NMVOC from agricultural sources

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1 Project description

The purpose of the project is to find the key sources of emissions of Non-Methane Volatile Organic Compounds (NMVOC) in the agricultural sector, estimate the amounts of emissions and provide reliable time-series to fulfil the reporting demands of national emissions within the United Nations Economic Commission for Europe's (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) conventions, UNFCC and EU NECD directive.

Categories producing notable NMVOC emissions in the agricultural field are hereby considered to be manure management (3.B) and cultivated crops (3.D.e) within the main category of crop production and agricultural soils (3.D), and field burning of agricultural wastes (3.F). The methodology for calculation of emissions from field burning of agricultural wastes pre-exists, and is thereby excluded from this project (1).

To guide calculation, all formulas and calculational principles are derived from EMEP/EAA Guidebook 2016 (further referred to as “the guidebook”). Some changes are made to adapt the methodology for Nordic environment. These exceptions are explained in their respective methodological descriptions.

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1.1 Manure management

The emissions of manure management are calculated according to the guidance of EMEP/EAA Guidebook 2016 by Tier 1, Tier 2 and with a possibility to extend calculation into Tier 3. The calculation model ties into previously developed Finnish Normative Manure System.

1.1.1 Sources

According to the guidebook emissions of NMVOC in manure management originate from (2):

- Silage store and feed
- Manure in the barns
- Outdoor manure stores
- Field application of manure
- Grazing of animals

In the calculation model sources of NMVOC-emissions are categorized (ranging from 1980 to 2050), by source activity and by animal species, of which many do not contribute to the emissions in all of the previously presented activities. Silage feed is considered as the dominant feed type for most cattle, horses, sheep and goat. Without reliable data of the use of silage as the feed for other livestock, it is considered negligible.

The SNAP categories for animal species cover the range of SNAP categories between 100901 to 100915, with the exclusion of categories 100913 Camels and 100914 Buffalo due to them being non-existent in Finland. The animal categorization is kept in unison with the Finnish Normative Manure calculation system. The main animal categories with their respective SNAP and NFR categories are presented in Table 1. A full list of animal species included in the Finnish Normative Manure system can be found in Annex 1. Inhouse emissions will be reported in the categories within NFR 3B, and emissions of field application of manure and grazing under 3Da2a and 3Da3 respectively.

Table 1 - Main animal categories included in NMVOC emissions from manure management

Animal species	SNAP	NFR
Dairy cow	100901	3B1a
Suckler cow	100902	3B1b
Heifer >1 yr	100902	3B1b
Bull >1 yr	100902	3B1b
Calf <1 yr	100902	3B1b
Sow (with piglets)	100904	3B3
Boar (50- kg)	100903	3B3
Fattening pig (50- kg)	100903	3B3
Weaned pig (20-50 kg)	100903	3B3
Laying hen breeder (female)	100907	3B4gi
Cockerel (laying hen breeder, male)	100907	3B4gi
Broiler	100908	3B4gii
Broiler breeder hen	100908	3B4gii
Broiler breeder, male	100908	3B4gii
Chicken	100909	3B4giv
Turkey	100909	3B4giv
Other poultry	100909	3B4giv
Horse	100906	3B4e
Pony	100906	3B4e
Sheep	100905	3B2
Goat	100910	3B4d
Fox and racoon	100911	3B4h
Mink and fitch	100911	3B4h
Reindeer	100915	3B4h
Animal manure applied to soils	100900	3Da2a
Urine and dung deposited by grazing animals	101100	3Da3

1.1.2 Methods

Emissions are calculated separately for silage store and feeding, housing, manure storage and field application of manure. The emissions are calculated for every animal category with annually calculated parameters (where available). In each activity, emissions are calculated for the count of one animal. The animal and year specific emissions are then multiplied by average annual population. The corresponding equation is presented in equation 1.

$$E_{i,j} = AAP_{i,j} * \left(E_{silage_{store}} + E_{silage_{feed}} + E_{house} + E_{manure_{storage}} + E_{manure_{application}} + E_{grazing}\right)_{i,j} \quad (1.)$$

Where,

i = Livestock category

j = Active year

$AAP_{i,j}$ = Annual average population within the calculated livestock category in the given year

$E_{silage_{store}}$ = Emissions from silage store

$E_{silage_{feed}}$ = Emissions from silage feeding

E_{house} = Emissions from housing

$E_{manure_{storage}}$ = Emissions from manure in barns and outside stores

$E_{manure_{application}}$ = Emissions from field application of manure

$E_{grazing}$ = Emissions from grazing

Emissions from housing

Emissions from housing are estimated based on the time that the livestock spends in buildings. The time animals spend indoors is estimated annually. The estimates are retrieved from the Finnish Normative Manure System. The emission values are calculated with equations 2 and 3 which similar to each other, with the exception of primary activity data (gross feed intake as (MJ/a) and volatile solids excreted (kg/a)) being different for cattle and other livestock.

Cattle**:**

$$E_{house} = MJ_i * X_{house_i} * EF_{house_i} \tag{2.}$$

Other livestock**:**

$$E_{house} = VS_i * X_{house_i} * EF_{house_i} \tag{3.}$$

Where,

i = Livestock category

MJ_i = Gross feed intake as (MJ/a)

VS_i = Volatile solids excreted (kg/a)

X_{house_i} = Annual proportion of time the livestock spends inside buildings (%)

EF_{house_i} = Emission factor for emissions from housing

Emissions from silage feed

Emissions from silage store are estimated based on the time that the livestock spends in buildings and by estimating the fraction of silage feeding in the given livestock category. In order for the formula to be applicable, it is to be assumed that silage feed always occurs inside livestock buildings.

