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Methane emissions from enteric fermentation as well as nitrogen and volatile solids excretions of German calves – a national approach

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Abstract

Enteric methane emission rates and (renal and faecal) nitrogen and volatile solids excretion rates were calculated using a procedure that reflects the development of the calves' rumen as well as German national animal performance data and representative diet properties.

Standard calves have a birth weight of 41 kg animal^{-1}, a final weight of 125 kg animal^{-1} and a mean weight gain of 0.67 kg animal^{-1} d^{-1}.

The emission rate of 9.4 kg methane per place and year and the methane conversion rate of 41 kJ MJ^{-1} exceed those derived from expert judgements currently applied (4.4 kg place^{-1} a^{-1} and 20 kJ MJ^{-1}, respectively). These differences are caused by different weights and weight gains. The newly derived methane emissions and methane conversion rates fall below those obtained from the application of IPCC Tier 2 procedures.

Nitrogen excretion rates amount to about 19 kg place^{-1} a^{-1}. The share of renally excreted nitrogen is 0.64 kg kg^{-1} rather than 0.60 kg kg^{-1} provided in the UNECE guidebook.

It is common practice to quantify volatile solids release rates according to IPCC guidance documents. However, this procedure had been shown to be inadequate. The results obtained in this work (144 kg place^{-1} a^{-1}) fall below those assessed with the IPCC methodology (about 500 kg place^{-1} a^{-1}).

Keywords: *calves, enteric fermentation, nitrogen, volatile solids, excretion, model*

Zusammenfassung

Methan-Emissionen aus der Verdauung sowie Stickstoff- und "volatile solids" – Ausscheidungen von deutschen Kälbern – ein nationaler Ansatz

Die Emissionsraten von Methan aus der Verdauung, die Ausscheidungsraten von (renalem und fäkalem) Stickstoff und von „volatile solids" von Kälbern werden unter Berücksichtigt der Entwicklung des Kälberpansens sowie deutscher nationaler Leistungsdaten und repräsentativer Futtereigenschaften berechnet.

Standard-Kälber haben ein Geburtsgewicht von 41 kg, ein Endgewicht von 125 kg und eine mittlere Gewichtszunahme von 0,67 kg pro Tier und Tag.

Die Emissionsraten von 9,4 kg Methan pro Tierplatz und Jahr und eine Umwandlungsrate von 41 kJ MJ^{-1} übersteigen die bisher verwendeten Raten (4,4 kg Tierplatz^{-1} a^{-1}) bzw. Methan-Umwandlungsraten (bisher 20 kJ MJ^{-1}). Die Unterschiede sind auf unterschiedliche Gewichte und Gewichtszunahmen zurückzuführen. Die jetzt berechneten Methan-Emissionen und -Umwandlungsraten sind kleiner als die, die sich aus der Anwendung von IPCC Tier-2-Verfahren ergeben.

Die berechneten Stickstoff-Ausscheidungen belaufen sich auf etwa 19 kg pro Platz und Jahr. Der Anteil an renal ausgeschiedenem N von 0,64 kg kg^{-1} ist höher als der im UNECE-Guidebook angegebene Wert von 0,60 kg kg^{-1}.

Es ist üblich, die Ausscheidung von „volatile solids" nach den Regeln des IPCC-Regelwerks zu berechnen. Das Verfahren ist jedoch unangemessen. Die in dieser Arbeit aus dem Futter berechneten Mengen (144 kg pro Platz und Jahr) liegen unter den Mengen, die sich bei Anwendung der IPCC-Methode ergäben (etwa 500 kg pro Platz und Jahr).

Schlüsselwörter: *Kälber, Verdauung, Stickstoff, volatile solids, Modell*

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1 Introduction

Methane (CH_4) from enteric fermentation in cattle contributes significantly to greenhouse gas emissions. International conventions aim at a reduction of these emissions. A first step is the adequate recording and reporting of these emissions. In order to ensure compatibility and comparability in international programmes, the United Nations Convention on Climate Change (IPCC) recommend the use of methodologies set down in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996, 2000, 2006) [1]. For emissions from enteric fermentation, the recommended procedure relates the CH_4 emission rate to the gross energy (GE) intake rate, using a methane conversion rate (MCR). A detailed procedure to derive GE intake rates and MCR default values are provided in the Guidelines. For Western Europe the use of an MCR of 60 and 65 kJ MJ^{-1} (or 6.0 and 6.5 %) is recommended in the 1996 and 2006 versions of the Guidelines, respectively. The application of default MCR explicitly includes "dairy cows and their young". Although it is evident that MCR is a function of feed composition, poorer feed leading to higher MCR (see IPCC, 2006, pg. 10.30, comments on calves and feedlot cattle). However, no procedure to derive MCR reflecting this relation is explicitly recommended. For calves in particular, the fact that there is a delay after birth before ruminating becomes established is not taken into account.

