if emissions are provided, values for every individual compound are not always given or only total emissions are reported.
- The EMEP/EEA guidebook (2016) does not give any definition of NMVOC in a sense of reactivity which would be useful since the compounds differ in reactivity and thus in relevance regarding environmental impacts.

Nevertheless, based on this review, the 36 most important compounds in terms mentioned in studies and amount of contribution to total emission, were selected (see Chapter 4.3). Here, the EFs for these individual compounds – where available – are displayed and an EF of total NMVOC emission is given. The latter is actually the sum of all emission factors of the measured individual compounds. It has to be mentioned that the determination of emission factors for NMVOC from manure management is challenging. Often, the focus of the studies was not on the total NMVOC emission but rather on individual compounds relevant for odorous nuisance, which are not necessary the ones being emitted most. Hence, not all NMVOC possibly contributing to total emission were measured. This hampers a comparison of individual studies and impedes the derivation of emission factors. Annex 2 includes studies on NMVOC which could be relevant as well although they were not considered owing to the restricted time of the present mandate.

4.1 3B Manure management

4.1.1 Sources of NMVOC

Manure management in terms of the EMEP/EEA Guidebook (2016) comprises the sources animal feeds (i.e. silage stores and rations supplied to the animals in the barns, e.g. as total mixed ratio (TMR)), soiled surfaces in the barns and outside areas, manure stores. Most studies show that silage produces the major part of the NMVOC emissions from manure management. Since not all livestock categories are fed with rations containing silage, the emissions must be determined separately for animals receiving and not receiving silage. In the Guidebook the results from Alanis et al. (2008) and Chung et al. (2010) were used to subtract the silage emissions for animals where silage is not supplied.

Since most of the NMVOC measurements were carried out in the US, a conversion to western European feed intake and volatile solids excretion was applied (EMEP/EEA Guidebook, 2016). The EFs for the swine categories not included in the NAEMS program were derived according to their gross feed intake or excreted volatile solids (EMEP/EEA Guidebook, 2016).

4.1.2 Cattle

In Table 21, an overview of the studies reporting EFs from dairy cattle is given. Ngwabie et al. (2007) present measurement results obtained from farms located in Germany which included silage feeding. The resulting EFs of different NMVOC species should be taken with caution as the provided EFs were scaled up to entire Germany by the author with a correlation between VOC and methane or ammonia flux. They are expressed in units of carbon equivalent. Based on the molar mass of each compound, the molar mass of carbon and the total numbers of dairy cattle (given in the study), EFs in units of kg animal^{-1} a^{-1} were calculated. The total EF for NMVOC of 19.559 kg animal^{-1} a^{-1} in this study is assumed to be underestimated as not for every measured compound an emission was given and a total emission was also missing. Zhao et al. (2010c) conducted their research within the National Air Emissions Monitoring Study (NAEMS) program of the US Environmental Protection Agency (EPA). They measured in one loose housing for dairy cattle during winter with silage feeding. The reported data are confusing, as the measuring dates are partly outside the reported period of the measuring campaign. Possibly, they were shifted by one year. To calculate EFs from the emissions given in the study, it is crucial to know the exact number of animals. They also measured negative emissions, which were neglected here. In Table 21 only the total emission is given, as in the paper besides the total emission only concentrations for the 20 most prevalent VOC species are available. Filipy et al. (2006) measured downwind of a freestall in Washington State (USA) with a tracer method. Only the emission factor of ethanol and (methylsulfanyl)methane were given. However, they detected 82 different NMVOC downwind of the stall. Cai et al. (2015) is an add-on study to the NAEMS program. They conducted measurements spread over the year in Wisconsin (US) and Indiana (US) and measured 20 pre-selected odorous NMVOC. The resulting EF of total NMVOC for Wisconsin of 3.651 kg animal^{-1} a^{-1} is about one order of magnitude larger than the EF from the barn in Indiana of 0.401 kg animal^{-1} a^{-1}. Possible reasons for this difference are not mentioned. Neither is information given about feeding type. Because the study focused on odorous emission, important NMVOC contributing significantly to the total emissions, like ethanol, methanol, propan-2-one are missing. This might be the main reason for the rather low EF. An experimental study with three cows in a freestall was conducted by Shaw et al. (2007) resulting in an EF for total NMVOC of 1.348 kg animal^{-1} a^{-1}. The emissions are the sum of reactive organic carbon, acetone and propanal. Trimethylamin is not included, since it could not be calibrated.

Table 21 EFs of dairy cattle in kg animal^{-1} a^{-1}. If available, the EF of the 36 most important NMVOC is given. The total NMVOC EF is the sum of all measured compounds

IUPAC name	Ngwabie et al., 2007	Zhao et al., 2010c	Filipy et al., 2006	Cai et al., 2015	Cai et al., 2015	Shaw et al., 2007
			EF [kg animal^{-1} a^{-1}]			
Acetaldehyde	0.484					
Acetic Acid	3.407			1.934	0.147	
Benzaldehyde						
Butan-1-ol						
Butan-2-one	0.251					
Butane-2,3-dione						
Butanoic acid				0.373	0.020	
Ethanol	11.806		32.356			
Ethyl acetate						
4-Ethylphenol				0.008	0.006	
Heptanal						
Hexanal						
Hexane						
Hexanoic acid				0.035	0.002	
Indole				0.003	0.000	
Methanedithione						
Methanol	0.880					
(Methyldisulfanyl)methane			0.435	0.006	0.001	
(Methylsulfanyl)methane	0.136					
(Methyltrisulfanyl)methane				0.000	0.000	
N,N-Dimethylmethanamine	1.407					
2-Methylpropanoic acid				0.070	0.003	
3-Methyl-1*H*-indole				0.003	0.000	
3-Methylbutanoic acid				0.053	0.003	
4-Methylphenol				0.055	0.024	
Nonanal	0.078					
Pentanal						
Pentane						
Pentanoic acid				0.046	0.001	
Phenol				0.034	0.014	
Propan-1-ol						
Propan-2-ol						
Propan-2-one	0.744					
Propanoic acid	0.366			0.995	0.179	
Propyl acetate						
Toluene						
Total NMVOC EF	19.559	11.891	32.791	3.641	0.401	1.348

4.1.3 Swine

In Table 22 the EFs from studies reporting swine emission are listed. Cai et al. (2015) is an add-on study to the NAEMS program. They conducted measurements in Iowa (US) on a farm with two buildings with each keeping 1’100 dry sows. Another measurement with nursing sows was conducted in barns where the manure was removed only twice a year. All measurements were spread over the year. The measurements on fattening pigs were conducted in Indiana in a building with a capacity of 4’000 heads. A set of 20 pre-selected odorous NMVOC was measured. Hence, it seems likely that some significant compounds contributing to total emission are missing. The study provides EFs of total NMVOC for dry sows, nursing sows and fattening pigs of 0.148 kg animal^{-1} a^{-1} or 0.297 kg LU^{-1} a^{-1}, of 0.443 animal^{-1} a^{-1} or 0.803 kg LU^{-1} a^{-1} and of 0.905 animal^{-1} a^{-1} or 6.511 kg LU^{-1} a^{-1}, respectively. A study from Korea published by Kim et al. (2007) included emissions of (methyldisulfanyl)methane and (methyltrisulfanyl)methane only from five large scale pig feeding operations in spring and autumn. Their EFs are related to livestock units and cannot be reliably transformed to units per animal because of missing live weight data. However, for a better comparison we assumed a live weight for nursing sows and fattening pigs of 200 kg and 70 kg, respectively (KTBL, 2017). Feilberg et al. (2010) conducted their measurements in Denmark from May to July which resulted in an EF for total NMVOC of 0.530 kg animal^{-1} a^{-1} or 5.530 kg LU^{-1} a^{-1}. Methanol and other alcohol fragments were also measured but only a concentration range is given and thus, a conversion to an EF is not possible. However, it seems that these compounds could contribute significantly to the total emission. Amon et al. (2007) investigated the emissions from three slightly different housing systems for fattening pigs. The average thereof resulted in a total EF of 2.917 kg animal^{-1} a^{-1}. The reason for the rather high NMVOC EF of this study compared with others is unknown. The EMEP/EEA Guidebook (2016) (default Tier 1 EF, Table 3.4) uses an EF of 1.704 kg animal^{-1} a^{-1} for sows and 0.551 kg animal^{-1} a^{-1} for fattening pigs, which are based on the NAEMS program from the EPA.

Table 22 EF of dry sows, nursing sows and fattening pigs given in kg animal^{-1} a^{-1}. If available, the EFs of the 36 most important NMVOC is given. The total NMVOC EF is the sum of all measured compounds

IUPAC name	Cai et al., 2015	Kim et al., 2007	Cai et al., 2015	Kim et al., 2007	Cai et al., 2015	Feilberg et al., 2010	Amon et al., 2007
	Dry sows	Nursing sows		Fattening pigs			
	EF [kg animal^{-1} a^{-1}]						
Acetaldehyde							
Acetic Acid	0.030		0.070		0.105	0.262	
Benzaldehyde							
Butan-1-ol							
Butan-2-one						0.004	
Butane-2,3-dione						0.002	
Butanoic acid	0.023		0.126		0.245	0.101	
Ethanol							
Ethyl acetate							
4-Ethylphenol	0.002		0.003		0.002	0.001	
Heptanal							
Hexanal							
Hexane							
Hexanoic acid	0.001		0.065		0.009		
Indole	0.000		0.001		0.000	0.000	
Methanedithione							
Methanol							
(Methyldisulfanyl)methane	0.000	0.018	0.004	0.027	0.001	0.006	
(Methylsulfanyl)methane	0.000	0.032		0.048			
(Methyltrisulfanyl)methane			0.000		0.000	0.000	
N,N-Dimethylmethanamine						0.011	
2-Methylpropanoic acid	0.007		0.015		0.033		
3-Methyl-1*H*-indole	0.002		0.001		0.001	0.001	
3-Methylbutanoic acid	0.009		0.019		0.031		
4-Methylphenol	0.032		0.027		0.044	0.010	
Nonanal							
Pentanal							
Pentane							
Pentanoic acid	0.004		0.028		0.042		
Phenol	0.003		0.007		0.006	0.002	
Propan-1-ol							
Propan-2-ol							
Propan-2-one						0.007	
Propanoic acid	0.034		0.073		0.377	0.100	
Propyl acetate							
Toluene							
Total NMVOC EF	0.148	0.049	0.443	0.075	0.895	0.530	2.917

4.1.4 Poultry

For poultry, we only found the studies of Cortus et al. (2010a, b). Cortus et al. (2010b) investigated the emissions from laying hens kept in A-Valco cages and Cortus et al. (2010a) the NMVOC volatilisation from broilers. For the latter, the paper provides different numbers in tables, text and summary for the same mean emission value. This is the case for the emissions from both houses. It remains unknown, which of these emission numbers are the correct values. For the calculation of the EF in this report the numbers from the tables were used. The average of the emissions from both buildings was taken and divided by 21'000 birds which resulted in an EF of 0.035 kg animal^{-1} a^{-1}. The EF for the laying hens is 0.030 kg animal^{-1} a^{-1}. However, the data given in Cortus et al. (2010b) were partly outside the given measuring campaigns period and did not match with the animal numbers provided. Therefore, the animal numbers given for the subsequent year were used for the determination of the EFs. Since different animal numbers lead to different emission factors, these EFs have to be considered with caution.

4.1.5 Silage

Different studies that measured the emissions from silage feeding are available. The problem is that the units differ between the studies and can only be converted with some assumptions. Therefore, this section is based on Hafner et al. (2013). They compiled a table with measured concentrations of NMVOC within silage from various studies. The emissions from silage feeding can then be calculated with a mass balance method based on Hafner et al. (2010) and Hafner et al. (2012). Here, only the mean values from maize and grass silage were considered. Losses of 75% and of 40% (20%-60%) are assumed for aldehydes and alcohols, respectively (Hafner et al., 2012). Species with other functional groups like esters and volatile fatty acids (VFA) also occur in silage emissions. However, they were not considered here since they only have a small contribution to the total mass of NMVOC emitted and because of the high uncertainty in the loss of alcohols. Further, it is difficult to predict the emissions of VFA, because they are not as volatile as aldehydes and alcohols. The studies considered for this report and the measured compounds are given for maize and grass silage in Table 23 and Table 24, respectively. These studies were conducted at different scales (farm or laboratory), types of silo (tower or bunker), number of silage samples and number of measurements.