Cattle**:**

$$E_{silage_{store}} = MJ_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage}\right)_i \tag{4.}$$

Other livestock**:**

$$E_{silage_{store}} = VS_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage}\right)_i \tag{5.}$$

Where,

i = Livestock category

$EF_{silage_{feed}}$ = Emission factor for silage feed (*see chapter 1.1.4*)

$Frac_{silage}$ = Proportion of silage as feed (%)

Emissions from silage store

Emissions from silage store are estimated as the share of stored silage in relation to silage in feeding table by introducing an estimate of the fraction of the stored silage to equations *4* and *5*.

Cattle**:**

$$E_{silage_{store}} = MJ_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage} * \boldsymbol{Frac_{silage_{store}}}\right)_i \tag{6.}$$

Other livestock**:**

$$E_{silage_{store}} = VS_i * X_{house_i} * \left(EF_{silage_{feed}} * Frac_{silage} * \boldsymbol{Frac_{silage_{store}}}\right)_i \tag{7.}$$

Where,

i = Livestock category

$Frac_{silage_{store}}$ = The relative share of stored silage in relation to silage in feeding table (%)

This model applies the guidebook default of 0.25 for all species and all years, including species known not to be silage fed. Emission factors of silage feeding however are not cross-applied between species except with categories with close resemblance to each other. The model suggests emissions from silage store to occur for all cattle, horses, sheep and goats.

Emissions from manure storage

The proportion of emissions from storage is assumed to possess the same ratio as with ammonia. The equation only factorizes NMVOC emissions from housing (*equation 8*) with the storage/building-ratio of ammonia emissions. Ammonia emissions are calculated in the Finnish Normative Manure System.

$$E_{manure_{storage}} = E_{NMVOC_{house}} * \left(\frac{E_{NH3_{storage}}}{E_{NH3_{building}}}\right)_i \tag{8.}$$

Where,

i = Livestock category

$E_{NMVOC_{house}}$ = NMVOC emissions from housing (*Equations 2 and 3*)

$E_{NH3_{storage}}$ = Ammonia emissions from storage

$E_{NH3_{building}}$ = Ammonia emissions from housing

Emissions from field application of manure

Emissions from field application of manure follows the same principle than emissions from manure storage, thus the equation substitutes the term of ammonia emissions from storage in equation 8 with ammonia emissions from field application of manure.

$$E_{manure_{application}} = E_{NMVOC_{house}} * \left(\frac{E_{NH3_{application}}}{E_{NH3_{building}}}\right)_i \tag{9.}$$

Where,

i = Livestock category

$E_{NMVOC_{house}}$ = NMVOC emissions from housing (*Equations 2 and 3*)

$E_{NH3_{application}}$= Ammonia emissions from application

$E_{NH3_{building}}$ = Ammonia emissions from housing

Emissions from grazing

Emissions from outdoors grazing of animals are estimated with the assumption of the time spent in buildings. The time animals spend indoors is estimated annually. The estimates are retrieved from the Finnish Normative Manure System.

Cattle**:**

$$E_{graz} = MJ_i * (1 - X_{house_i}) * EF_{graz_i} \tag{10.}$$

Other livestock**:**

$$E_{graz} = VS_i * (1 - X_{house_i}) * EF_{graz_i} \tag{11.}$$

Where,

i = Livestock category

MJ_i = Gross feed intake as (MJ/a)

VS_i = Volatile solids excreted (kg/a)

EF_{graz_i} = Emission factor for grazing (*see chapter 1.1.4*)

X_{house_i} = annual proportion of time the animal spends inside a livestock building (%)

General principles in methodology

All actual activity data based on statistics and verified by sector experts. Secondary data consists of default values from the guidebook, logical assumptions, projections of trends and cross-application of data from species with similar properties.

Wherever annual data for a given year is not available, data from the nearest year available is used. If the nearest available year is considered not to reflect to the target year in sufficing accuracy, the year 2015 is used as reference.

1.1.3 Activity data

The main parameters are Gross feed intake (MJ), volatile solids excreted (VS), annual average population (AAP) which are provided by Natural Resources Institute Finland (LUKE). Detail increasing parameters such the share of time the animals spend in housing, fractions of silage store and feed are national values. Ammonia emissions in different activities are calculated in the Finnish Normative Manure system.

Activity data is available for MJ and VS for the years 1990-2015 and for AAP for the years 1980-2015. The livestock classification varies between data sources. MJ it is available for dairy cows, non-dairy cattle, suckler cows, bulls (age over 1 year), heifers, calves (under 1 year) and non-dairy GE. For VS primary data is available for dairy cows, non-dairy cattle, suckler cows, bulls (age over 1 year), heifers, calves (under 1 year), swine, sow, piglets, fattening pigs, boars, Weaned pigs, sheep, goats, horses, poultry , laying hens, chickens, cockerels, broiler hens, broilers, turkeys, other poultry (ducks), other animals, reindeer, fur animals, mink and fitch, fox and raccoon.

1.1.4 Emission factors

Emission factors for manure management are based on the Tier 2 suggestions of EMEP/EAA Guidebook 2016 which are presented in Table 2.

