Report to the attention of IPCC about the data set and calculation method used to estimate methane formation from enteric fermentation of agricultural livestock population and manure management in Swiss agriculture

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1. Agriculture
1.1 Basic Characterization

1.1.1 Livestock Species and Categories
To estimate Swiss methane formation from agriculture the following livestock categories were integrated: Cattle (defined sub-categories are listed in chapter 1.2), sheep, goats, horses, mules and asses, swine and poultry.

1.1.2 Milk Production
Country-specific data about the average annual milk yield of dairy cows and collected by the national office of the Swiss Farmer's Union (SBV) were used in the present calculations. Average annual milk production from suckler cows was estimated according to RAP (2004).

1.1.3 Climate
In the *IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, 1996, Table 4-1, three climate regions are defined in terms of annual average temperature: cool (<15°C), temperate (15°C-25°C), and warm (>25°C). In Switzerland the average annual temperature is below 15°C and therefore was allocated to cool climate.

1.2 Enhanced Characterization
According to the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* 2000, a complete list of all significant livestock populations that have default emission factor values provided in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories must be developed.

1.2.1 Origin of Data Set for Animal Inventory
In Switzerland data regarding animal inventory, annual milk production, etc. are evaluated on an annual basis by the SBV. In their statistics out of the significant livestock populations especially the category of the dairy cattle and the non-dairy cattle are further divided into well defined detailed sub-categories.

Sub-categories for cattle
It is common knowledge that the methane formation capacity differs between cattle of different age as well as purpose and, mainly, cattle on different feeding programs. A division of the cattle category in well defined sub-categories is therefore useful as the calculation of enteric methane formation is based on the energy intake (e.g. Mega Joules (MJ) per day), which highly differs between the sub-categories. Whereas in Switzerland dairy cattle are mainly fed with roughage and only few concentrate, fattening cattle are fed with concentrate-based diets. Milk-fed calves (as well as milk-fed lambs) produce no (IPCC 2000, Agriculture, Chapter 4, 4.26) or only small amounts of methane (when fed roughage in addition to milk).

Sub-categories for the other animal categories
No sub-categories to calculate enteric methane formation were made for sheep and goats as in Switzerland they are mostly fed similarly with the purpose of meat production. Further their proportion to total enteric and manure methanogenesis from agricultural livestock amounts to approximately 5.0 and 1.0%, respectively, which is rather small. Because of the lack of sub-categories methane formation from enteric fermentation in sheep is slightly overestimated, as the milk-fed lambs, included in the calculation, do actually not produce significant amounts of methane. The horse genres, swine and poultry were also not further divided into sub-categories as their

contribution to the total Swiss methane budget from livestock husbandry approximately amounts to only 1.0, 5.0 and 0.8%, respectively.

Table 1 Cattle sub-categories identified for Switzerland to calculate methane formation

Fattening Calves	Fattening Cattle	Breeding Cattle	Dairy Cattle
Suckler cow calves male & female (up to 10 month)	Calves male & female (up to 4 months)	Calves male & female (up to 4 months)	Suckler cows*
		Cattle male & female (4 to 12 months)	
Milk-fed calves male & female (up to 4 month)	Cattle male & female (4 to 12 months)	Cattle male & female (1 to > 2 years)	Dairy cows

*The suckler cows were calculated in the Swiss methane budget only from the year 1998 onwards as these data had not been evaluated separately from dairy cows by the SBV before.

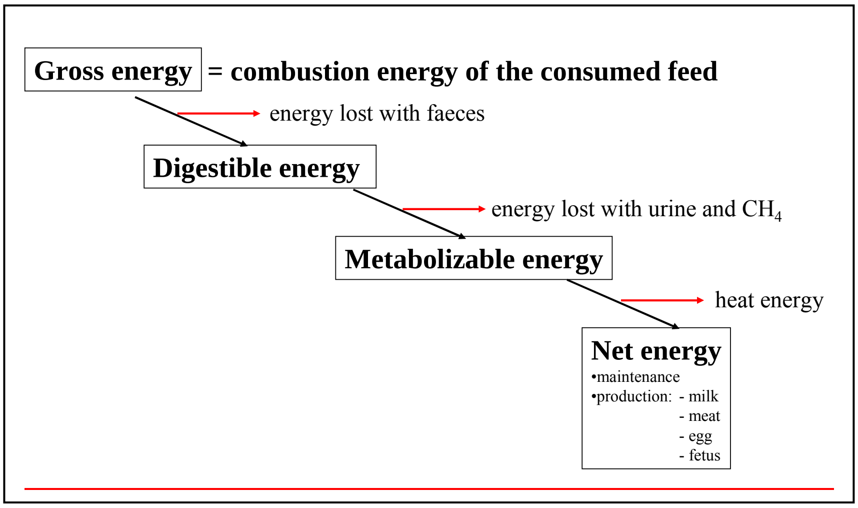
1.2.2 Gross Energy (GE) Estimations

GE intake is derived based on the net energy estimates and the feed characteristics as described in the *IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, 1996 (Agriculture, Chapter 4, 4.12 – 4.20) for each animal category.