This paper aims primarily at a derivation of a mean national CH_4 emission rate (emission factor) and an MCR for German standard calves up to a weight of 125 kg $animal^{-1}$. As the methodology used for these calculations presupposes the knowledge of the amounts of feed and of the feed ingredients' properties, the calculations are extended to derive consistent data for nitrogen (N) and volatile solids (VS) excretion rates.

2 Background

In emission inventories, animal subcategories are formed by populations receiving the same type of feed. In German animal production, it is usual to feed male and female calves up to a weight of 125 kg the same feeds. The respective time span lasts for about 18 weeks (or 125 days). The weight at birth is here taken to be 41 kg $animal^{-1}$, the resulting average weight gain to be 0.67 kg $animal^{-1}$ d^{-1}. Typical mean requirements for metabolizable energy (ME) during this time span are 21 to 24 MJ $animal^{-1}$ d^{-1}. This data is in line with Stamer et al. (2004), DLG (1999) and KTBL (2010, pg 554).

As detailed data on the variation in time and region of weights and weight gains cannot be obtained, the calf described above serves as a **standard calf** in this work. Hence, the diet composition used to characterize energy and feed intake is a mean composition and does not reflect individual feeding situations.

[1] For cattle, the information provided in IPCC (2000) does not deviate from IPCC (1996).

The procedure to derive German national data describing the release of methane from enteric fermentation as well as of renal and faecal nitrogen (N) and volatile solids (VS) will comprise the following steps:

- assessment of calves' energy and nutrient requirements
- establishing diet composition and feed intake rates to meet these requirements
- listing feed properties needed
- calculating the respective release rates of methane
- calculating the excretion rates of N and VS

3 Feed requirements and intake rates

3.1 Metabolizable energy and nutrient requirements

Feed intake rates are governed by animal weights and weight gains and the resulting energy requirements. Germany uses the ME (metabolizable energy) system for the assessment of energy requirements of calves and for energetic feed evaluation. In Germany, official recommendations were provided in GfE (1997) and GfE (1999) to assess feeds satisfying the ME and nutrient requirements.

In the following, feed intake rates and diet compositions appropriate for German agriculture are used to calculate weekly ME intake rates. These are then compared to recommended intake rates that cover the span of a calf's life.

In addition the assessment of annual ME requirements presupposes the knowledge of animal rounds, i.e. the number of animals produced per place and year.

3.2 Feed intake rates and diet compositions

Feed intake rates and diet composition vary with the age of the animal. Examples can be derived from textbooks. Table 94 in Weiß et al. (2005) (similar in Meyer, 2005, and Teepker, 2007), supplemented with information from Kirchgeßner et al. (2008) formed the basis for the presumed diet in this paper. Typical weekly diet compositions are listed in Table 1. [2]

According to Kirchgeßner et al. (2008), hay should be of the best available quality, "tender" and "first cut". This standard textbook in animal nutrition also lists typical concentrate compositions in calf feed (Table 2). An arithmetic mean composition of the four examples given in Kirchgeßner et al. (2008) was calculated and used in the subsequent calculations.

[2] Table 1 does not cover milk replacer. However, as milk replacer is used to substitute milk, the (known) properties and amounts of the milk fed are used instead.

Table 1
Amounts of milk, concentrates and hay fed to calves used in the calculations

week	colostrum	cows' milk	concen-trates	hay	silage
			kg animal^{-1} d^{-1}		
1	4.8	5			
2		6	0.2	0.1	
3		6	0.3	0.1	
4		6	0.4	0.1	
5		6	0.5	0.1	
6		6	0.7	0.1	
7		5	0.8	0.3	
8		5	0.9	0.5	
9		4.5	1.0	0.5	
10		4	1.2	0.6	
11		3.5	1.3	0.6	
12		2	1.4	0.5	0.5
13			1.5	0.5	1
14			1.5	0.5	1.5
15			1.5		2.5
16			1.5		3.5
17			1.6		4.5
18			1.6		5.5
			kg animal^{-1} round^{-1}		
total	approx. 35	approx. 400	approx. 125	approx. 30	approx. 130

Table 2
Example concentrate compositions (Kirchgeßner et al., 2008)

diet constituent	I	II	III	IV	mean	unit
linseed expeller	0.20	0.12	0.10	0.00	0.105	kg kg^{-1}
oat	0.10	0.00	0.00	0.18	0.070	kg kg^{-1}
barley	0.20	0.00	0.29	0.20	0.173	kg kg^{-1}
wheat	0.25	0.30	0.23	0.00	0.195	kg kg^{-1}
maize	0.00	0.30	0.00	0.20	0.125	kg kg^{-1}
wheat bran	0.09	0.08	0.00	0.00	0.043	kg kg^{-1}
sugar beet pulp	0.00	0.00	0.13	0.08	0.053	kg kg^{-1}
soya bean extraction meal	0.13	0.17	0.10	0.17	0.143	kg kg^{-1}
rape seed extraction meal	0.00	0.00	0.12	0.14	0.065	kg kg^{-1}
mineral feed	0.03	0.03	0.03	0.03	0.03	kg kg^{-1}

3.3 Energy and relevant nutrient contents of feed ingredients

CH_4 emissions for fully ruminating animals are modelled using an approach suggested by Kirchgeßner et al. (1995) (for selection criteria see Dämmgen et al., 2012). The feed properties needed to calculate these emission rates, i.e. dry matter, crude fibre, N-free extracts, crude protein and crude fat contents were obtained from Beyer et al. (2004). They are collated in Table 3.