Table 2 - Default NMVOC Tier 2 EFs for livestock

NFR	Livestock	$EF_{silage_feeding}$	$EF_{building}$	$EF_{grazing}$	Unit
3B1a	Dairy cattle	2,00E-04	3,53E-05	6,90E-06	kg NMVOC kg/MJ feed intake
3B1b	Non-dairy cattle	2,00E-04	3,53E-05	6,90E-06	kg NMVOC kg/MJ feed intake
3B2	Sheep	1,08E-02	1,61E-03	2,35E-05	kg NMVOC/kg VS excreted
3B3	Swine (fattening pigs		1,70E-03		kg NMVOC/kg VS excreted
3B3	Swine (sows)		7,04E-03		kg NMVOC/kg VS excreted
3B4a	Buffalo	1,08E-02	1,61E-03	2,35E-05	kg NMVOC/kg VS excreted
3B4d	Goats	1,08E-02	1,61E-03	2,35E-05	kg NMVOC/kg VS excreted
3B4e	Horses	1,08E-02	1,61E-03	2,35E-05	kg NMVOC/kg VS excreted
3B4f	Mules and Asses	1,08E-02	1,61E-03	2,35E-05	kg NMVOC/kg VS excreted
3B4gi	Laying hens		5,68E-03		kg NMVOC/kg VS excreted
3B4gii	Broilers		9,15E-03		kg NMVOC/kg VS excreted
3B4giii	Turkeys		5,68E-03		kg NMVOC/kg VS excreted
3B4giv	Other poultry (ducks, geese)		5,68E-03		kg NMVOC/kg VS excreted
3B4h	Other animals (fur animals		5,68E-03		kg NMVOC/kg VS excreted
3B4h	Other animals (rabbits)		1,61E-03		kg NMVOC/kg VS excreted
3B4h	Other animals (reindeer)		1,61E-03	2,35E-05	kg NMVOC/kg VS excreted

To accommodate the emission factors to the categorization of livestock in the Finnish Normative Manure system (Annex 1), the following applications are made:

- Heifers: emission factor of dairy cattle applied
- Bulls: emission factor of dairy cattle applied
- Calves: emission factor of dairy cattle applied
- Weaned pig (20-50kg): emission factor of Swine (fattening pigs), possible overestimate

Data of gross energy intake as required by the EF of dairy cattle is available for heifers, bulls and calves.

1.2 Cultivated Crops (NFR 3.D.e)

The emissions of cultivated crops are calculated according to the guidance of EMEP/EAA Guidebook 2016. The model is constructed to calculate by Tier 1 and Tier 2 methods with a possibility to extend calculation into Tier 3 level of detail.

1.2.1 Sources

According to Simpson et al. (1999), biogenic NMVOC is commonly released by naturally growing vegetation (trees and natural grasslands) and cultivated crops including the cultivation of cereals, grasslands and silage (3). NMVOC-compounds emitted by agricultural crops may be isoprene, terpenes, alcohols, aldehydes, ketones, ethers and others (2).The following Table 3 presents all cultivated land areas by species. Total cultivated land area for 2015 was 2241 hectares.

Table 3 – Cultivated area of 2015 by species and corresponding SNAP and NFR categories

Species	Cultivated area (1 000 ha)	SNAP	NFR
Wheat	249	100102	3De
Rye	32	100102	3De
Barley	513	100102	3De
Oats	307	100102	3De
Mixed grain	36	100102	3De
Other grains	3	100102	3De
Peas	12	100102	3De
Potatoes	22	100102	3De
Sugar beet	13	100102	3De
Turnip rape and rape	57	100102	3De
Hay	86	100105	3De
Silage	492	100105	3De
Pasture	58	100105	3De
Other grassland	16	100105	3De
Other crops	75	100104	3De
Fallow	271	100101	3De
Total	2 241		

1.2.2 Methods

The methodology is based on guidebook Tier 2 method which reproduces the calculation of Tier 1 emission factor of by substituting guidebook (2016) *Table 3-3 Estimation of NMVOC Tier1 emission factor in kg ha-1 a-1* with national data wherever possible. The recalculation is done for each year independently taking into account the annual relative changes within crop distribution and mean dry matter.

Emissions are calculated with Tier 1 and Tier 2 methods simultaneously. Tier 2 method provides consistently smaller emission estimates than Tier 1.

1.2.3 Activity data

All activity data is based on statistics by Natural Resources Institute Finland (LUKE). Data from the use of arable land area is available 1980 onwards. Crop yields as (kg/ha/a) and harvested surface areas are available 2000 onwards.

1.2.4 Emission factors

Default emission factor for Tier 1 calculation is 0.86 kg of NMVOC per hectare (2). Tier 2 Emission factor is calculated annually with equation 12 below.

$$EF_j = \sum \left(E_{i,\mathrm{NMVOC}} * 24 * 365 * Frac_{emit,i}\right) * m_{dm_i} * Frac_{i,j} \tag{12.}$$

Where,

i = Crops species

j = Active year

$E_{j,\mathrm{NMVOC}}$ = Hourly emission flux of NMVOC per species (kg/dm^3/h)

$Frac_{emit}$ = Fraction of the year during which the species is emitting

m_{dm} = Mean dry matter of crop (kg/ha/a)

$Frac_{i,j}$ = = Fraction of species j in relation to the total of cultivated areas and fallows for the year i

The guidebook presents the values of Table 4. These defaults are used whenever national data is not available, and they are replaced if more detailed information is available.

Table 4 – Default values for emission factor calculation

Species (i)	$E_{j,NMVOC}$	$Frac_{emit}$	$m_{dm,}$	$Frac_{ij}$
Wheat	2.60E-8	0,3	4700	0,35
Rye	1.41E-7	0,3	2800	0,05
Rape	2.02E-7	0,3	2500	0,1
Grass (15 C)	1.03E-8	0,5	9000	0,25
Grass (25 C)	4.67E-8	0,5	9000	0,25

Mean dry matter is derived from national statistics of species-specific yields per hectare by estimating their share of dry matter. Yield mean dry matter content remains constant throughout all years. Statistical data for yield per hectare is available for 2000-2015. The values for the year 2015 are presented in Table 5 below.