Table 23 Studies provided in Hafner et al. (2013) and their measured compounds used to calculate an EF for maize silage

Source	Measured compounds
BYERS et al., 1982	Ethanol
Chmelova et al., 2009	Acetaldehyde, 7 others
Cumberland Valley Analytical Services, 2012	Methanol, ethanol, propan-1-ol, 1 other
Driehuis and van Wikselaar, 2000	Ethanol, propan-1-ol
Filya, 2004	Ethanol
Hafner et al., 2010	Ethanol
Hafner et al., 2012	Acetaldehyde, methanol, ethanol, propan-1-ol
Hartman, 1974	Acetaldehyde, methanol, ethanol, propan-1-ol, 1 other
Kalac and Pivnickova, 1987	Methanol, ethanol, propan-1-ol, 2 others
Kim and Adesogan, 2006	Ethanol
Kleinschmit and Kung, 2006	Ethanol
Langin et al., 1989	Acetaldehyde, ethanol, propan-1-ol, 4 others
Li and Nishino, 2011	1-Propanol
Nielsen et al., 2007	Methanol, ethanol, propan-1-ol, 2 others
Nishino et al., 2003	Ethanol, propan-1-ol
Raun and Kristensen, 2010	Ethanol, propan-1-ol, 2 others
Reich and Kung, 2010	Ethanol
Schmidt and Kung, 2010	Ethanol
Sorensen, 2004	Ethanol
Addah et al., 2011	Ethanol
Contreras-Govea et al., 2011	Ethanol
Huisden et al., 2009	Ethanol
Kristensen et al., 2010	Ethanol, propan-1-ol, 1 other
Kung et al., 2004	Ethanol
Rodrigues et al., 2004	Ethanol
Tabacco et al., 2009	Ethanol
Teller et al., 2012	Ethanol

Table 24 Studies provided in Hafner et al. (2013) and their measured compounds used to calculate an EF for grass silage

Source	Measured compounds
Chmelova et al., 2009	Acetaldehyde, 7 others
Driehuis and van Wikselaar, 2000	Ethanol
Hartman, 1974	Acetaldehyde, methanol, ethanol, propan-1-ol, 1 other
Kalac and Pivnickova, 1987	Acetaldehyde, methanol, ethanol, propan-1-ol, 5 others
Krizsan et al., 2007	Propanal
Langin et al., 1989	Acetaldehyde, ethanol, propan-1-ol, 4 others
Nishino and Touno, 2005	Ethanol, propan-1-ol
Sorensen, 2004	Ethanol

For each aldehyde and alcohol compound the average concentration measured in the listed studies was taken. Then all aldehyde and alcohol compounds were summed up and the mentioned losses of 75% and 40%, respectively, were applied. To calculate EFs for dairy cattle in Switzerland an average consumption of 4.2 kg grass silage (dry matter) and 2.9 kg maize silage (dry matter) per day and cow was assumed (Ineichen et al., 2016). This resulted in an EF for dairy cattle of 9.8 kg animal^{-1} a^{-1} and 7.5 kg animal^{-1} a^{-1} for maize and grass silage, respectively. The percent of each single compound contributing to these EFs are given in Table 25 and Table 26 for maize and grass silage, respectively. This leads to a total emission factor from silage feeding itself for dairy cattle in Switzerland of 17.3 kg animal^{-1} a^{-1}. It is important to mention that only alcohols and aldehydes were considered.

Table 25 Maize silage - NMVOC and their functional group with the share and cumulative share contributing to a total emission of 9.8 kg animal^{-1} a^{-1} for Switzerland

Measured compound	Functional group	% of total	Cumulative %
Ethanol	Alcohol	69.2%	69.2%
1-Propanol	Alcohol	19.7%	88.9%
Methanol	Alcohol	3.2%	92.1%
2-Propanol	Alcohol	1.7%	93.8%
2-Butanol	Alcohol	0.8%	94.6%
Butanol	Alcohol	0.7%	95.3%
Hexanal	Aldehyde	1.6%	96.9%
3-Methylbutanal	Aldehyde	1.1%	98.0%
Butanal	Aldehyde	0.6%	98.5%
Ethanal	Aldehyde	0.5%	99.1%
2-Methylpropanal	Aldehyde	0.3%	99.4%
Heptanal	Aldehyde	0.3%	99.6%
Propanal	Aldehyde	0.3%	99.9%
Pentanal	Aldehyde	0.1%	100.0%

Table 26 Grass silage - NMVOC and their functional group with the share and cumulative share contributing to a total emission of 7.5 kg animal^{-1} a^{-1} for Switzerland

Measured compound	Functional group	% of total	Cumulative %
Ethanol	Alcohol	65.2%	65.2%
1-Propanol	Alcohol	22.4%	87.6%
Methanol	Alcohol	3.0%	90.5%
2-Butanol	Alcohol	1.7%	92.2%
2-Propanol	Alcohol	1.2%	93.5%
Hexanal	Aldehyde	1.8%	95.2%
Pentanal	Aldehyde	1.3%	96.5%
Butanal	Aldehyde	1.1%	97.6%
3-Methylbutanal	Aldehyde	0.8%	98.4%
Propanal	Aldehyde	0.6%	99.0%
Ethanal	Aldehyde	0.5%	99.5%
Heptanal	Aldehyde	0.3%	99.7%
2-Methylpropanal	Aldehyde	0.2%	99.9%
2-Methylbutanal	Aldehyde	0.1%	100.0%

4.2 3D Agricultural soils

We found only a few studies reporting NMVOC EFs from crop production and agricultural soils. However, König et al. (1995) and Lamb et al. (1993) give EFs in kg NMVOC per kg dry matter and hour. For a better comparison, the EFs were transformed to kg NMVOC per ha and day. Therefore, mean dry matter amounts for wheat, rye, rape and grass of 4'700 kg dm ha^{-1}, 2'800 kg dm ha^{-1}, 2'500 kg dm ha^{-1} and 9'000 kg dm ha^{-1}, respectively, were assumed (EMEP/EEA Guidebook, 2016). The EFs are given in Table 27. The EFs in the EMEP/EEA Guidebook (2016) are based on these two studies. Because the EFs for wheat and rye differ significantly between the two studies, the EMEP/EEA Guidebook (2016) adopted the average thereof. However, if the EF of each functional group for wheat given in the Guidebook from Lamb et al. (1993) is summed up it results in an EF of 0.0011 kg ha^{-1} d^{-1}instead of 0.0046 kg ha^{-1} d^{-1}, which is almost identical the EF from König et al. (1995). Therefore, we assume that there is an transcription error in the Guidebook, however we do not know where exactly it is because the original paper of Lamb et al. (1993) was not available. Further, Lamb et al. (1993) and König et al. (1995) measured different functional groups and therefore taking an average of both is not really correct. Additionally, they measured during a different grow stage where probably different emissions occur. For rye it is similar as for wheat. They also measured different functional groups and the summed up EF in the EMEP/EEA Guidebook (2016) would be 0.0009 kg ha^{-1} d^{-1} instead of 0.0011 kg ha^{-1} d^{-1} and therefore the difference to the EF from König et al. (1995) would even be bigger.

Table 27 NMVOC emission factors from König et al. (1995) and Lamb et al. (1993) with the functional groups from which compounds were measured

Crop	Measured functional groups	NMVOC EF [kg^{-1} ha^{-1} d^{-1}]	Source
Wheat	Alcohols, aldehydes, ketones, ethers and others	0.0012	König et al., 1995
Rye	Terpenes, alcohols, aldehydes	0.0179	
Rape	Terpenes, alcohols, aldehydes, ethers and others	0.0121	
Grass (15 °C)	Isoprene, terpenes, alcohols, aldehydes, ethers and others	0.0022	
Grass (25 °C)	Isoprene, terpenes, alcohols, aldehydes, ketones, ethers and others	0.0101	
Wheat	Isoprene, terpenes, ethers and others	0.0046	Lamb et al., 1993 in EMEP/EEA Guidebook (2016)
Rye	Isoprene, terpenes, ethers and others	0.0011	

Davison et al. (2008) conducted measurements over alpine grassland in Switzerland. They report EFs from drying cut grass and after removal of the cut grass, respectively. The EF for drying cut grass is 1.32 kg ha^{-1} d^{-1}. This is an average over three days. If only the first 24 hours would be considered, an EF of 2.64 kg ha^{-1} d^{-1} results. The EF after the drying cut grass was removed is 0.32 kg ha^{-1} d^{-1}. The authors claim that this EF is comparable to intact grassland but results are not given in the study. Ruuskanen et al. (2011) made similar measurements in Austria. The EF measured 2 h after the cut for 24 h is 2.5 kg ha^{-1} d^{-1}. The EFs after the grass was removed and over intact grassland on a sunny day are 0.32 kg ha^{-1} d^{-1} and 0.17 kg ha^{-1} d^{-1}, respectively. The two studies show a similar result. However, Ruuskanen et al. (2011) measured actually the net flux and showed that there is also a deposition. Therefore, the net NMVOC EF for intact grass, after the cut and after removal are -0.27 kg ha^{-1} d^{-1}, 2.50 kg ha^{-1} d^{-1} and 0.14 kg ha^{-1} d^{-1}, respectively. According to Ruuskanen et al. (2011) intact or growing grass is a sink for NMVOC. However, only biogenic NMVOC like mono- and sesquiterpenes are deposited. On the other hand, Bamberger et al. (2010) report an EF from mountain grassland during the growing season of 0.069 kg ha^{-1} d^{-1}.

An EF for maize of 0.0065 kg ha^{-1} d^{-1} is given by Bachy et al. (2016). They measured biogenic volatile organic compounds (BVOC) emissions over a maize field during the entire growing season (May-October), but without the cutting.

4.3 Selection of NMVOC species relevant for NMVOC emissions

As described in the beginning of chapter 4 we conclude that it is not meaningful to elaborate a list of individual NMVOC which should be included in the literature review. Instead of, we suggest to include all the studies which we considered as important and report, thus, all the individual compounds studied or the sum of NMVOC. Nevertheless, we provide a list of 36 NMVOC which we consider as the most important ones for source category 3B Manure management, see Table 28. The selected compounds were either the most often measured ones or contribute significantly amount to the total NMVOC emissions for some animal categories. In Table 28 the compounds are listed in alphabetical order of the International Union of Pure and Applied Chemistry (IUPAC) name and the Chemical Abstracts Service (CAS) Number. For source category 3D Agricultural soils, a corresponding list was not established due to the very limited number of available studies where individual compounds were often not provided.

Table 28 The 36 most important NMVOC from source category 3B with their CAS number from given in alphabetical order of their IUPAC name

IUPAC name	CAS Number
Acetaldehyde	75-07-0
Acetic Acid	64-19-7
Benzaldehyde	100-52-7
Butan-1-ol	71-36-3
Butan-2-one	78-93-3
Butane-2,3-dione	431-03-8
Butanoic acid	107-92-6
Ethanol	64-17-5
Ethyl acetate	141-78-6
4-Ethylphenol	123-07-9
Heptanal	111-71-7
Hexanal	66-25-1
Hexane	110-54-3
Hexanoic acid	142-62-1
Indole	120-72-9
Methanedithione	75-15-0
Methanol	67-56-1
(Methyldisulfanyl)methane	624-92-0
(Methylsulfanyl)methane	75-18-3
(Methyltrisulfanyl)methane	3658-80-8
N,N-Dimethylmethanamine	75-50-3
2-Methylpropanoic acid	79-31-2
3-Methyl-1*H*-indole	83-34-1
3-Methylbutanoic acid	503-74-2
4-Methylphenol	106-44-5
Nonanal	124-19-6
Pentanal	110-62-3
Pentane	109-66-0
Pentanoic acid	109-52-4
Phenol	108-95-2
Propan-1-ol	71-23-8
Propan-2-ol	67-63-0
Propan-2-one	67-64-1
Propanoic acid	79-09-4
Propyl acetate	109-60-4
Toluene	108-88-3

5 Short comments on EFs used in the EMEP/EEA Guidebook – 2016

In this section we give a short comment on each PM and NMVOC emission factor provided in the EMEP/EEA Guidebook (2016) for the source categories 3B Manure management and 3D Agricultural soils.