In Switzerland different energy levels (Figure 1) are used to express the energy conversion from energy intake to the energy required for maintenance and performance. The reason for this is that, with the different digestible tract of different livestock categories, feed is digested to different extents. In Switzerland net energy (NE) is used to express the energy required by the ruminants such as cattle, sheep and goats. NE in cattle feeding is further sub-divided into NE for lactation (NEL) and NE for growth (NEV). Exceptions in the cattle category are the calves, whose requirements for energy are expressed as metabolizable energy (ME). Horses, mules, asses and swine are fed on the basis of digestible energy (DE), whereas poultry are fed according to metabolizable energy (ME).

The national office of SBV collects the NE, DE and ME estimates of the different animal categories according to their performance (pregnancy, lactation, growth, egg production etc.) and the energy required for maintenance (body weight). In their energy estimation also some feed energy losses are integrated in the calculations and have to be subtracted before the data can be used to estimate methane formation. Feed losses are defined as the feed not eaten by the animal and therefore remaining in the feeding trough or even distributed on the floor of the barn and therefore represent a loss of net energy. In the calculations for budgeting Swiss methane formation from agriculture this calculation for NE, DE and ME consumption was used for the livestock categories sheep, goats, horses, mules and asses, swine and poultry, respectively.

Figure 1 Levels of feed energy conversion



For the livestock category cattle detailed estimations for NE are necessary. As the SBV does not calculate the NE for the cattle detailed enough, NE data for each cattle sub-category was calculated individually according to the animal's requirements following the feeding recommendations of RAP (2004). These RAP recommendations are also used by the Swiss farmers as basis for their cattle feeding regimen and for filling in application forms for subsidies for ecological services, and are therefore highly appropriate. In the calculation of the NE data, the animal's weight, daily growth rate, daily feed intake (DM), daily feed energy intake, and energy required for milk production for the respective sub-categories were considered.

Conversion factors from NE, DE and ME to GE

In order to be sufficiently accurate, different conversion factors (Table 2) have to be applied for each livestock category and, regarding cattle, sub-category, as they highly depend on the diet types fed to the animals. Accordingly, the calculations of the conversion factors are based on the average amount of NE, DE and ME (MJ/ kg feed dry (DM) matter intake) divided by the average content of GE in feed GE (MJ/kg feed DM). As described in IPCC (2000), a GE assumption of 18.45 MJ/kg feed DM was taken for feeds without excessive contents of fat.

Table 2: Conversion factors used for calculation of energy requirements of individual livestock categories

Livestock category	Conversion factors	
Milk-fed calf	ME to GE	0.930
Suckler cow calf	NEL to GE	0.291
Breeding calf	NEL to GE	0.341
Breeding cattle 1[a]	NEL to GE	0.322
Breeding cattle 2[b]	NEL to GE	0.313
Fattening calf	NEV to GE	0.350
Fattening cattle	NEV to GE	0.401
Dairy cow	NEL to GE	0.318
Suckler cow	NEL to GE	0.275
Sheep (breeding)	NEL to GE	0.287
Sheep (fattening)	NEV to GE	0.350
Goats	NEL to GE	0.283
Horses, mules, asses	DE to GE	0.560
Swine	DE to GE	0.682
Poultry	ME to GE	0.700

[a]Breeding cattle of an age between 4 and 12 months
[b]Breeding cattle more than 1 year old

1.2 Methane emission from enteric fermentation

In Switzerland an estimated 63% of anthropogenic methane emission originates from agriculture with the enteric fermentation of the ruminants being the biggest source (87%) followed by methane formation from manure storage (13%) (BUWAL, 1998).