Table 5 – Yields per hectare and dry matter of 2015

Species	**Yield per hectare (kg/ha)**	**Yield mean dry matter content (kg/kg)**	**Mean dry matter m_{dm} (kg/ha)**
Wheat	4100	0,86	3526
Rye	3420	0,86	2941,2
Barley	3470	0,86	2984,2
Oats	3480	0,86	2992,8
Mixed grain	3020	0,86	2597,2
Other grains	3020	0,86	2597,2
Peas	2130	0,86	1831,8
Potatoes	24310	0,22	5348,2
Sugar beet	32740	0,23	7530,2

Turnip rape and rape	1540	0,92	1416,8
Grassland crops total	13904		0
Hay	3760	0,86	3233,6
Silage	15670	0,25	3917,5
Pasture	15670	0,2	3134
Other grassland	15670	0,2	3134
Other crops	9000	0,22	1980
Fallows	7835	0,21	1645,35

Table 6 below presents the total cultivated area as thousands of hectares for all species accompanied with the calculational crop distribution (from the total of 2 241 000 hectares including fallows and other grasslands).

Table 6 – Weighed emission factor and crop distribution of 2015

Species	Cultivated area (1 000 ha)	Crop distribution (%)	NMVOC (kg/dm/a)	Weighted EF (kg NMVOC / ha / a)
Wheat	248,8	11,1 %	6,82E-05	2,67E-02
Rye	31,6	1,4 %	3,70E-04	1,53E-02
Barley	512,5	22,9 %	6,82E-05	4,65E-02
Oats	306,5	13,7 %	5,30E-04	2,17E-01
Mixed grain	36,4	1,6 %	6,82E-05	2,88E-03
Other grains	2,5	0,1 %	6,82E-05	1,98E-04
Peas	12,3	0,5 %	6,82E-05	6,86E-04
Potatoes	22,1	1,0 %	6,82E-05	3,60E-03
Sugar beet	12,5	0,6 %	6,82E-05	2,86E-03
Turnip rape and rape	56,8	2,5 %	5,30E-04	1,90E-02
Hay	85,7	3,8 %	4,51E-05	5,58E-03
Silage	492,3	22,0 %	4,51E-05	3,88E-02
Pasture	58	2,6 %	4,51E-05	3,66E-03
Other grassland	16,4	0,7 %	4,51E-05	1,03E-03
Other crops	75,1	3,4 %	4,51E-05	2,99E-03
Fallows	271,3	12,1 %	4,51E-05	8,98E-03

The sum of all weighed EF's of Table 6 below presents the total cultivated area as thousands of hectares for all species accompanied with the calculational crop distribution (from the total of 2 241 000 hectares including fallows and other grasslands).

Table 6 brings as a Tier 2 emission factor of 3,96E-01 kg NMVOC/ha/a for 2015.

Table 7 below presents the annual emission factors.

Table 7 - Tier 2 emission factors of cultivated crops in 5-year intervals

Year	1980	1985	1990	1995	2000	2005	2010	2015
Total Cultivated Area	2372	2276,4	2271	2141,3	2186,8	2234,6	2253,3	2240,9
Emission Factor	0,482	0,470	0,513	0,431	0,477	0,399	0,358	0,396

Tier 3 adjustment on land use is made on fallows to reduce the surface area of open fallows and stubble fallows[1] from grass covered fallows.

[1] Avo- ja Sänkikesannot

2 Technical solutions

The calculation model is entirely compiled on VBA-enabled Microsoft Excel worksheet. The calculation uses the Finnish normative manure calculation system and gaseous nitrogen emission calculation system for partial activity data.

2.1.1 Used techniques

On top of traditional calculation the system uses the following Excel techniques:

- Structured tables (with total rows)
- Named ranges
- VBA macros
- INDEX-MATCH- MATCH –method
- SUMIF and IF-ISNUMBER –functions
- Exponentially smoothed TREND-functions (see chapter 2.1.2)
- Conditional formatting

2.1.2 Methodology for trend projection

For some key parameters, the range of annual primary data is extended beyond their initial range to suffice for time series calculation. This is done with a trend adjusted and exponentially smoothed projection of the primary data. This methodology combines utilizes Excel-built in trend-function calculation with the exponential smoothing method as expressed in the online resource of Excel-easy.com (3). For narrow and variating datasets Holt's linear trend method could be used to provide double exponential smoothing (5). The methodology described in this chapter was however found easier to adapt and adjust to new sets of data.

The trend-function is used to find the best fit for selected sets of y- and x- values using the least squares method (6). Without exponential smoothing, the trend function would return a value which serves as a best linear fit as in equation 12.

$$y = m_1 x_1 + m_2 x_2 + \ldots + b \tag{13.}$$

where,

y = The new parameter to be calculated

x_i = the range of independent variables

m_i = are constant multipliers for each x range;

b = a linear equation constant

In Excel environment equation 12 translates into equation 13 (3):

$$y_j = TREND(\ known_y's, [known_x's], [new_x's], [const]\ ) \tag{14.}$$

where,

y_j = Missing value for the parameter j

$known_y's$ = The range of known parameters

$[known_x's]$, = the range of independent variables,

$[new_x's]$ = The x equivalent for the searched y

$[const]$ = a linear equation constant

The bracketed values are optional and can be utilized if a dataset of similar properties has a linear dependency to the observed parameter. To estimate progression of a natural event in better accuracy, the trend can be exponentially smoothed with by introducing a smoothing constant α into equation 13 as expressed in equation 14 below. Accompanied with the trend function this leads to recalculating the new slope in each iterative step.

$$y_j = (1 - \alpha) * TREND\left(known'_y s, [known'_x s], [new'_x s], [const] \right) * \alpha * y_{j-1} \tag{15.}$$

where,

y_{j-1} = Previous value in series y

α = Smoothing constant

The smoothing constant α can be adjusted iteratively to provide the best fit by comparing actual data to projected data. Table 8 below presents an example of the methodology applied to gross intake energy (as MJ/d) of dairy cows, with actual data existing for the years 1990-2015. The values for 1980-1989 and 2015-2020 are projected values.