5.1 3B Manure management

5.1.1 Emission factors for particulate matter

In this section short comments on the EFs listed in the EMEP/EEA Guidebook (2016) are given after the Table 29. It is a copy of Table 3.5 given in source category 3B Manure management of the EMEP/EEA Guidebook (2016). It lists the Tier 1 emission factors of the different livestock categories for particulate matter.

Table 29 Tier 1 emission factors for 3B Manure management according to the EMEP/EEA Guidebook (2016). Letters in brackets indicate the indices of the sources and comments given below

Code	Livestock	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]
3B1a	Dairy cattle	1.38 (a)	0.63 (a)	0.41 (a)
3B1b	Non-dairy cattle (including young cattle, beef cattle and suckling cows)	0.59 (a)	0.27 (a)	0.18 (a)
3B1b	Non-dairy cattle (calves)	0.34 (a)	0.16 (a)	0.10 (a)
3B2	Sheep	0.14 (b)	0.06 (b)	0.02 (b)
3B3	‘Swine’ (Fattening pigs)	1.05(c)	0.14 (d)	0.006 (e)
3B3	‘Swine’ (Weaners)	0.27 (c)	0.05 (f)	0.002 (c)
3B3	‘Swine’ (Sows)	0.62 (c)	0.17 (f)	0.01 (c)
3B4a	Buffalo	1.45 (a)	0.67 (a)	0.44 (a)
3B4d	Goats	0.14 (b)	0.06 (b)	0.02 (b)
3B4e	Horses	0.48 (g)	0.22 (g)	0.14 (g)
3B4f	Mules and asses	0.34 (a)	0.16 (a)	0.10 (a)
3B4gi	Laying hens (laying hens and parents)	0.19 (c)	0.04 (h)	0.003 (i)
3B4gii	Broilers (broilers and parents)	0.04 (c)	0.02 (j)	0.002 (k)
3B4giii	Turkeys	0.11 (l)	0.11 (m)	0.02 (c)
3B4giv	Other poultry (Ducks)	0.14 (a)	0.14 (a)	0.02 (a)
3B4giv	Other poultry (Geese)	0.24 (a)	0.24 (a)	0.03 (a)
3B4h	Other animals (Fur animals)	0.018 (b)	0.008 (b)	0.004 (b)

(a) (Takai et al., 1998). A detailed explanation for cattle is given in section 2.1.1 and 2.1.2. All EFs from Takai et al. (1998) are not background corrected which is likely to lead to EFs too high in value. Further, it seems that these EFs are generally at the upper end of reported values.

(b) (Mosquera et al., 2010; Mosquera and Hol, 2011). The here listed EFs do not coincide with the EFs given in the cited literature. Mosquera and Hol (2011) give EFs for PM10 and PM2.5 of 0.019 kg animal place^{-1} year^{-1} and 0.005 kg animal place^{-1} year^{-1}, respectively. These EFs are also given in Vonk et al. (2016). Animal place and animal can be used here interchangeably since the empty period of the housing was zero. The original source could not be found. Furthermore, the PM2.5 EF is probably too high by a factor of 5 to 10. Mosquera et al. (2011) provide EF for minks in animal place per year, which are then used for fur animals.

(c) (Winkel et al., 2015). The TSP EFs are not background corrected which is likely to lead to EFs too high in value. Winkel et al. (2015) is a study that published several EFs measured by the Wageningen UR Livestock Research and we did not examine every EF that is given in this paper. Other erroneous information might be present as it was the case with dairy cattle (see section 2.1.1). It seems to be unambiguous that the EMEP/EEA Guidebook (2016) copied an incorrect EF for TSP for fattening pigs. It should be either 0.840 or 0.365 kg animal^{-1} a^{-1}. Or if the average of both housing systems given in Winkel et al. (2015) is taken 0.603 kg animal^{-1} a^{-1}.

(d) (Chardon and van der Hoek, 2002; Schmidt et al., 2002; Jacobson et al., 2004; Koziel et al., 2004; Haeussermann et al., 2006; Haeussermann et al., 2008; Costa and Guarino, 2009; van Ransbeeck et al., 2013; Winkel et al., 2015). Big variety of studies. Some of the original sources were not available and we cannot do a complete assessment.

(e) (van Ransbeeck et al., 2013; Winkel et al., 2015). The EFs from van Ransbeeck et al. (2013) accounted for empty periods and are therefore lower than those from Winkel et al. (2015). Otherwise very solid EF.

(f) (Haeussermann et al., 2008; Costa and Guarino, 2009; Winkel et al., 2015). No comments are necessary.

(g) (Seedorf and Hartung, 2001). The only study that provides EFs from horses. Therefore, the best available source. However, other EFs from this paper were rather high in value.

(h) (Lim et al., 2003; Costa and Guarino, 2009; Demmers et al., 2010; Costa et al., 2012; Valli et al., 2013; Hayes et al., 2013; Shepherd et al., 2015; Winkel et al., 2015; Haeussermann et al., 2008). Good selection of sources.

(i) (Lim et al., 2003; Fabbri et al., 2007; Demmers et al., 2010; Hayes et al., 2013; Dunlop et al., 2013; Shepherd et al., 2015; Winkel et al., 2015). Good selection of sources.

(j) (Redwine et al., 2002; Lacey et al., 2003; Roumeliotis and van Heyst, 2007; Calvet et al., 2009; Demmers et al., 2010; Modini et al., 2010; Roumeliotis et al., 2010; Lin et al., 2012; Winkel et al., 2015). Good selection of sources although we were not able to evaluate all of them.

(k) (Roumeliotis and van Heyst, 2007; Demmers et al., 2010; Modini et al., 2010; Roumeliotis et al., 2010; Lin et al., 2012; Winkel et al., 2015). We were not able to evaluate all of the sources, however it seems to be a good selection.

(l) “Assume same ratio for TSP to PM10 as ‘Other poultry’”. Good assumption.

(m) (Schmidt et al., 2002; Li et al., 2008; Winkel et al., 2015). We recommend not to use Li et al. (2008). Schmidt et al. (2002) could not be assessed.

(n) (Lim et al., 2003; Fabbri et al., 2007; Demmers et al., 2010; Costa et al., 2012; Valli et al., 2013; Hayes et al., 2013; Dunlop et al., 2013; Shepherd et al., 2015; Winkel et al., 2015). Good selection of sources. However, it remains unknown for which EF these sources were used for.

5.1.2 Emission factors for NMVOC

The Tier 1 and Tier 2 EFs in the EMEP/EEA Guidebook (2016) are based on results from the National Air Emissions Monitoring 2007-2010 (NAEM) study in the USA. The EFs were converted to European agricultural conditions using Intergovernmental Panel on Climate Change (IPCC) default values for livestock feed intake and excretion of Volatile Substances (VS) (EMEP/EEA Guidebook, 2016). An assessment of four of the 16 measurements revealed important inconsistencies within these studies. For example, we found three different EF values based on the same measurements (Cortus et al., 2010a) or, according to the published data, the measurements were done in empty housings or outside the measuring campaign (Lim et al., 2010d; Zhao et al., 2010c; Cortus et al., 2010b). Therefore, the validity of these EFs is difficult to assess. It is also challenging to find valuable information on their quality assurance and calibration. According to VOC measuring experts, measuring devices were used that are not suitable for livestock emission measurements (personal communication Feilberg, 2017; Mohn, 2017). Further, it remains unknown, how the original EFs were converted to European agricultural conditions as this task was outsourced to a company and a description of the procedure is not available (personal communication Amon, 2017). The emission factors from the NAEM study for dairy cattle included silage feeding. First, only one study measured ethanol and methanol emissions, which are usually prevalent in high concentration at housings with dairy cattle and silage feeding (see section 4.1.1 and 4.1.5). Second, the emissions from silage feeding are based on Alanis et al. (2008) and Chung et al. (2010) who used flux chamber measurements to determine silage emission factors from the feeding table. However, flux chambers are appropriate for sources that are production or diffusion limited. But silage is convection limited and therefore wind tunnel experiments should be used. It can be assumed that the chamber measurements lead to an underestimation of EFs (personal communication Hafner, 2017). A more detailed explanation on both Tier approaches is given in section 8.1. At the present time, it is impossible to assess the accuracy of the EFs given in the EMEP/EEA Guidebook (2016). Further investigations are needed.

5.2 3D Agricultural soils

5.2.1 Emission factors for particulate matter

Both Tier methodologies are based on van der Hoek and Hinz (2007). In this study a possible deposition within the field of 50% or 90% is given. The EMEP/EEA Guidebook (2016) uses for the operation “Harvesting” a reduction of 82% without giving any information why or how this number was determined. For the other operations, no field deposition is used, even though deposition might occur. Furthermore, the EMEP/EEA Guidebook (2016) provides EFs for PM2.5 even though such information is not given in van der Hoek and Hinz (2007). For the Tier 1 methodology, the same EF for PM10 is also used for TSP. The Tier 1 EF does not include emissions from grassland and it remains also unknown how it was aggregated. For the Tier 2 methodology no TSP EFs are given, therefore we assume to use to PM10 EFs. Nevertheless, van der Hoek and Hinz (2007) is still the best available source that provides information on harvesting operations. New sources on particulate matter emissions from agricultural soils are necessary for a more accurate emission inventory.

5.2.2 Emission factors for NMVOC

The emission factors are based on Lamb et al. (1993) and König et al. (1995). Both are still the most comprehensive studies available. However, these studies are short term measurements and measured only a few functional groups, which differed between the two studies. Where the EFs of the two studies for the same crop differed widely the Guidebook took an average of both. It needs to be discussed if this is a valid step since different functional groups were measured. It might have been a better option to sum up the EFs for each crop from the two studies instead. Further, the studies were conducted during a different growing stage of the crops and therefore, different VOC might have been prevalent. Additionally, in these studies emission factors for maize are missing and for grassland better studies are available. For reliable EFs, measurements from different crops over the entire growing season inclusive the harvest are necessary. Nevertheless, if emissions are reported we advise to use country specific sources for the dry matter content of the crops, which are needed to calculate emissions of the Tier 2 approach.

6 Recommendation of revised EFs and activity data

6.1 3B Manure management

In order to calculate emissions, EMIS needs for each of its livestock category a time series of emission factors and activity data. Emission factors are needed for TSP (PM in EMIS), PM10, PM2.5 and NMVOC. Additionally, the animal number of the livestock category is required. The time series consists of numbers for the years 1900, 1980, 1990 and then every year until 2050. In the following sections, it is explained how the emission factors of each livestock category in EMIS were derived and the sources are provided. Emission factors are only given for the years for which data was available. The linear interpolation between these years is done by EMIS, except for young cattle (see Table 30) and swine, where the EFs are dependent on animal numbers.

6.1.1 Particulate Matter

6.1.1.1 Cattle

The EMIS data base has cattle categories different from the ones implemented in the ammonia emission inventory calculated by Kupper et al. (2018). In EMIS, some categories are aggregated. A comparison of the categories and how they are aggregated in EMIS is shown in Table 30.

Table 30 Livestock categories for cattle in Kupper et al. (2018) and in EMIS

Categories according to Kupper et al. (2018)	EMIS categories
Dairy cattle	LF Manure Man. Dairy Cattle
Non-dairy cattle (suckling cows)	LF Manure Man. Non-Dairy Cattle
Non-dairy cattle (calves of suckling cows)	LF Manure Man. Young Cattle
Non-dairy cattle (heifers 1year)	
Non-dairy cattle (heifers 2year)	
Non-dairy cattle (heifers 3year)	
Non-dairy cattle (beef cattle)	
Non-dairy cattle (fattening calves)	

Distinct emission factors are implemented for dairy cattle and for all other cattle categories. Since the emissions depend on the housing system different emission factors for tied and loose housings are used (see Table 31). These "base" emission factors were derived from Schrade (2009). A detailed explanation can be found in chapter 3. The emission factors from the different housing systems were then aggregated according to their occurrence in the corresponding year.