1.2.1 Calculation of enteric methane formation

Methane formation from enteric fermentation was calculated according to IPCC (2000)

$$\text{Total } CH_4 \text{ emissions} = \sum_i E_i$$

$$E_i = EF \times \text{population}/(10^6 \text{kg/Gg})$$

where:
CH_4 emissions = methane emissions from enteric fermentation, Gg CH_4/year
EF = emission factor for the specific population, kg CH_4/head/year

$$EF = (GE \times Y_m \times 365 \text{ days/yr}) / (55.65 \text{ MJ/kg } CH_4)$$

where:
GE = gross energy intake, MJ/head/day
Y_m = methane conversion rate which is the fraction of gross energy in feed converted to methane
55.65 MJ/kg = energy content of methane

CH_4 conversion rate (Y_m)

In the IPCC guidelines (1996) default values for the CH_4 conversion rates are provided for the different animal categories when no respective values are available from country-specific research. These estimates are based on the general feed characteristics and production practices found in either developed or developing countries.

Only few country-specific data exist on the methane conversion rate of agricultural livestock from Swiss research. Therefore the default values (Y_i) described in the (1996, Appendix A, Table A-1 to A-4) valid for different animal categories in developed countries in Western Europe (in percentage of GE intake) were used:

Cattle with less than 90% concentrate in the diet	6.00
Milk-fed calves	0.00
Breeding calves	6.00
Sheep	7.00*
Goats	5.00
Horses, mules and asses	2.50
Swine	0.60
Poultry	not estimated

*According to IPCC (2000).

For poultry no default value for the methane conversion rate is given in the IPCC guidelines (1996). Therefore a country-specific value ($Y_{poultry}$= 0.1631) was used evaluated in an in vivo trial with broilers (Hadorn and Wenk, 1996). For all juveniles consuming only milk (i.e. milk-fed lambs as well as calves) the CH_4 conversion rate is assumed to be zero (IPCC, 2000).

Country-specific studies evaluating CH_4 conversion rates for ruminants

The default values for the CH_4 conversion rates given by the IPCC guidelines are suitable for the Swiss situation. This can be noticed when comparing the IPCC default values with the values found in some studies carried out to calculate country-specific CH_4 conversion rates in Switzerland.

Methane conversion rate of cattle

In the study of Estermann et al. (2002), CH_4 conversion rate was measured for suckler cows together with their own calf. At an age of 1, 4, 7, or 10 months of the suckler cow calves (with the latter age being the typical time of weaning), the combined CH_4 conversion rate of the suckler cow and the calf amounted to 8.6, 7.8, 8.5, and 5.7% of GE intake, respectively. This means that the average CH_4 conversion rate over 10 months was 7.7%. Whereas the suckler cows were fed with a mixture of hay, grass silage, and straw (1:0.7:0.3), the calves got free access to milk and hay. Calculating the proportion of NE consumed by the calves and the suckler cows individually the CH_4 conversion rates of the calves and the cows amounted to 7.6%, and 7.7% respectively. In another study of Estermann et al. (2001), a CH_4 conversion rate of 6.4% of the GE intake was found for suckler cows together with their calves and a CH_4 conversion rate of 5.8% for dairy cows. In this study, all the cattle were fed with fresh cut grass only. In the study of Schönhusen et al. (2003), a CH_4 conversion rate of 6% was found for 9 week old calves, fed with hay and concentrate.

Comparing methane formation of dairy cows of different breeds fed diets typical for Swiss situation (grass supplemented with silage and concentrate) an average CH_4 conversion rate of 7.65% of GE intake could be measured whereas the lowest and the highest rate amounted to 7.24 and 8.1%, respectively (Münger and Kreuzer, 2006). When feeding diets consisting of concentrate characterized by different carbohydrate types to dairy cows, CH_4 conversion rates of 7.4% of GE intake were found on average (Hindrichsen et al. 2006a). Diets with lignified concentrate ingredients (oat hulls) thereby was found to reduce CH_4 conversion rate of dairy cows to 5.9% of GE intake, but this diet is not really representative for Swiss conditions. Dairy cows fed hay and grass silage only and producing 10 or 20 kg milk/day were shown to have CH_4 conversion rates of 7.1%, and 7.4% of GE, respectively (Hindrichsen et al. 2006b). The exchange of half of the forage by concentrate reduced the CH_4 conversion rates in the same study to 6.3% and 6.1% of GE intake with milk yields of 20 and 30 kg/day, respectively.

Methane conversion rate of sheep

In the study of Machmüller and Kreuzer (2005), CH_4 conversion rates of 7.4% und 6.4% of GE intake were found in adult castrated male sheep when diets rich in concentrate or roughage were fed, respectively. In two other studies (Machmüller und Kreuzer 1999; Machmüller et al. 2003) average CH_4 conversion rates of 7.5% and 4.3% of GE intake were determined, when sheep were fed with a hay/concentrate mixture or a mixture of hay, maize silage and concentrate, respectively.

1.3 Methane emission from manure management

1.3.1 Calculations of manure methane formation

Methane formation from manure management was calculated according to IPCC (2000).