Table 8 Projected gross energy intake (MJ/d) for Dairy cows

Year	MJ	Year	MJ	Year	MJ	Year	MJ
1980	249,45	1990	263,54	2000	300,47	2011	340,11
1981	251,12	1991	265,48	2001	305,46	2012	340,73
1982	252,77	1992	264,35	2002	310,98	2013	342,91
1983	254,40	1993	269,03	2003	316,31	2014	348,88
1984	256,00	1994	274,89	2004	321,63	2015	353,14
1985	257,54	1995	276,95	2005	322,66	2016	353,95
1986	259,01	1996	277,38	2006	327,11	2017	354,97
1987	260,39	1997	283,47	2007	332,97	2018	356,13
1988	261,64	1998	284,85	2008	333,59	2019	357,42
1989	262,71	1999	289,56	2009	336,42	2020	358,79

Figure 1 below presents the data of Table 8 graphically with linear trend line added as reference.

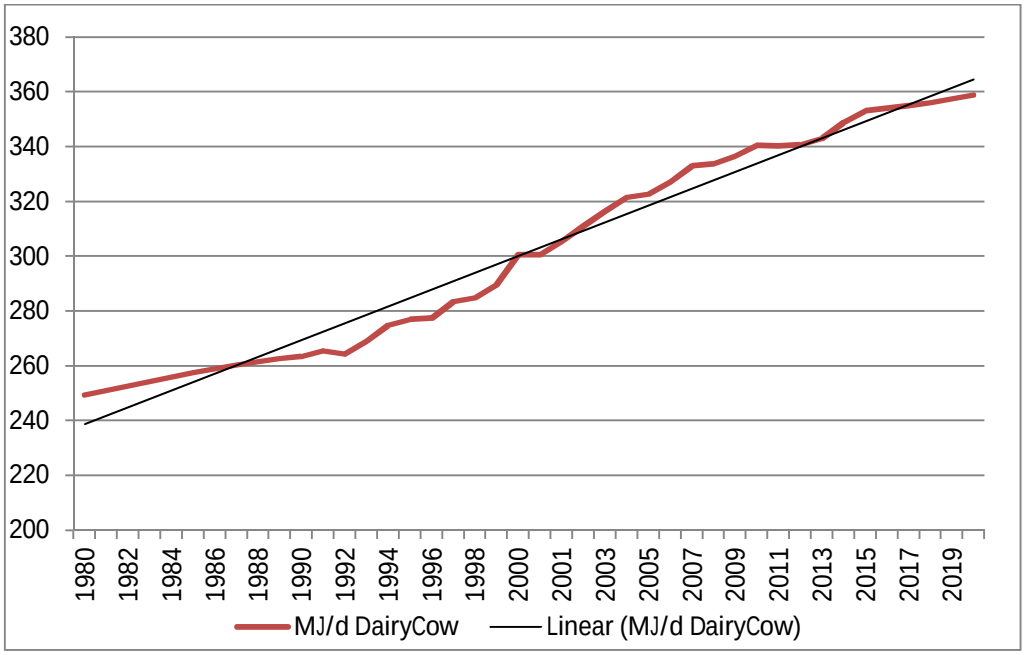

Figure 1 Actual and projected gross energy intake for Dairy Cows

3 Results

The following tablesTable 9Table 12Table 13 present the initial NMVOC emission estimates in five-year intervals from 1980 to 2015 as kilotons and grouped into their NFR reporting classes. The category of 3.B. contains emissions from silage store, feeding, inhouse emissions and manure storage. Emissions from field application of manure and grazing are reported in categories 3Da2a and 3Da3 respectively.

Table 9 - NMVOC emissions as kilotons from 3.B Manure management

Species	1980	1985	1990	1995	2000	2005	2010	2015
Dairy cow	9,57	8,65	7,37	6,50	6,61	6,28	6,16	6,46
Suckler cow	0,12	0,13	0,22	0,44	0,43	0,55	0,88	0,92
Heifer >1 yr	1,27	1,19	1,21	1,12	1,15	1,12	1,27	1,26
Bull >1 yr	1,03	1,22	1,48	1,12	1,22	1,27	1,39	1,30
Calf <1 yr	0,73	0,74	0,61	0,57	0,52	0,50	0,48	0,47
Sow (with piglets)	0,26	0,25	0,29	0,27	0,31	0,29	0,23	0,18
Boar (50- kg)	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,00
Fattening pig (50- kg)	0,11	0,10	0,12	0,13	0,11	0,13	0,13	0,12
Weaned pig (20-50 kg)	0,05	0,05	0,05	0,04	0,04	0,04	0,04	0,04
Laying hen breeder (female)	0,28	0,29	0,24	0,20	0,15	0,15	0,17	0,18
Broiler	0,13	0,18	0,21	0,29	0,54	0,37	0,31	0,47
Broiler breeder hen	0,00	0,00	0,01	0,03	0,05	0,06	0,06	0,07
Chicken	0,06	0,04	0,04	0,03	0,02	0,02	0,02	0,02
Turkey	0,01	0,01	0,01	0,01	0,02	0,06	0,03	0,03
Other poultry	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Horse	0,24	0,27	0,31	0,34	0,40	0,44	0,52	0,51
Pony	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01
Sheep	0,12	0,12	0,11	0,18	0,11	0,10	0,14	0,17
Goat	0,00	0,00	0,00	0,00	0,01	0,01	0,00	0,00
Fox and racoon	0,66	1,17	0,56	0,68	0,70	0,87	0,72	0,76
Mink and fitch	1,59	1,90	0,68	0,73	0,56	0,55	0,59	0,44

The figures of Table 10 suggest a notable decline in overall NMVOC emissions. For some species however, the model suggest an increasing trend. 73-78% of total emissions per year result from manure management of cattle. The share of cattle emissions does not reveal any notable trends throughout the time series as is presented in Table 11 below.