Table 31 Derived EFs for dairy and non-dairy cattle in tied housings and loose housings used in the model for the EFs in EMIS

Livestock category and system	EF TSP [kg animal^{-1} a^{-1}]	EF PM10 [kg animal^{-1} a^{-1}]	EF PM2.5 [kg animal^{-1} a^{-1}]
Dairy cattle – tied housing	0.33	0.10	0.02
Non-dairy cattle – tied housing	0.14	0.04	0.01
Dairy cattle – loose housing	0.78	0.23	0.06
Non-dairy cattle – loose housing	0.34	0.10	0.02

In order to calculate individual emission factors, the share of animals kept in tied and loose housings had to be known for every year. Data was available for the years 1990, 1995, 2002, 2007, 2010 and 2015 (Kupper et al., 2018). From the year 2015 onwards, the shares were kept constant. For the years 1900 and 1980 100% tied housings was assumed (Klossner et al., 2014). The emission factors for each Kupper et al. (2018) livestock category was calculated as follows:

$$EF_{i,k} = EF_{TH_i} * r_{i,k} + EF_{LH_i} * (1 - r_{i,k}) \quad \textbf{(1)}$$

where the subscript *i* stands for the livestock category and *k* for the year. $EF_{i,k}$ is the emission of livestock category *i* of the year *k*. EF_{TH} the base emission factor of tied housings, EF_{LH} the base emission factor for loose housings and *r* the ratio of animals kept in tied housings. Equation (1) can be used for all PM size fractions. The calculated EFs for dairy cattle and suckling cows could directly be used. For the EMIS category young cattle, the emission factors had to be aggregated according to the number of animals. Therefore, the emissions of each of the young cattle livestock category were calculated, then summed up and divided by the sum of the animals (see Equation (2)).

$$EF\_YC_k = \frac{\sum_i EF_{i,k} * N_{i,k}}{\sum_i N_{i,k}} \quad \textbf{(2)}$$

where YC stands for young cattle, $EF_{i,k}$ is the emission of livestock category *i* of the year *k* and $N_{i,k}$ is the number of animals of livestock category *i* of the year *k*.

6.1.1.2 Other livestock categories besides cattle

For all livestock categories other than cattle, except for the TSP EF of fattening pigs, PM10 and PM2.5 EFs of goats, sheep, deer and camels/lamas we suggest applying default Tier 1 EFs (Table 3.5, source category 3B Manure management) from the EMEP/EEA Guidebook (2016). For fattening pigs, a TSP EF of 0.603 kg animal^{-1} a^{-1} from Winkel et al. (2015) is proposed (see Section 2.1.3 and Table 11). For goats, the EFs for PM10 and PM2.5 of 0.05 kg animal^{-1} a^{-1} and 0.002 kg animal^{-1} a^{-1}, respectively from Aarnink et al. (2014) are suggested, as for the currently used EFs the original source could not be found and the EFs differ significantly from EFs found in the literature (see Section 2.1.5). The same EFs as for goats are also assumed for the livestock categories sheep, camels/lamas, deer and bison. For rabbits, the Tier 1 EFs of fur animals should be used since there is no better EF available. All EFs are kept constant over the entire time series, except for the EF of the aggregated category swine. For the animals outside agriculture the same EFs as for the corresponding agricultural animal were used.

6.1.2 NMVOC

Despite the fact we recommend not to report any NMVOC emissions (section 4.1 and 5.1.2) we show here how we would apply a Tier 1 approach.

The Tier 1 approach of EMEP/EEA Guidebook (2016) provides EFs for animals with silage feeding and without silage feeding (Table 3.4, source category 3B Manure management). For all livestock categories other than cattle the provided EFs without silage feeding were used. For the cattle categories, an aggregation of the EFs with and without silage feeding was used based on data available for dairy cows for 1980 (Klossner et al., 2014), 2002, 2007, 2010, 2015 (Kupper et al., 2018) and expert judgement for non-dairy cattle. For heifers, it is reasonable to use the same share of animals getting rations containing silage feed as for dairy cattle, since heifers are mostly kept on the same farms as dairy cows. For suckling cows, calves of suckling cows and beef cattle, the proportions of the populations receiving silage is likely to be underestimated and for fattening calves overestimated if the numbers from dairy cattle are applied. Therefore, numbers based on our expert judgement were used which are at 95%, 95% and 0% silage feeding for suckling cows and calves of suckling cows, beef cattle and fattening calves, respectively (see Table 32). For the year 1900, 0% silage feeding was assumed (Klossner et al., 2014) for all cattle categories. In 1900 and 1980 the livestock category suckling cows did not yet exist in Switzerland and therefore no shares are given. From the year 2015 onwards, the shares were kept constant. A comparison with an expert judgement for the year 2017 (personal communication with Reidy (2017)) supports our used shares (see footnote in Table 32).

The emission factors for dairy cattle, non-dairy cattle and young cattle were calculated in the same way as the particulate matter emissions (see Equation (1) and (2)). Instead of tied housings and loose housings, the parameters with silage feeding and without silage feeding were used. For the livestock categories camel/lamas, deer and rabbits, we propose to apply the EFs of camels, reindeer and fur animals, respectively. For bison, we suggest using the emission factor of suckling cows without silage feeding. For the animals outside agriculture, the same EFs as for the corresponding agricultural animal were used.

Table 32 Percentage of animals getting silage feed

Livestock category	1900	1980	2002	2007	2010	2015*	Source
Dairy cattle (DC)	0%	30%	56%	61%	58%	56%	Klossner et al., 2014 and Kupper et al., 2018
Heifers (H)	0%	30%	56%	61%	58%	56%	Expert judgement
Suckling cows + calves (SC + CSC)	-	-	95%	95%	95%	95%	Expert judgement
Beef cattle (BC)	0%	95%	95%	95%	95%	95%	Expert judgement
Fattening calves (FC)	0%	0%	0%	0%	0%	0%	Expert judgement

*Expert judgement for 2017 from Reidy, 2017 of DC: 66%, H: 66%, SC + CSC: 95%, BC: 100%, FC: 0%

6.1.3 Animal numbers

For the calculation of the emission factors for young cattle as well as the emissions for every year for all livestock categories, the number of animals must be known. Continuous data was available for the years 1990 and onwards. If not otherwise stated these animal numbers are provided by EMIS. No data was available for the years 1900 and 1980. But based on the data for the years 1886, 1906, 1978 and 1983 from Klossner et al. (2014), the years 1900 and 1980 were linearly interpolated.

6.1.3.1 Cattle

All numbers of cattle categories for the years 1990 until 2030 were adopted from the ammonia emission inventory (Kupper et al., 2018). From 2030 onwards, the numbers were kept constant. In the present model, the numbers from the ammonia emission inventory are used, as EMIS does not provide the corresponding subcategories. The number of animals for suckling cows and their calves for the years 1900 and 1980 were set to zero as there was no data available or did not exist at that time.

6.1.3.2 Swine

For swine, the same livestock categories as in Kupper et al. (2018) were used. Additionally, there is an aggregated swine category. The animal numbers for each livestock category for the years 1990-2030 were taken from the ammonia emission inventory. The interpolated animal numbers for 1900 and 1980 are incomplete. Klossner et al. (2014) provide numbers for fattening pigs, boars and breeding sows only. The latter are dry sows and nursing sows together. For weaned piglets, no data was available. To derive the numbers of the missing swine categories, the average of the ratio weaned piglets, dry sow or nursing sows to breeding sows from the years 1990-1993 was multiplied with the numbers of breeding sows in the years 1886, 1906, 1978 and 1983 and then interpolated.

Moreover, an aggregated swine category with implied emission factors was generated. Important to mention is that the animal numbers from the five swine categories should be summed up instead of using the numbers from EMIS. In total numbers of swine from EMIS the piglets (not to be confused with weaned piglets) are also accounted for, but in the PM emission factors the piglets are already included in the emission factors of nursing sows.

6.1.3.3 Poultry

For the years before 1990, Klossner et al. (2014) do provide numbers for other poultry only, but in these numbers turkeys are also included. For the year 1900 it can be assumed that the number of turkeys is zero. In 1980, data for turkeys are not available. For reasons of simplicity, the number of turkeys in 1980 was also set to zero, because it can be assumed that other poultry probably includes turkeys as well.

6.1.3.4 Other livestock categories

For sheep, goats, horses, mules and asses, it was possible to interpolate the animal numbers for the years 1900 and 1980 (Klossner et al., 2014). The numbers for bison, camels/lamas and deer for the years 1900 and 1980 were assumed to be zero. Buffalos in Switzerland are sparse. They are included in the numbers of dairy cattle and are not provided by the statistics as separate livestock category.

For the animals outside agriculture no data before 1990 was available. However, it can be assumed that those numbers for the year 1900 and 1980 were zero.

6.2 3D Agricultural soils

Under agricultural soils we suggest to distinguish two different kinds of areas, i.e. “Cultivated area” and “Grassland”. Both are aggregated categories. How they were aggregated is described in the following sections. The data source for the areas is the farm structure survey of the Federal Statistical Office (FSO) (Federal Statistical Office, 2017). For summering pastures a compilation established by the FSO was used (personal communication Bretscher, 2017).

6.2.1 Particulate Matter

The EMEP/EEA Guidebook (2016) provides Tier 2 EFs for different kind of agricultural operations (Tables 3.5 – 3.8, source category 3D Crop production and agricultural soils) for wet and dry climate conditions. However, it does not differentiate between TSP and PM10. We decided to use the operations of soil cultivation and harvesting at wet conditions (Tables 3.5 and 3.7). In addition, the EMEP/EEA Guidebook (2016) includes the operations cleaning and drying. The latter is relevant for wet climate conditions but not further specified in the EMEP/EEA Guidebook (2016). To our perception they mean by drying the drying of crops after the harvest, which occurs in the barn. This is a practise e.g. common in Scandinavia, where the crop is dried in drying operations located at the farm sites. In Switzerland, this practice does hardly occur. The cleaning and final drying process of crops is performed in the grain receiving facilities. The emissions from Switzerland’s grass drying plants are reported in source category 1A4ci Grass drying. We further assume that these emissions cannot be compared with those occurring e.g. in Scandinavia in a barn where possibly no particle filters are used. Therefore, we argue not to include any emissions from the cleaning and drying process.

In order to derive the implied EFs of aggregated source categories, the emission from the cultivation of each single type of crop has to be calculated, summed up and afterwards divided by the total area of the included crops. The emissions are calculated as follows:

$$E_i = EF\_sc_i * N\_sc_i * A_i + EF\_h_i * N\_h_i * A_i \quad \textbf{(3)}$$

where EF_sc_i and EF_h_i are the default Tier 2 emission factors of crop *i* for soil cultivation and harvesting, respectively, given in the EMEP/EEA Guidebook (2016). N_sc_i and N_h_i, the annual number of soil cultivation or harvesting operations, are needed for the respective crop (see Table 33). A_i stands for the area of crop *i*. Table 34 shows schematically how the input data from the Federal Statistical Office (2017) was aggregated in order to match the available crop parameters of the EMEP/EEA Guidebook (2016) which are used in the model, and finally yielding the two aggregated categories of cultivated area and grassland (proposed for EMIS).