CH_4 emissions (Gg/year) = emission factor EF_i (kg/head/year) × population / (10^6kg/Gg)

$$EF_i = VS_i \times 365 \text{ days/year} \times Bo_i \times 0.67\text{kg/m}^3 \times \sum_{(jk)} MCF_{jk} \times MS_{ijk}$$

where:
EF_i = annual emission factor for defined livestock population i, kg/head/year
population = the number of heads in a defined livestock population
VS_i = daily volatile solids excreted by an animal within a defined population i kg DM/day
DM = dry matter
Bo_i= maximum CH_4 production capacity for manure produced by an animal within a defined population i, m^3/kg volatile solid DM
MCF_{jk}= CH_4 conversion factors for each manure management system j by climate region k
MS_{ijk}= fraction of animal species/category i's manure handled using manure system j in climate region k

Volatile solids (VS)

According to IPCC (2000) it would make sense to use country-specific values for the daily excretion of VS of the different livestock categories. As in Switzerland no such data exist, the following default values for VS, valid for developed countries, were taken for the livestock categories swine, sheep, goats, horses, mules and asses, and poultry (IPCC, 1996, Appendix B, Tabellen B1-B7).

The VS for the cattle sub-categories were estimated according to IPCC (2000). Thereby GE-intake, feed digestibility and manure ash content were considered.

$$VS = GE \times (1\text{kg DM}/18.45\text{ MJ}) \times (1 - DE/100) \times (1 - ASH/100)$$

where:
VS = daily volatile solid excreted for an animal within a defined population i kg DM/day
GE = estimated daily average of the feed intake (MJ/day)
18.45 MJ = average energy density of feed expressed in MJ per kg DM
DE = digestible energy of the feed in percent (e.g. 60%)
ASH = ash content of the manure in percent (e.g. 8%)

The ash content of cattle manure is assumed to amount to 8% on average (IPCC, 1996), while the digestible energy of the feed for cattle is assumed to be 60% on average.

VS calculation (e.g. dairy cows / suckler cows):

Dairy cows: GE* = 276.7 (MJ/Tier/Tag)
VS= 276.7 (MJ/head/day) × (1kg DM/18.45 MJ) × (1-60/100) × (1-8/100) = 5.52

Suckler cows (without calf): GE = 173.7 (MJ/head/day)
VS= 173.7 (MJ/Tier/Tag) × (1kg DM/18.45 MJ) × (1-60/100) × (1-8/100) = 3.46

*average GE intake per head per day calculated as described in chapter 1.2.2.

Maximum CH_4 production capacity for manure produced by animals (Bo)

There are no country-specific Bo values available for Switzerland. Therefore Bo default values valid for developed countries were taken for all livestock categories (IPCC, 1996, Appendix B, Tabellen B1-B7).

CH_4 conversion factors for each manure management system (MCF)

For Switzerland only few values exist for the MCF values. Therefore default values according to IPCC (2000) were used for calculating methane formation from manure management. In Switzerland mainly two manure management systems exist, solid storage and liquid/slurry storage. Calves are mainly kept in deep litter systems and there exist also specific MCF values for pasture and for poultry systems. Therefore the following MCF's were used, valid for the cool climate category:

Solid manure:	1%; dung and urine are excreted in a barn. The solids (with and without litter) are collected and stored in bulk for a long time (months) before disposal.
Liquid/slurry*:	10%; combined storage of dung and urine under animal confinements for longer than 1 month.
Pasture:	1%; manure is allowed to lie as it is, and is not managed (distributed, etc.).
Deep litter:	39%; dung and urine is excreted in a barn with lots of litter and is not removed for a long time (months). This is applied for the cattle sub-categories of milk-fed calves and fattening calves, and for sheep and goats.
Poultry:	1.5%; manure is excreted on the floor with or without bedding

*Although in the IPCC (2000) a MCF default value of 39% was mentioned, in the present calculation an amount of 10% was used (according to IPCC, 1996). This is justified by the results obtained in the studies of Külling et al. (2002) and Møller et al. (2004) in which MCF factors were measured for slurry storage, which were much closer to 10% than to 39%.

Fraction of animal's manure handled using different manure management systems (MS)

The fraction of animal's manure was separately calculated for each livestock category and the respective manure management systems. The information about the percentage of a livestock category kept in a specific housing system is based on a special issue of the Swiss journal Agrarforschung (2001). The percentages of solid manure or slurry produced by different animals within specific housing systems were obtained from Menzi et al. (1997), as were the percentages of the grazing time for each livestock category.

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