Table 11 – The share of cattle in relation to the overall NMVOC emissions

	1980	1985	1990	1995	2000	2005	2010	2015
Total (kt)	16,2	16,3	13,5	12,7	13,0	12,8	13,2	13,4
Cattle (kt)	12,7	11,9	10,9	9,8	9,9	9,7	10,2	10,4
Cattle (%)	78,3 %	73,1 %	80,5 %	76,8 %	76,6 %	75,8 %	77,4 %	77,6 %

Table 12 - NMVOC emissions as kilotons from 3Da2: Animal manure applied to soils

Species	1980	1985	1990	1995	2000	2005	2010	2015
Dairy cow	2,49	2,31	2,02	1,83	1,87	1,85	1,64	1,48
Suckler cow	0,01	0,01	0,02	0,04	0,05	0,06	0,10	0,10
Heifer >1 yr	0,22	0,21	0,23	0,21	0,22	0,22	0,24	0,22
Bull >1 yr	0,20	0,24	0,30	0,24	0,26	0,28	0,30	0,22
Calf <1 yr	0,50	0,54	0,47	0,47	0,43	0,42	0,37	0,30
Sow (with piglets)	0,10	0,10	0,11	0,10	0,12	0,11	0,09	0,06
Boar (50- kg)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fattening pig (50- kg)	0,05	0,04	0,05	0,05	0,05	0,05	0,05	0,04
Weaned pig (20-50 kg)	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01
Laying hen breeder (female)	0,14	0,14	0,11	0,09	0,07	0,07	0,08	0,08
Broiler	0,06	0,08	0,09	0,13	0,24	0,17	0,14	0,21
Broiler breeder hen	0,00	0,00	0,00	0,01	0,02	0,03	0,03	0,03
Chicken	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Turkey	0,00	0,00	0,00	0,00	0,01	0,02	0,01	0,01
Other poultry	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Horse	0,01	0,02	0,03	0,02	0,02	0,04	0,04	0,04
Pony	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sheep	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02
Goat	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fox and racoon	0,19	0,33	0,16	0,19	0,20	0,25	0,20	0,22
Mink and fitch	0,45	0,54	0,19	0,21	0,16	0,16	0,17	0,12

The figures of Table 12 suggest a minor decline in overall NMVOC-emissions. For most species the rates of emissions are constant. Dairy cows are the largest contributor of emissions in this category.

Table 13 - NMVOC emissions as kilotons from 3Da3: Urine and dung deposited by grazing animals

Species	1980	1985	1990	1995	2000	2005	2010	2015
Dairy cow	1,2E-01	1,1E-01	7,0E-02	5,4E-02	4,7E-02	4,0E-02	3,2E-02	2,9E-02
Suckler cow	1,5E-03	1,6E-03	2,6E-03	5,9E-03	5,7E-03	7,3E-03	1,4E-02	1,5E-02
Heifer >1 yr	2,0E-02	2,0E-02	2,1E-02	1,8E-02	1,8E-02	1,8E-02	1,4E-02	1,2E-02
Bull >1 yr	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	1,3E-03	1,7E-03
Calf <1 yr	1,6E-02	1,2E-02	7,1E-03	5,3E-03	4,8E-03	4,7E-03	6,2E-03	6,9E-03
Horse	2,0E-04	2,3E-04	2,6E-04	2,9E-04	3,4E-04	3,7E-04	4,3E-04	4,2E-04
Pony	4,3E-06	1,0E-05	2,0E-05	2,1E-05	2,2E-05	2,5E-05	3,2E-05	3,4E-05
Sheep	1,2E-04	1,3E-04	1,3E-04	1,7E-04	1,1E-04	9,9E-05	1,5E-04	1,8E-04
Goat	4,9E-06	5,3E-06	5,5E-06	4,9E-06	7,1E-06	5,7E-06	4,3E-06	4,0E-06
Reindeer	6,2E-04	7,4E-04	8,0E-04	7,0E-04	6,8E-04	6,9E-04	6,5E-04	6,4E-04
Total (kt)	0,16	0,14	0,10	0,08	0,08	0,07	0,07	0,07

As of NMVOC emissions from agricultural activities the model suggests that grazing of animals is a minor contributor to overall emissions. Table 13 presents only the species that get a non-zero value.

The following Table 14 presents the NMVOC emission estimates of cultivated crops in five-year intervals from 1980 to 2015 as kilotons using the methodology described in this document.