Table 33 Numbers of soil cultivation and harvest used to calculate EFs

Agricultural crop	Operation	Numbers per year	Source
Cultivated area	Soil cultivation	1	Expert judgement
Grassland valley area	Soil cultivation	1	Expert judgement
Grassland alpine area	Soil cultivation	0	Expert judgement
Total grassland area	Soil cultivation	0.5	Expert judgement and Federal Statistical Office (2017)
Cultivated area	Harvesting	2	Expert judgement
Grassland valley area	Harvesting	5	Richner and Sinaj (2017)
Grassland alpine area	Harvesting	3	Richner and Sinaj (2017)
Total grassland area	Harvesting	3.9	Richner and Sinaj (2017) and Federal Statistical Office (2017)

For the model input category “other arable”, no emission factor for harvesting was provided by the EMEP/EEA Guidebook (2006). We decided that this emission factor for harvesting is zero. This might lead to an underestimation of emissions. However, using the EF of wheat would probably overestimate the PM emissions. The number of grass harvests differs between the alpine and the valley area. In the valley and the alpine area, generally five and three harvests, respectively, occur (Richner and Sinaj, 2017). FSO provides also the share of agricultural area that is situated in the alpine and valley area, respectively (Federal Statistical Office, 2017). We assumed that in the entire alpine area the entire area can be classified as natural meadows. Therefore, the numbers of grassland harvests are calculated as follows,

$$N = \frac{LN * r_a * h_a + \left((G_t - LN * r_a) * h_v\right)}{G_t} \tag{4}$$

where LN is the agricultural area, G_t the grassland area, r_a the share of the agricultural area that is in the alpine area and h_a and h_v are the number of harvests in the alpine, respectively valley area. Vineyards, orchards, reed and remaining agricultural area are classified as grassland because they are largely covered by grass. The calculated average numbers of grassland harvests have a variance of $\sigma^2 < 0.0001$ and therefore the resulting EF is the same. Thus, the number of grassland harvests was set constant at the value of 3.9, which is the average of the grassland harvests for the years 1900, 1980, 1990-2016 and 2050. For the soil cultivation of grassland, a similar approach was used. Based on our assumption that in the alpine area only natural meadows or grassland occur, we further assumed that no soil operations are carried out in this area. Therefore, the value was set to zero (see Table 34). Compared to harvesting, the number of soil operations occurring on grassland between the years varies even less and therefore also an average was used. Summering pastures are not considered as an area of PM emissions, because they are almost exclusively grazed by animals and thus no PM emissions are produced from the grass itself. The updated PM EFs are 10-13% smaller than the previously provided ones.

Table 34 Aggregation of the Federal Statistical Office (FSO) data used in EMIS

Federal Statistical Office (2017)	EMEP/EEA Guidebook (2016)*/Model input	EMIS (proposed)
Barley	Barley	Cultivated area
Oat	Oat	
Wheat Grain maize Other grains	Wheat	
Potatoes Sugar beet Fodder beet Outdoor vegetables Silage maize Other plants	Other arable	
Artificial grassland Natural meadows and pastures Vineyards Orchards Reed and remaining agricultural area	Grassland	Grassland

*In the EMEP/EEA Guidebook (2016) EFs are only available for the crops listed here.

6.2.2 NMVOC

For NMVOC we suggest using country-specific Tier 2 emission factors based on Table 3.3 (source category 3D Crop production and agricultural soils) of the EMEP/EEA Guidebook (2016). For the cultivated area, the values of wheat are assumed whereas for grassland and summering pastures the one for grass at a mean temperature of 15 °C should be used. The emission factors depend on the growing period and the dry matter content of the plants. For the growing period for wheat and grassland, the values of 0.5 and 0.3, respectively, given in Table 3.3 of the EMEP/EEA Guidebook (2016), are proposed to be used. For summering pastures, a growing period, respectively fraction of the year when emissions occur, of 0.3 instead of 0.5 as for grassland is assumed. Reasons therefore are the shorter growing period in the high alpine area. As summering pastures are mostly not cut, they are not considered for calculation of particulate matter emissions (see Section 6.2.1). The dry matter yield of wheat, grassland and summering pastures was determined based on Richner and Sinaj (2017). Dry matter amounts of 5'500 kg dm $ha^{-1}a^{-1}$, 8'800 kg dm $ha^{-1}a^{-1}$ and 5'200 kg dm $ha^{-1}a^{-1}$ are proposed for wheat, grassland and summering pastures, respectively (Richner and Sinaj, 2017). These values are slightly different than the ones of the EMEP/EEA Guidebook (2016) that uses 4'700 kg dm $ha^{-1}a^{-1}$ and 9'000 kg dm ha^{-1} a^{-1} for grassland and for wheat, respectively. For the entire time series, all NMVOC emission factors are assumed to remain constant.

6.2.3 Areas

The Federal Statistical Office (2017) provides area data for the years 1985, 1990 and 1996 to 2016. For 1900, only the total agricultural area was available. The different types of crops in 1985 were extrapolated to 1900. We are aware that this is a simplification which does not reflect the reality in this period. However, it was not possible to simulate the occurrence of crops of 1900 in the present project. It can also be assumed that the results of emissions would change only slightly because the available EFs of the different crop types are largely aggregated (see Table 30). From 2016 onwards, the areas of each agricultural crop were kept constant. For summering pastures the Federal Statistical Office (2017a) provide data from 1990 onwards. For the years 1900 and 1985 the areas were interpolated with data from 1886, 1906, 1983 and 1988 from Klossner et al. (2014).

7 Uncertainty assessment

It was difficult to estimate an uncertainty for the EFs suggested to use in EMIS. There are many factors that influence the PM and NMVOC emissions.

7.1 3B Manure management

The emissions for particulate matter depend on many factors. A summary of possible factors that influence PM emissions are given below (adopted from EMEP/EEA Guidebook (2016)):

The design of the building and how it is operated:

- Forced vs naturally ventilated buildings: the concentration measurements within the building are multiplied with a measured ventilation rate. Ventilation rates lead to the largest uncertainty. Especially, if the ventilation rate is low. In forced ventilated buildings the standard uncertainty can easily be up to 25%. This uncertainty is because (i) each fan is different and there is a variation of more than 20% between the fans. (ii) The manufacture performance curves are not advisable to use and (iii) also laboratory certificated fans behave differently in the field. Generally, this leads to an overestimation of the emission (Gates, 2017). Naturally ventilated buildings are even more difficult to measure, and it is assumed that the uncertainty is at least as large as in forced ventilated buildings.
- The climate within the building: the climate inside and outside the building often regulates the ventilation rate. But a warmer and less humid climate also produces higher PM concentration within the building than a colder and especially more than a humid one.
- The type of floor (solid floor, partly slatted, fully slatted) might also influence the concentrations.
- Geometry and positions of inlets and outlets: depending on the sites where they are located, it can lead to re-entrainment of deposited particles caused by turbulences above the surfaces.

The livestock bedding in the building:

- The type of material and their physical properties: straw, chopped straw, short straw, wood shavings, sawdust or a mixture of different materials have different emissions, which are also dependent on the moisture of the bedding.
- The quantity and quality of the bedding: if it was de-dusted before or some de-moistening agents were added or also the mass of bedding material per animal that is given influences the concentration and finally the emission.

Livestock management:

- Animal activity: the animal species, circadian rhythms, young vs adult animals, tied vs loose housings are all factors that influence the emissions.
- The amount of time the animals spend in a building. If it is the whole year or only a seasonal housing.
- The feeding systems: dry vs liquid feed, automatic vs manual feed and the feed storage conditions.
- The manure systems: liquid vs solid manure, manure removal intervals, manure storage are also influencing the emissions.

Concentration measurements:

- Type of device: there are manual devices like gravimetric filtration and online devices like tapered element oscillating microbalance (TEOM) or DustTrak that is a direct-reading real-time monitor incorporating a light scattering laser photometer. DustTrak tend to overestimate concentration by a factor of 2 if the factory calibration is used. If the device is adjusted to the aerosols with the right optical properties they provide the most reliant data.

However, they are very expensive compared to other devices. TEOM tend to underestimate concentration because of the loss of semi-volatile compounds in the heated air stream. TEOM are therefore less reliable in environments with rapid changing temperature and humidity (Kingham et al., 2006). Nevertheless, online devices are necessary to relate particulate matter concentrations with animal activity. Probably the best option is a combination of several gravimetric devices within the building and at least one online device. Independent of the device, it is important that the measurements are done isokinetically. The uncertainty of the concentration measurements are usually below 1% if the device is operated correctly (Gates, 2017)

- Location of the device: the PM concentrations within a building are heterogeneous. For emission measurements it is crucial that the devices are placed close to the outlet.

This list shows that many factors can potentially influence the emission factor of PM from livestock buildings. An additional uncertainty is the animal numbers, which should be below 5%. Overall, we assume an uncertainty for the particulate matter emission factors from manure management of at least a factor of two up to four.

With the currently available data and the reasons mentioned in chapter 4.3 an uncertainty assessment for NMVOC is difficult. Based on the knowledge from the different studies we looked at the uncertainty factor is at least two, but it could also easily be ten. There are just not enough data available to determine valid EFs from manure management for NMVOC.

7.2 3D Crop production and agricultural soils

The uncertainty of the current EFs are even higher than those for manure management. The EMEP/EEA Guidebook (2016) defines emission as the particle that are leaving the field border. However, mostly measurements conducted directly at the source are available, which were then multiplied with a reduction factor. Due to the lack of data from different crops and insufficient measurements we assume the PM EFs have an uncertainty of at least a factor of two up to a factor of five.

With the currently available data and the reasons mentioned in chapter 4.2 and 4.3 an uncertainty assessment for NMVOC is difficult. The EFs of the studies suggested to use in EMIS are rather old and do not cover enough different crops. Additionally, they are based on short-term measurements and measured different functional groups. Therefore, we assume that the NMOC EFs could deviate by a factor of ten or more from reality.

8 Discussion of emissions calculated by Tier 1 and Tier 2 approaches

The EMEP/EEA Guidebook (2016) provides often a Tier 1 and a Tier 2 methodology for calculating emissions. Here, we explain why certain methodologies were suggested to use and others not. Further, the differences in emission between the two approaches for the year 2015 are shown. In this chapter the terms "non-dairy cattle" and "young cattle" are used according to EMIS (see Table 30).

8.1 3B Manure management

The EMEP/EEA Guidebook (2016) only provides a Tier 1 methodology, which was rejected for dairy cattle, non-dairy cattle, young cattle, fattening pigs, sheep and goats because of misleading data (see chapter 2). Hence, for dairy cattle, non-dairy cattle and young cattle country specific EFs differentiating tied and loose housings were used that led to a Tier 2 methodology (see section 2.1). For fattening pigs the TSP from Winkel et al. (2015) and for sheep and goats the PM10 and PM2.5 EFs from Aarnink et al. (2014) were used which corresponds rather to a Tier 1 approach but with revised (country-specific) emission factors (see section 2.1). The difference in emissions between the default Tier 1 approach and the proposed combination of Tier 2 (dairy, non-dairy and young cattle) and Tier 1 (using revised EFs for the above mentioned livestock categories) approaches for the year 2015 is given in Table 35. The latter methodology yields 32%, 40% and 81% lower emissions of TSP, PM10 and PM2.5 from all livestock categories, respectively. The shares of these livestock categories on the total emission of each size fraction calculated with the default Tier 1 approach and proposed methodology suggested to use in EMIS for the example year 2015 is given in Table 36.

Table 35 Additional emissions (E) for particulate matter for the year 2015 if a default Tier 1 instead of the suggested country specific Tier 2 and Tier 1 (with revised EFs) methodology is used

Livestock category	E TSP [t]	E PM10 [t]	E PM2.5 [t]
Dairy cattle	456	263	214
Non-dairy cattle	33	21	19
Young cattle	240	152	134
Fattening pigs	347	0	0
Sheep, goats, deer and camels/lamas	0	4	8
Sum	1076	440	374

Table 36 Comparison of the share on total TSP, PM10 and PM2.5 emissions of aggregated livestock categories using the default Tier 1 approach of the EMEP/EEA Guidebook (2016) for all livestock categories and as suggested using a Tier 2 approach for dairy cattle, non-dairy cattle, young cattle and a Tier 1 approach with revised EFs for fattening pigs, sheep, goats deer camels/llamas for the example year 2015.