Table 14 - NMVOC emissions as kilotons from 3.D.e Crop production and agricultural soils

Species	1980	1985	1990	1995	2000	2005	2010	2015
Wheat	0,06	0,07	0,10	0,04	0,07	0,09	0,08	0,10
Rye	0,03	0,01	0,04	0,01	0,02	0,01	0,01	0,01
Barley	0,26	0,30	0,26	0,22	0,27	0,24	0,16	0,20
Oats	0,22	0,19	0,24	0,14	0,19	0,14	0,11	0,12
Mixed grain	0,01	0,00	0,01	0,00	0,01	0,01	0,01	0,01
Other grains	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Peas	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Potatoes	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01
Sugar beet	0,02	0,01	0,02	0,02	0,02	0,01	0,01	0,00
Turnip rape and rape	0,03	0,03	0,03	0,04	0,03	0,03	0,06	0,02
Hay	0,23	0,19	0,15	0,12	0,08	0,04	0,04	0,03
Silage	0,11	0,10	0,11	0,13	0,18	0,16	0,16	0,19
Pasture	0,10	0,08	0,07	0,05	0,06	0,04	0,03	0,02
Other grassland	0,02	0,01	0,02	0,02	0,02	0,01	0,01	0,01
Other crops	0,01	0,01	0,01	0,01	0,01	0,02	0,03	0,03
Fallow	0,05	0,03	0,09	0,10	0,09	0,10	0,11	0,11

4 Discussion

The guidebook suggests that research of NMVOC emissions from animal husbandry is incomplete thus leading to large uncertainties in the emission estimates. (1) Also the guidebook in this field seems incomplete and lacks in notation accuracy. Calculating the Tier 2 emission factor for cultivated crops is not explained sufficiently.

Data of shares of silage store and feed need further research. This model applies the guidebook default of 0.25 for all species and all years, including species known not being silage fed.

A possible overlap of NMVOC emissions was noticed between field burning and cultivated crops. Assuming the field burnt was used for agricultural purposes, the surface area of field burnt should be removed from the cultivated land area. The overlap seems negligible by amounts, but could be later taken into account as a Tier 3 reduction factor.

5 References

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Annex 1 – categorization of animals in the Finnish normative manure system.

	Animal	Explanation
Cattle	**DC**	**Dairy cow**
	DCB	Dairy cow, big breed
	DCS	Dairy cow, small breed
	SC	**Suckler cow**
	SCB	Suckler cow, big breed
	SCS	Suckler cow, small breed
	He>1	**Heifer >1 yr**
	HeB>2	Heifer, beef breed (2- yrs)
	HeB1-2	Heifer, beef breed (1-2 yrs)
	HeD>2	Heifer, dairy breed (2- yrs)
	HeD1-2	Heifer, dairy breed (1-2 yrs)
	HeS>2	Heifer, small breed (>2 yrs)
	HeS1-2	Heifer, small breed (1-2 yrs)
	Bu>1	**Bull >1 yr**
	BuB>2	Bull, beef breed (>2 yrs)
	BuB1-2	Bull, beef breed (1-2 yrs)
	BuD>2	Bull, dairy breed (>2 yrs)
	BuD1-2	Bull, dairy breed (1-2 yrs)
	BuS>2	Bull, small breed (1-2 yrs)
	BuS1-2	Bull, small breed (>2 yrs)
	Ca<1	**Calf <1 yr**
	CaFB<6	Calf, female, beef (< 6 months)
	CaFB6-12	Calf, female, beef (6-12 months)
	CaFD<6	Calf, female, dairy (< 6 months)
	CaFD6-12	Calf, female, dairy (6-12 months)
	CaFS<6	Calf, female, small breed (< 6 months)
	CaFS6-12	Calf, female, small breed (6-12 months)
	CaMB<6	Calf, male, beef (< 6 months)
	CaMB6-12	Calf, male, beef (6-12 months)
	CaMD<6	Calf, male, dairy (< 6 months)
	CaMD6-12	Calf, male, dairy (6-12 months)
	CaMS<6	Calf, male, small breed (< 6 months)
	CaMS6-12	Calf, male, small breed (6-12 months)
Pigs	**So**	**Sow (with piglets)**
	FS	Farrowing sow + gilts (<10-12 kg)
	GS	Gestating sow
	MS	Mating sow
	Bo	**Boar (50- kg)**
	FP	**Fattening pig (50- kg)**

	VP	**Weaned pig (20-50 kg)**
	VP<30	Weaned pig (<30 kg)
	VP<50	Weaned pig (<50 kg)
	Gi	**Gilt**
Poultry	**LHB**	**Laying hen breeder (female)**
	Co	**Cockerel (laying hen breeder, male)**
	Br	**Broiler**
	BH	**Broiler breeder hen**
	BM	**Broiler breeder, male**
	Ch	**Chicken**
	Tu	**Turkey**
	TuG	Groving turkey
	TuH	Turkey breeder hen
	TuM	Turkey breeder male
	OP	**Other poultry**
Horses and ponies	**Ho**	**Horse**
	Po	**Pony**
	PoB	Pony (120-140)
	PoL	Pony, little (<120)
Sheep and Goat	**Sh**	**Sheep**
	Ew	Ewe
	Ra	Ram
	Go	**Goat**
	Doe	Female goat
	Buck	Male goat
	Kid	Goatling
Fur Animals	**Fo**	**Fox and racoon**
	FoF	Fox breeder, female
	FoM	Fox breeder, male
	FoG	Fox grover
	Mi	**Mink and fitch**
	MiF	Mink breeder, female
	MiM	Mink breeder, male
	MiG	**Mink grover**
	Re	**Reindeer**