Livestock category	E TPS [%]	E PM10 [%]	E PM2.5 [%]
	Default Tier 1 approach		
Dairy cattle	24	33	51
Non-dairy cattle	2	3	5
Young cattle	15	21	33
Swine	30	13	1
Poultry	26	26	6
Other Animals	3	4	4
	Tier 2 approach		
Dairy cattle	16	16	28
Non-dairy cattle	2	2	3
Young cattle	12	12	22
	Tier 1 approach with revised EFs		
Swine	28	22	7
Poultry	38	43	29
Other Animals	4	6	12

For NMVOC emissions the Tier 2 approach is complicated and the algorithm and the EFs can be found on page 27 and 28 and in Table 3.11 and 3.12, respectively, in source category 3B Manure management of the EMEP/EEA Guidebook (2016). The Tier 2 approach was calculated for dairy cattle, non-dairy cattle and young cattle only. For livestock categories other than cattle the emissions were not calculated due to lack of data. Instead of feed intake in MJ the excreted volatile solids are needed. This data was not available, and it would have been necessary to derive it from several sources with additional assumptions. Hence, only dairy cattle, non-dairy and young cattle can be compared. With the Tier 2 methodology the emissions for all cattle categories are 10'721 t higher than with a Tier 1 methodology. This means the Tier 2 methodology yields about twice as high emissions as with a Tier 1 methodology (see Table 37).

Table 37 NMVOC emissions for dairy, non-dairy and young cattle using a Tier 1 or a Tier 2 methodology and the difference in NMVOC emissions between the two approaches for the year 2015

Livestock category	Tier 1 E [t]	Tier 2 E [t]	Tier 2 – Tier 1 E [t]	Factor
Dairy cattle	7924	15603	7679	2.0
Non-dairy cattle	1018	2964	1946	2.9
Young cattle	5782	6878	1096	1.2
All cattle	14724	25445	10721	1.7

The reason for these differences is the use of different emission factors. The EFs are not easy to compare with each other as they do not provide the same information. The EFs that were derived with the provided Tier 2 algorithm and country specific data for the year 2015 are given in Table 38. For a comparison with the Tier 1 EF, the derived Tier 2 EFs had to be aggregated. The EFs with silage feeding are the sum of all sources and the EFs without silage feeding are the sum of EF building, EF manure store, EF manure application and EF grazing (Table 39).

Table 38 Derived EF for each source with a Tier 2 algorithm and country specific data for the year 2015

Livestock category	EF silage store [kg animal^{-1} a^{-1}]	EF silage feeding [kg animal^{-1} a^{-1}]	EF building [kg animal^{-1} a^{-1}]	EF manure store [kg animal^{-1} a^{-1}]	EF manure application [kg animal^{-1} a^{-1}]	EF grazing [kg animal^{-1} a^{-1}]
Dairy cattle	4.6	18.5	3.3	2.6	7.8	0.1
Non-dairy cattle	3.3	13.2	2.3	2.1	4.9	0.2
Young cattle	1.4	5.5	1.0	0.8	2.0	0.1
All cattle	2.7	10.9	1.9	1.6	4.4	0.1

In Table 39 the aggregated EFs form the Tier 2 methodology are compared with the EFs from the Tier 1 approach. Additionally, an EF from silage feeding based on a silage study is shown (see Section 4.1.5). “All cattle” are implied values according to animal numbers and share of silage feeding in Switzerland for the year 2015. The EFs for dairy cattle are in the Tier 2 methodology larger by a factor of two compared with the Tier 1 methodology. This means that not only the emissions originating from silage feeding and silage stores are twice as big, but also the emissions coming from the building, manure application, manure stores and grazing are in the sum twice as large. The reason for this difference is unknown. For the classification of these EFs it is possible to take the EFs from silage from Hafner et al. (2013) into account (see Section 4.1.5). To the calculated EF of 17.37 kg animal^{-1} a^{-1} 25% is added for the emissions from silage stores (EMEP/EEA Guidebook, 2016). The resulting EF of 21.71 kg animal^{-1} a^{-1} is close to the EF from the Tier 2 methodology.

Table 39 Comparison of EFs based on Tier 1 and Tier 2 methodologies and from silage studies (Hafner et al., 2013) for the year 2015

Livestock category	EF with silage feeding [kg animal^{-1} a^{-1}]	EF without silage feeding [kg animal^{-1} a^{-1}]	EF silage [kg animal^{-1} a^{-1}]
Tier 1 methodology			
Dairy cattle	17.9	8.1	9.9
Non-dairy cattle	8.9	3.6	5.3
Young cattle	8.9	3.6	5.3
All cattle	12.3	5.3	7.0
Tier 2 methodology			
Dairy cattle	36.9	13.8	23.1
Non-dairy cattle	26.0	9.4	16.5
Young cattle	10.7	3.8	6.9
All cattle	21.7	8.0	13.7
Silage studies			
Dairy cattle	-	-	21.7

However, no statement is possible about the emissions not originating from the silage itself. We do not know if the Tier 1 or the Tier 2 methodology is closer to reality. We have the impression that the emissions originating from manure application and manure stores in the Tier 2 methodology are too high (see Table 38). These EFs are based on a correlation ($r^2 \approx 50$) between NH_3 and NMVOC emissions measured by Feilberg et al. (2010) in an experimental pig production facility. Cattle and pigs have a somewhat similar NH_3/NMVOC ratio. However, these are measurements from inside a barn which has a much lower NH_3/NMVOC ratio than for pig slurry or respectively manure stores. The same can be assumed for manure application. Therefore, it is certainly not correct to use this relation to determine NMVOC emissions from manure stores and manure applications and it consequently leads to an overestimation of the emissions (personal communication Feilberg, 2017). It is likely that the current NMVOC EFs are off by a factor of two to ten.

8.2 Agricultural soils

For Agricultural soils there are also differences between the two methodologies. The Tier 1 approach for PM does not include emissions from fertiliser, pesticides or grassland (e.g. hay making). Further, only one EF is available for all crop types. Therefore, the Tier 1 methodology was not used. The Tier 2 methodology proposed to use in EMIS yields 578 t and 15 t less PM10 and PM2.5 emissions, respectively, for the year 2015 than the emissions calculated with the Tier 1 methodology.

For the NMVOC Tier 1 methodology, only a single EF is available. This EF is based on the Tier 2 methodology with an assumed European average crop distribution (see Table 3.3, source category 3D Crop production and agricultural soils of the EMEP/EEA Guidebook (2016)). The Tier 2 methodology suggested to use in EMIS results in 492 t less NMVOC emissions than the Tier 1 approach for the year 2015.

9 Differences between the EMEP/EEA Guidebook – 2013 and 2016

This report is based on the EMEP/EEA Guidebook (2016). In chapter 0 we compare the air pollution emission inventories and IIR of the submission 2017 from the selected countries Austria, Denmark, Germany, the Netherlands and Switzerland with each other. Because chapter 3 of the IIR for the year 2017 of Germany is based on the Guidebook version of 2013, a comparison between the EMEP/EEA Guidebook (2013) and the EMEP/EEA Guidebook (2016) is necessary. Additionally, it helps to better understand the Guidebook version of 2016.

In general, the structure of both versions is the same and only minor changes were done. It seems that the updates were not always done carefully. Especially changes in indices and footnotes were forgotten, which is sometimes a bit confusing in the version of 2016.

9.1 3B Manure management

9.1.1 Particulate Matter

The default Tier 1 EFs differ between the two versions. For dairy cows, other cattle (including young cattle, beef cattle and suckling cows), calves, sheep, goats, horses, mules and asses, ducks, geese, fur animals and buffalo, the EFs of both versions are the same. Different EFs are used for fattening pigs, weaners, sows, laying hens (laying hens and parents), broilers (broilers and parents) and turkeys, see Table 40. Remarkably, the PM2.5 EFs of all these livestock categories are about one order of magnitude smaller in the version of 2016 compared to the version of 2013.

Table 40 List of livestock categories that have a different default Tier 1 EFs in the EMEP/EEA Guidebook 2016 (3B Manure management Table 3.5) compared to the version of 2013 (3B Manure management Table 3.3)

Livestock	EF for TSP [kg AAP^{-1} a^{-1}]	EF for PM10 [kg AAP^{-1} a^{-1}]	EF for PM2.5 [kg AAP^{-1} a^{-1}]
		EMEP/EEA Guidebook 2013	
Fattening pigs	0.75	0.34	0.06
Weaners	0.21	0.10	0.02
Sows	1.53	0.69	0.12
Laying hens (laying hens and parents)	0.119	0.119	0.023
Broilers (broilers and parents)	0.069	0.069	0.009
Turkeys	0.52	0.52	0.07
		EMEP/EEA Guidebook 2016	
Fattening pigs	1.05	0.14	0.006
Weaners	0.27	0.05	0.002
Sows	0.62	0.17	0.01
Laying hens (laying hens and parents)	0.19	0.04	0.003
Broilers (broilers and parents)	0.04	0.02	0.002
Turkeys	0.11	0.11	0.002

In the version of 2013, the Tier 2 approach was calculated with an algorithm that takes the different housing systems into account (slurry/solid and cages/perchery). The EFs were taken from Takai et al. (1998). This Tier 2 approach existed therefore only for livestock categories examined in the underlying literature. For the other livestock categories no Tier 2 approach was available. In the version of 2016, the Tier 2 approach per se does not exist anymore. It is stated that the current available literature does not allow the estimation of EFs necessary for a Tier 2 approach. However, the default Tier 1 EFs in the version of 2016 for some livestock categories (dairy cattle, beef cattle and calves) were calculated with the Tier 2 approach in the version of 2013 by using European averages.

9.1.2 Non-methane volatile organic compounds

There is no difference between the Tier 1 approaches in the two versions. For the Tier 2 approach, the EFs in both versions are the same. However, the EMEP/EEA Guidebook (2013) provides additional EFs for camels, which are the same as for reindeer.

The algorithms for the calculation of the emissions differ somewhat in the two versions. In the 2016 version, the formula for cattle and for all livestock categories other than cattle are the same, except that instead of the parameter mega joule feed intake (MJ), the parameter volatile solids (VS) for all livestock categories other than cattle is used. In the 2013 version, the algorithm used for the two categories differ also in other parameters, which might be an error. In Table 41, the algorithms applied in 2013 and 2016 for all animal categories and for dairy cattle and other cattle, respectively, is shown. Highlighted in blue are the parts, which we assume are notation errors. Highlighted in red and bold are the differences between the two versions besides the mentioned errors. The difference beside the notation errors between the two versions is that for $E_{NMVOC,manure\_store\_i}$ and $E_{NMVOC,appl.\_i}$ in 2013 also the fraction of time the animals spent inside (x_{house_i}) was included. In the version of 2016, the index "house" is sometimes named "building". In Table 41, this error is already corrected. Further, the E_{NMVOC_xxx} are actually not emissions as they are not yet multiplied with an animal number but emission factors with the unit [kg animal^{-1} a^{-1}]. The $EF_{\_NMVOC\_xxx}$ from the Guidebook have the unit [kg NMVOC/MJ feed intake] (there is a notation error in the Guidebook) or [kg NMVOC/kg VS excreted] (see Table 3.11 and 3.12, source category 3B Manure management of EMEP/EEA Guidebook (2016)).