Annex 2a – variables used in the NMVOC calculation module - Descriptions

Section	Variable	Description
Basic parameters	AAPcase	Selected case in the finnish Normative Manure System.
	AAPyear	Selected year in the finnish Normative Manure System
	MJ	Annual gross energy of livestock in megajoules. Fetched from spreadsheet containing national statistics.
	Xhouse	Annual proportion of time the livestock spends inside buildings (%)
	Fracsilage	Proportion of silage as feed (%). Value varies by species, but is constant for all years
	Fracsilage_store	The relative share of stored silage in relation to silage in feeding table (%). Value varies by species, but is constant for all years
	EFsilage_feeding	Emission factor for silage feed. Value varies by species, but is constant for all years
	EFhouse	Emission factor for emissions from housing. Value varies by species, but is constant for all years
	EFgraz	Emission factor for grazing. Value varies by species, but is constant for all years
	VS kg/head/a	Volatile solids excreted (kg/a). Values based on national statistics for the major livestock species for the years 1990-2015.
Tier 1	EFNMVOC, kg AAP–1 a–1	Tier 1 emission factors from Guidebook. Value varies by livestock species, but is constant for all years
	Etot	Total emissions by Tier 1 methodology.
Tier 2	Esilage_store	Emissions from silage store
	Esilage_feeding	Emissions from silage feeding
	Ehouse	Emissions from housing
	Emanure_store	Emissions from manure in barns and outside stores
	Eapplication	Emissions from field application of manure
	Egraz	Emissions from grazing
	E3B	Emissions reported in the category 3B: Manure management
	E3Da2a	Emissions reported in the category 3Da2a: Animal manure applied to soils
	E3Da3	Emissions in the category 3Da3: Urine and dung deposited by grazing animals
	Etot	Tier 2 NMVOC emissions in total
Tier 3	RFsoilPH	Reserved for Tier 3 adjustment based on soil pH.
	RFlanduse	Tier 3 adjustment based on changes in land use.
	RFrate	Reserved for Tier 3 adjustment based on changes in emission rates
	RFrainfall	Reserved for Tier 3 adjustment based on rainfall.
	RFtemperature	Reserved for Tier 3 adjustment based on temperature.
	Emissions with reductions	Tier 3 NMVOC emissions in total

Annex 2b – variables used in the NMVOC calculation module – Formulas for variables

Section	Variable	Formula
Basic parameters	AAPcase	=[Normilantajärjestelmä.xlsm]START!$K4
	AAPyear	=IFERROR(INDEX([Normilantajärjestelmä.xlsm]AnimStat!$A$1:$CW$100,MATCH([@Animal],[Normilantajärjestelmä.xlsm]AnimStat!$A$1:$A$100,0),MATCH("Finland \| "&NMVOCyear,[Normilantajärjestelmä.xlsm]AnimStat!$A$1:$CW$1,0)),0)
	MJ	=INDEX(MJ!I$4:CD$73,MATCH(F$1,GrossEnergy[Year],0),MATCH([@Animal],MJ!I$2:CD$2,0))
	Xhouse	=1-INDEX(INDIRECT("'[Typpimalli.xlsm]"&$E$1&"'"&$F$1&"'!"&"$A$5:$CC$26"),10,MATCH([@Animal],[Typpimalli.xlsm]DATA_MANURE!$5:$5,0))
	Fracsilage	0.56
	Fracsilage_store	0.25
	EFsilage_feeding	0.0002002
	EFhouse	0.0000353
	EFgraz	0.0000069
	VS kg/head/a	=INDEX(VS!AD$4:CZ$73,MATCH(F$1,VSperday[Year],0),MATCH([@Animal],VS!AD$2:CZ$2,0))
Tier 1	EFNMVOC	17.937
	Etot	=IF(ISNUMBER(NMVOCActivityData[@AAPyear]),NMVOCActivityData[@AAPyear],0)*Q5
Tier 2	Esilage_store	=NMVOCActivityData[@MJ]*NMVOCActivityData[@Xhouse]*(NMVOCActivityData[@[EFsilage_feeding]]*NMVOCActivityData[@Fracsilage])*NMVOCActivityData[@[Fracsilage_store]]
	Esilage_feeding	=NMVOCActivityData[@MJ]*NMVOCActivityData[@Xhouse]*(NMVOCActivityData[@[EFsilage_feeding]]*NMVOCActivityData[@Fracsilage])
	Ehouse	=NMVOCActivityData[@MJ]*NMVOCActivityData[@EFhouse]*NMVOCActivityData[@Xhouse]
	Emanure_store	=IF(ISNUMBER([@Ehouse]*INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$52")/INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$45")),[@Ehouse]*INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$52")/INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$45"),0)
	Eapplication	=IF(ISNUMBER([@Ehouse]*INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$60")/INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$45")),[@Ehouse]*INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$60")/INDIRECT("'[Typpimalli.xlsm]"&C5&"'!"&"CD$45"),0)
	Egraz	=NMVOCActivityData[@MJ]*(1-NMVOCActivityData[@Xhouse])*NMVOCActivityData[@EFgraz]
	E3B	=([@[Esilage_store]]+[@[Esilage_feeding]]+[@Ehouse]+[@[Emanure_store]])*IF(ISNUMBER(NMVOCActivityData[@AAPyear]),NMVOCActivityData[@AAPyear],0)
	E3Da2a	=[@Eapplication]*IF(ISNUMBER(NMVOCActivityData[@AAPyear]),NMVOCActivityData[@AAPyear],0)
	E3Da3	=[@Egraz]*IF(ISNUMBER(NMVOCActivityData[@AAPyear]),NMVOCActivityData[@AAPyear],0)
	Etot	=SUM(NMVOCCalc[@[Esilage_store]:[Egraz]])*IF(ISNUMBER(NMVOCActivityData[@AAPyear]),NMVOCActivityData[@AAPyear],0)
Tier 3	RFsoilPH	1
	RFlanduse	0.88395
	RFrate	1
	RFrainfall	1
	RFtemperature	1
	Emissions with reductions	=NMVOCCalc[@Etot]*[@RFsoilPH]*[@RFlanduse]*[@RFrate]*[@RFrainfall]*[@RFtemperature]