Table 41 Algorithms for calculating Tier 2 NMVOC emissions given in the EMEP/EEA Guidebook 2013 and 2016

Dairy cattle and other cattle: EMEP/EEA Guidebook 2013		
$E_{NMVOC,graz\_i}$	=	$MJ_{\_i}$ * (1-x_{house_i}) * $EF_{NMVOC,graz\_i}$
$E_{NMVOC,appl.\_i}$	=	$E_{NMVOC,house\_i}$ * x_{house_i} * ($E_{NH3,appl.\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,manure\_store\_i}$	=	$E_{NMVOC,house\_i}$ * x_{house_i} * ($E_{NH3,storage\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,house\_i}$	=	$MJ_{\_i}$ * x_{house_i} * ($EF_{NMVOC,house\_i}$ * $Frac_{silage}$)
$E_{NMVOC,silage\_feeding\_i}$	=	*formula is missing*
$E_{NMVOC,silage\_store\_i}$	=	$MJ_{\_i}$ * x_{house_i} * ($EF_{NMVOC,silage\_feeding\_i}$ * $Frac_{silage}$) *(multiplication with $Frac_{silage\_store}$ missing)*
E_{NMVOC_i}	=	AAP_{animal_i} * ($E_{NMVOC,silage\_store\_i}$ + $E_{NMVOC,silage\_feeding\_i}$ + $E_{NMVOC,house\_i}$ + $E_{NMVOC,store\_i}$ + $E_{NMVOC,appl.\_i}$ + $E_{NMVOC,graz\_i}$)
All livestock categories other than cattle: EMEP/EEA Guidebook 2013		
$E_{NMVOC,graz\_i}$	=	$VS_{\_i}$ * (1-x_{house_i}) * $EF_{NMVOC,graz\_i}$
$E_{NMVOC,appl.\_i}$	=	$E_{NMVOC,house\_i}$ * x_{house_i} * ($E_{NH3,appl.\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,manure\_store\_i}$	=	$E_{NMVOC,house\_i}$ * x_{house_i} * ($E_{NH3,storage\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,house\_i}$	=	$VS_{\_i}$ * x_{house_i} * $EF_{NMVOC,house\_i}$
$E_{NMVOC,silage\_feeding\_i}$	=	$VS_{\_i}$ * x_{house_i} * ($EF_{NMVOC,silage\_feeding\_i}$ * $Frac_{silage}$)
$E_{NMVOC,silage\_store\_i}$	=	$VS_{\_i}$ * x_{house_i} * ($EF_{NMVOC,house\_i}$) * ($EF_{NMVOC,silage\_feeding\_i}$ * $Frac_{silage}$) * 0.25
E_{NMVOC_i}	=	AAP_{animal_i} * ($E_{NMVOC,silage\_store\_i}$ + $E_{NMVOC,silage\_feeding\_i}$ + $E_{NMVOC,house\_i}$ + $E_{NMVOC,store\_i}$ + $E_{NMVOC,appl.\_i}$ + $E_{NMVOC,graz\_i}$)
Dairy cattle and other cattle: EMEP/EEA Guidebook 2016		
$E_{NMVOC,graz\_i}$	=	$MJ_{\_i}$ * (1-x_{house_i}) * $EF_{NMVOC,graz\_i}$
$E_{NMVOC,appl.\_i}$	=	$E_{NMVOC,house\_i}$ * ($E_{NH3,appl.\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,manure\_store\_i}$	=	$E_{NMVOC,house\_i}$ * ($E_{NH3,storage\_i}$ / $E_{NH3,house\_i}$)
$E_{NMVOC,house\_i}$	=	$MJ_{\_i}$ * x_{house_i} * $EF_{NMVOC,house\_i}$
$E_{NMVOC,silage\_feeding\_i}$	=	$MJ_{\_i}$ * x_{house_i} * ($EF_{NMVOC,silage\_feeding\_i}$ * $Frac_{silage}$)
$E_{NMVOC,silage\_store\_i}$	=	$MJ_{\_i}$ * x_{house_i} * ($EF_{NMVOC,silage\_feeding\_i}$ * $Frac_{silage}$) * $Frac_{silage\_store\_i}$
E_{NMVOC_i}	=	AAP_{animal_i} * ($E_{NMVOC,silage\_store\_i}$ + $E_{NMVOC,silage\_feeding\_i}$ + $E_{NMVOC,house\_i}$ + $E_{NMVOC,store\_i}$ + $E_{NMVOC,appl.\_i}$ + $E_{NMVOC,graz\_i}$)
AAP_{animal}	=	Average annual animal population
MJ_i	=	Gross feed intake [MJ a^{-1}]
VS_i	=	Excreted volatile substance for livestock category i [kg a^{-1}]
x_{house_i}	=	Proportion of time the animals spend in the livestock building in a year
$Frac_{silage}$	=	Fraction of feed in dry matter during housing that is silage, out of the maximum proportion of silage possible in the feed composition.
$Frac_{silage\_store\_i}$	=	Proportion of the emissions from the silage store compared with the emissions from the feeding table in the building. On average 0.25.
$EF_{NMVOC,graz\_i}$	=	EF of NMVOC from grazing animals [kg MJ^{-1}] or [kg kg^{-1}]
$EF_{NMVOC,house\_i}$	=	EF of NMVOC from livestock housing [kg MJ^{-1}] or [kg kg^{-1}]
$EF_{NMVOC,silage\_feeding\_i}$	=	EF of NMVOC from silage feeding [kg MJ^{-1}] or [kg kg^{-1}]
$E_{NMVOC,graz\_i}$	=	EF of NMVOC from grazing animals [kg $animal^{-1}$ a^{-1}]
$E_{NMVOC,appl.\_i}$	=	EF of NMVOC from manure application [kg $animal^{-1}$ a^{-1}]
$E_{NMVOC,manure\_store\_i}$	=	EF of NMVOC from outdoor manure stores [kg $animal^{-1}$ a^{-1}]
$E_{NMVOC,house\_i}$	=	EF of NMVOC from livestock housing [kg $animal^{-1}$ a^{-1}]
$E_{NMVOC,silage\_feeding\_i}$	=	EF of NMVOC from silage feeding [kg $animal^{-1}$ a^{-1}]
$E_{NMVOC,silage\_store\_i}$	=	EF of NMVOC from silage storage [kg $animal^{-1}$ a^{-1}]
E_{NMVOC_i}	=	Total NMVOC emission [kg a^{-1}]
$E_{NH3,appl.\_i}$	=	Emission of NH_3 from manure application
$E_{NH3,house\_i}$	=	Emission of NH_3 from livestock buildings
$E_{NH3,storage\_i}$	=	Emission of NH_3 from outdoor manure stores

9.2 3D Agricultural soils

9.2.1 Particulate matter

In both versions the Tier 1 and Tier 2 methodologies are the same.

9.2.2 Non-methane volatile organic compounds

The Tier 1 approach for both versions is identical. In 2013, no Tier 2 approach per se is available and the Tier 1 approach should be used. However, the methodology given in the appendix in 2013 that shows how the EFs for Tier 1 approach was derived, is the same as the Tier 2 approach in 2016. One just needs to change certain country specific parameters instead of using the European mean values according to the FAO.

9.3 3Df Use of pesticides, 3F Field burning of agricultural residues and 3I Agriculture other

The two Guidebook versions do not differ.

10 Comparison of the air pollution emission inventories and IIR from Austria, Denmark, Germany, the Netherlands and Switzerland

In this chapter, the 2017 submissions of the air pollution emission inventories (NFR tables) and Informative Inventory Reports (IIR) from Austria, Denmark, Germany, the Netherlands and Switzerland are compared.

10.1 Austria

The PM and NMVOC emissions from source categories 3B Manure management and 3D Agricultural soils of Austria's air pollution emission inventory and Informative Inventory Report (2017) are either based on the EMEP/CORINAIR Guidebook (2007), the EMEP/EEA Guidebook (2016) or national sources. Because the Guidebook version of 2007 has a different structure and different source categories than the version of 2016, the comparison with the other countries is somewhat difficult. A stage 3 in-depth review report was not available for this IIR submission. The last review refers to the 2010 report (United Nations, 2010).

10.1.1 3B Manure management

PM: Austria states that the EFs given in the EMEP/CORINAIR Guidebook (2007) contrast the listed literature source (Winiwarter et al., 2009), which does not provide information on PM emissions from livestock. Instead, Austria uses the four EFs for TSP from the RAINS model given in Luekewille et al. (2001), see Table 42. However, for PM10 and PM2.5 Austria does not use the EFs of the RAINS model, but the fraction values given in Klimont et al. (2002) instead, which are 0.45 and 0.10 for PM10 and PM2.5, respectively. They are used for all livestock categories.

Table 42 TSP EF for animal housing used in Austria's IIR 2017, Table 218

Livestock	TSP EF [kg animal^{-1}]	Livestock	TSP EF [kg animal^{-1}]
Dairy cows	0.235	Laying hens	0.016
Other cattle	0.235	Broilers	0.016
Fattening pigs	0.108	Turkeys	0.016
Sows	0.108	Other poultry	0.016
Ovines	0.235	Goats	0.153
Horses	0.153	Other animals	0.016

NMVOC: Austria does not report any NMVOC emissions from the source category 3B Manure management.

10.1.2 3D Agricultural soils

PM: Austria assumes a PM10 EF of 5 kg ha^{-1} for both field operations and harvesting according to Oettl et al. (2005) and Hinz and van der Hoek (2006), respectively. A reduction of 90% of the emission for 90% of the area was assumed (wet conditions). For the remaining 10% of the cultivated area a 10 times higher EF as compared to wet conditions was assumed. The aggregated PM10 EF was then converted into TSP and PM2.5 EFs with the shares (TSP 100%, PM10 45%, PM2.5 10%) given in Klimont et al. (2002), which are the same as used in source category 3B Manure management. The resulting implied EFs of 4.44 kg ha^{-1}, 2.00 kg ha^{-1} and 0.44 kg ha^{-1} for TSP, PM10 and PM2.5, respectively, were then multiplied with the total cultivated area in Austria.

NMVOC: Austria claims to use the Tier 1 approach presented in EMEP/EEA Guidebook (2016) to calculate NMVOC emissions. However, they use the EF for wheat for their cultivated area and the EF for grassland at 15 °C given in Table 3.3 of the Tier 2 approach.

10.1.3 3.F Field Burning of Agricultural Residues

PM: For cereals, Austria uses EFs that match a Tier 1 approach in the EMEP/EEA Guidebook (2016) (Table 3-1). For vinicultures Austria uses an EF for all size fractions of 15 kg t^{-1} residual wood taken from Winiwarter et al. (2007).

NMVOC: For cereals Austria uses a country-specific EF of 28.52 kg ha^{-1} which is burnt provided by the Austrian Research Centre Seibersdorf (unpublished data). The EF reported for vinicultures is 14.20 kg Mg^{-1} waste, taken from a national study (original source could not be found).

10.2 Denmark

The emissions of sector 3 Agriculture of Denmark's air pollution emission inventory and Informative Inventory Report (2017) are based on the EMEP/EEA Guidebook (2016).

10.2.1 3B Manure management

PM: For the estimation of PM emissions Denmark used a Tier 1 approach according to the EMEP/EEA Guidebook (2016).

NMVOC: The calculations are based on a Tier 1 approach. Denmark differentiates between silage and non-silage feeding. For the time the animals (cattle, sheep, goats and horses) spent grazing, the EF for non-silage was used. Denmark uses constant EFs for all reported years.

10.2.2 3D Agricultural soils

PM: Denmark uses a Tier 2 approach for a wet climate. For harvesting, Denmark uses a reduction of 90% of the EFs provided in van der Hoek and Hinz (2007) compared to the Guidebook, which uses a reduction of 82%. For the EF for other arable, Denmark uses an average of wheat, rye, barley and oat. As TSP EFs were not given in the Guidebook, the EFs of PM10 were multiplied by a factor of 10 according to van der Hoek and Hinz (2007). However, no information supporting this assumption could be found in the underlying literature.

NMVOC: A Tier 2 approach is applied by using EFs for wheat, rye, rape and grassland (15 °C). Denmark applies country specific dry matter contents of the crops and multiplies the resulting EF with the corresponding crop area. These EFs were merged to an implied EF which was multiplied with the total cultivated area in Denmark in order to include crops not listed in the Guidebook.

10.2.3 3F Field Burning of agricultural residues

PM and NMVOC: Denmark states to use the default EF provided by the EMEP/EEA Guidebook (2016), which we understand as a Tier 1 methodology. However, Denmark uses the default EFs of a Tier 2 approach for burning rice instead.

10.3 Germany

Germany has a well-structured wiki webpage for the Informative Inventory Report 2017 instead of a pdf file. The webpage can be found under: http://iir-de.wikidot.com/. Sector 3 Agriculture of the report is based on the EMEP/EEA Guidebook (2013). The last review of Germany's IIR dates from 2014 (United Nations, 2014). No information about any approach or improvements are given for PM and NMVOC in the review. Note, that under the given link above, always the most current IIR is linked and older versions are not available. However, all the necessary information are also given in Rösemann et al. (2017).

10.3.1 3B Manure management

PM: Germany applies a Tier 2 approach using default EFs. Additionally, they consider air scrubber systems in swine husbandry. For TSP and PM10 Germany assumes a dust removal rate of 90% and for PM2.5 a rate of 70% (Rösemann et al., 2017).

NMVOC: Germany uses a Tier 1 approach. Silage feeding is considered only for cattle and horses. For sheep Germany uses an implied EF as they assume 40% less emissions for lambs compared to adult sheep. Germany uses a Tier 1 methodology because they claim inconsistencies in the Tier 2 approach which are not closer defined (Rösemann et al., 2017).

10.3.2 3D Agricultural soils

PM: Germany uses a Tier 1 approach with the default EFs provided by the EMEP/EEA Guidebook (2013) as a Tier 2 methodology cannot be applied due to the lack of input data (Rösemann et al., 2017).

NMVOC: Germany uses a Tier 2 methodology with country specific dry matter contents. For grassland areas, the EF for grass (15 °C) is used, for all other crops except rye and rape the EF of wheat is used (Rösemann et al., 2017).

10.3.3 3F Field burning of agricultural residues

Germany does not report any emissions at all from this source category.

10.4 The Netherlands

The emissions from sector 3 Agriculture of Netherland's air pollution emission inventory and Informative Inventory Report (2017) are either based on the EMEP/EEA Guidebook (2016) or on national studies. In the IIR, no specific information is provided which EFs were used. The Netherlands just state that they employed default values from the Guidebook or national emission factors. Default EFs could be either Tier 1 or Tier 2. A more conclusive report is provided by Vonk et al. (2016). However, we could not find sufficient information in the IIR and Vonk et al. (2016) to comprehend all the emissions reported.

10.4.1 3B Manure management

PM: The EFs used by the Netherlands are based on a measurement program conducted by Wageningen UR Livestock Research between 2007 and 2009 on particulate matter emission from animal houses (Netherland's Informative Inventory Report, 2017). For housing types given in the Guidebook which were not included in the studies from the Wageningen UR Livestock Research, the emission factors were estimated based "on housing characteristics and space per animal proportional to the studied housing types. Where emission factors had to be derived within animal categories (e.g. laying hens under and over 18 weeks of age), the excreted amount of phosphorus was used" The selected EFs are included in our literature review. As in Vonk et al. (2016) no EFs for TSP are reported, the Netherlands are using the same EFs for TSP as for PM10 (derived from their NFR tables).

NMVOC: The Netherlands do not report any NMVOC emission in this source category at all.

10.4.2 3D Agricultural soils

PM: The Netherlands use a Tier 2 methodology. For transportation and handling of concentrates, fertilizer and pesticide for which no EFs are given in the Guidebook, they are applying a country specific method taken from Chardon and van der Hoek (2002). These additional emission estimates are given in Table 43. Unfortunately, no EFs of these activities are available.

Table 43 Additional estimates of PM emissions in the Netherlands from Chardon and van der Hoek (2002)

Operation	E PM10 [t a^{-1}]	E PM2.5 [t a^{-1}]	Source
Haymaking	6	1.2	Chardon and van der Hoek, 2002
Concentrates	90	18	
Synthetic fertilisers	105	21	
Pesticides	125	25	

NMVOC: In the IIR, the Netherlands do not provide information on the methodology or EFs used for crop cultivation. In the report itself, just a total emission of 0.2 Gg a^{-1} is given. A more accurate number is provided in the NFR tables. However, the Netherlands do not report their area of cultivated land and therefore we cannot conclude if the Netherlands are using a Tier 1 or a Tier 2 approach or even something else.

10.4.3 3F Field Burning of agricultural residues

The Netherlands do not report any emission at all in this source category.

10.5 Switzerland

For the emissions of PM and NMVOC from source categories 3B Manure management and 3D Agricultural soils Switzerland uses country specific sources or does not report any information.

10.5.1 3B Manure management

PM: Switzerland does not use the provided EFs from the Guidebook but employs its own EFs. However, the source of these EFs is not provided. For TSP and PM10 the same EFs are assumed. The EFs used by Switzerland are compared with the default Tier 1 values of the EMEP/EEA Guidebook (2016) in Table 44. In Switzerland's Informative Inventory Report (2017) only the EFs for PM2.5 are given. The EFs for PM10 were taken from Switzerland's Informative Inventory Report (2016) and validated with the NFR Tables from 2017. For most PM10 and PM2.5 EFs, the differences between the Guidebook and the IIR are large.

Table 44 EF used in Switzerland's IIR compared with the default Tier 1 values in the EMEP/EEA Guidebook (2016)

Livestock category	EF TSP [g animal^{-1} a^{-1}] Guidebook	EF TSP/PM10 [g animal^{-1} a^{-1}] Switzerland	EF PM10 [g animal^{-1} a^{-1}] Guidebook	EF PM2.5 [g animal^{-1} a^{-1}] Switzerland	EF PM2.5 [g animal^{-1} a^{-1}] Guidebook
Dairy cattle	1380	392	630	59	410
Non-dairy cattle	590	392	270	59	180
Non-dairy cattle (calves)	340	98	160	15	100
Sheep	140	39	60	6	20
Swine*	647	726	120	109	6
Goats	140	39	30	6	20
Horses	480	39	220	6	140
Mules and asses	340	39	160	6	100
Poultry**	115	86	30	13	2.5

*The EFs from the Guidebook are mean values from fattening pigs, weaners, sows

**The EFs from the Guidebook are mean values from laying hens and broilers

NMVOC: Switzerland does not report any emissions from this source category.

10.5.2 3D Agricultural Soils

PM: Switzerland does not report any emissions from this source category.

NMVOC: Switzerland uses an EF of 3.72 kg NMVOC ha^{-1} for its agricultural area and does not report a source for this EF. The source provided is misleading since it relates to NH_3 emissions and no information related to NMVOC can be found. The EMEP/EEA Guidebook (2016) uses a default Tier 1 EF of 0.86 kg NMVOCha^{-1} agricultural area.

10.5.3 3F Field Burning of agricultural residues

Switzerland does not report emissions in this source category.

10.6 Summary

Table 45 shows a summary of the approaches the selected countries used. They are mainly based on the EMEP/EEA Guidebook (2016) or national sources. The webpage with all the submissions of NFR tables and IIR from the European countries can be found under:

http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2017_submissions/

The in-depth stage 3 reviews of the IIR were published here:

http://www.ceip.at/ms/ceip_home1/ceip_home/review_results/stage3_country_reports/

Table 45 Comparison of the different approaches used in the IIR for source categories 3B Manure management and 3 D Agricultural soils of Austria (AT), Denmark (DK), Germany (DE), the Netherlands (NL) and Switzerland (CH)

	AT		DK		DE		NL		CH	
	PM	**NMVOC**	**PM**	**NMVOC**	**PM**	**NMVOC**	**PM**	**NMVOC**	**PM**	**NMVOC**
3B	CS	NE	T1	T1	T2*/CS	T1	CS	NE	CS	NE
3D	CS	T1/CS	T2/CS	T2	T1	T2	T2/CS	not specified	NE	CS

CS = Country specific, NE = Not estimated, T1 = Tier 1, T2 = Tier 2
*according to EMEP/EEA Guidebook (2013)

In addition, a comparison of implied emission factors of PM2.5 and NMVOC from source categories of 3B Manure management is given in Table 46 and Table 47, respectively, for Austria, Denmark, Germany, the Netherlands and Switzerland based on emissions and activity data reported in the NFR tables of submission 2017 for the year 2015. Unfortunately, it was not possible to derive implied emission factors for most of the reported emissions from 3D Agricultural soils due to missing activity data in the NFR tables.

Table 46 Comparison of the PM2.5 implied emission factors for source category 3B Manure management based on the air pollution emission inventories 2015 (NFR Tables, submission 2017) of Austria (AT), Denmark (DK), Germany (DE), the Netherlands (NL) and Switzerland (CH)

2015		**AT**	**DK**	**DE**	**NL**	**CH**
IEF				**PM2.5**		
NFR Code	**Source category**			**g/animal**		
3B1a	Manure management - Dairy cattle	24	492	442	35	59
3B1b	Manure management - Non-dairy cattle	24	146	146	14	20
3B2	Manure management - Sheep	24	2	6	NE	6
3B3	Manure management - Swine	8	4	55	4	109
3B4d	Manure management - Goats	15	5	11	6	6
3B4e	Manure management - Horses	15	70	104	39	6
3B4f	Manure management - Mules and asses	IE	NO	IE	100	6
3B4gi	Manure management - Laying hens	2	3	21	3	13
3B4gii	Manure management - Broilers	2	2	9	2	IE
3B4giii	Manure management - Turkeys	2	20	70	(AD: NA)	IE
3B4giv	Manure management - Other poultry	2	1	11	(AD: NA)	IE
3B4h	Manure management - Other animals (please specify in IIR)	2	4	NE	(AD: NA)	(AD: NA)

AD = Activity data, IE = Included elsewhere NE = Not estimated, NO = Not occurring, NA = Not applicable

Table 47 Comparison of the NMVOC implied emission factors for source category 3B Manure management based on the air pollution emission inventories 2015 (NFR Tables, submission 2017) of Austria (AT), Denmark (DK), Germany (DE), the Netherlands (NL) and Switzerland (CH)

2015		AT	DK	DE	NL	CH
IEF				NMVOC		
NFR code	Source category			g/animal		
3B1a	Manure management - Dairy cattle	NE	17'449	17'937	NE	NE
3B1b	Manure management - Non-dairy cattle	NE	7'587	8'902	NE	NE
3B2	Manure management - Sheep	NE	199	131	NE	NE
3B3	Manure management - Swine	NE	634	651	NE	NE
3B4d	Manure management - Goats	NE	564	542	NE	NE
3B4e	Manure management - Horses	NE	6'028	6'639	NE	NE
3B4gi	Manure management - Laying hens	NE	167	165	NE	NE
3B4gii	Manure management - Broilers	NE	108	108	NE	NE
3B4giii	Manure management - Turkeys	NE	489	489	NE	NE
3B4giv	Manure management - Other poultry	NE	382	180	NE	NE
3B4h	Manure management - Other animals (please specify in IIR)	NE	1'937	NE	NE	NE

NE = Not estimated

11 Supplementary information

Supplementary information is provided in the form of excel sheets.

11.1 Supplementary_Information_Agricultural_emissions_of_NMVOC_and_PM.xlsx

Supplementary_Information_Agricultural_emissions_of_NMVOC_and_PM.xlsx with the worksheets PM – cattle, PM – swine, PM – poultry, PM – other animals, PM – soil + harvest, NMVOC – cattle, NMVOC- swine, NMVOC – poultry, NMVOC – silage, NMVOC – soil + harvest, 36 VOC and 3B Emissions_PM.

In these excel sheets there are all the EFs from the literature review included. For particulate matter emissions from source category 3B also the country, feeding rations, measurement duration, measuring method, indoor and outdoor temperature, relative humidity and exhaust air flow is given, if available. Additionally, there is a short comment to almost every study. For source category 3D the EFs form harvest and the different soil operations with the country and the measuring technique is given. Also to most of the studies a comment is included.

For NMVOC for source category 3B, there is a list with different compounds and their EF given. The list is the same for all livestock categories, which means that not always an EF is filled in. Further the 36 most important NMVOC mentioned in section 4.3 are highlighted in yellow. For the source category 3D, only the EFs of functional groups are given. Additionally, there is information about the temperature, measuring time, country and a short comment.

Additionally, there is a worksheet with the particulate matter emission calculations for the year 2015 for the source category 3B Manure management. This is provided to give detailed information on the emission differences.

11.2 EMIS_Importtabelle.xlsx

EMIS_Importtabelle.xlsx with the worksheets Importtabelle, 3B Manure Management_EF PM, 3B Manure Management_EF NMVOC, Nicht landwirtschaftliche Tiere, Tierzahlen, Anbindestall_Silage, 3D Agricultural Soils_EF, Flächenangaben.

This file contains all the EFs and activity data necessary to calculate annual emissions according to this report. Further, the derivation for all Tier 2 EFs is given.

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Annex 1

List of studies that might contain more information on PM emission factors which were not entirely considered in the literature review.

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Annex 2

List of studies that might contain more information on NMVOC emission factors which were not entirely considered in the literature review.

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