Table 3
Feed properties

	contents related to DM						
	dry matter	gross energy	metabolizable energy	crude fibre	N-free extracts	crude protein	crude fat
	η_{DM}	η_{GE}	η_{ME}	η_{Fi}	η_{NFE}	η_{XP}	η_{XF}
unit	kg kg^{-1}	MJ kg^{-1}	MJ kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}
feed ingredient							
colostrum [a]	0.15	23.98	18.55				
milk, 4.2 % fat	0.133	24.59	19.33				
hay	0.850	18.03	10.02	0.230	0.435	0.180	0.035
grass silage	0.350	18.40	10.20	0.245	0.452	0.162	0.042
maize silage	0.270	18.50	11.00	0.228	0.582	0.080	0.028
linseed expeller	0.900	20.69	12.70	0.110	0.375	0.380	0.370
oat	0.870	19.14	11.29	0.120	0.665	0.130	0.050
barley	0.870	18.56	12.91	0.050	0.765	0.135	0.025
wheat	0.870	18.60	13.44	0.020	0.485	0.115	0.025
maize	0.870	18.88	13.86	0.027	0.802	0.117	0.037
wheat bran	0.880	19.14	10.76	0.100	0.625	0.175	0.045
sugar beet pulp	0.920	16.28	12.66	0.200	0.645	0.095	0.005
soya bean extraction meal	0.900	19.96	14.00	0.080	0.345	0.495	0.017
rape seed extraction meal	0.900	20.30	12.20	0.130	0.350	0.370	0.020
minerals	1.000	0	0	0	0	0	0

[a] As the colostrum data set appeared to be inconsistent (see e.g. Foley and Otterby, 1978; Iváncsics and Kovács, 1999; and Morill et al., 2012) the energy contents of milk were used instead.

3.4 Comparison of calculated and recommended *ME* intake rates

As shown in Table 4, the use of the data listed in Tables 1 to 3 yields weekly *ME* input data whose period means fit the recommendations in GfE (1997), Table 8, for intervals of four to five weeks each, within the uncertainties involved. The animal weights are obtained from the birth weight of 41 kg animal^{-1} and the constant weight gain of 0.666 kg animal^{-1} d^{-1}.

Table 4

Metabolizable energy – requirements and recommendations

week	animal weight kg animal^{-1}	calculated *ME* input MJ animal^{-1} d^{-1}	calculated mean *ME* MJ animal^{-1} d^{-1}	*ME* recommended MJ animal^{-1} d^{-1} (GfE, 1997)
1	45.7	12.78	17.85	19
2	50.3	18.42		
3	55.0	19.54		
4	59.6	20.66		
5	64.3	21.77	24.82	24
6	69.0	24.01		
7	73.6	24.28		
8	78.3	27.10		
9	83.0	26.94		
10	87.6	28.75	26.85	27.5
11	92.3	28.59		
12	96.9	26.66		
13	101.6	24.31		
14	106.3	25.96		
15	110.9	24.99	30.47	30.5
16	115.6	28.27		
17	120.3	32.68		
18	124.9	35.96		

3.5 Animal rounds

German official statistics report the numbers of animal places occupied at the census day (animal places or animal populations in IPCC terminology). In order to assess the emissions or excretions per place, the number of animals produced per place and year (i.e. the number of animal rounds) has to be taken into account.

The duration of a round covers both the time for the calves to grow to their final weight and the time for service time (i.e. for cleaning, drying and disinfection the animal place). The latter amounts to about of seven d round^{-1} [3]. With a time span of 18 weeks for raising a calf, the number of animal rounds per year is thus about 2.8.

[3] In practice, service times range between one day and one month. The detailed instructions for FLI's experimental farm schedule give one week. This value is taken in subsequent calculations.

4 Calculation of methane emission rates

Calves only gradually emerge as ruminants (Kirchgeßner et. al., 2008, pg. 430 ff). A pre-ruminant phase of about three weeks can be distinguished from a transition phase, during which the rumen develops its size and function. After about nine weeks calves can be considered functional ruminants. At that time, their typical *MCR* is that of cows (see Lockyer, 1997; Kurihara et al., 2002; Schönhusen et al., 2003; also Dämmgen et al., 2012).

No experimental data could be identified that describe CH_4 emission rates from calves in the transition phase.

4.1 General approach

4.1.1 Physiological background

CH_4 is formed during the degradation of carbohydrates in the rumen. However, while concentrates and hay will enter the rumen, colostrum and milk bypass the rumen via the oesophagal groove and flow directly into the abomasum. The size and function of the rumen develop during the first seven to nine weeks of the calf's life (e.g. Baldwin et al., 2003).

The microbial degradation of carbohydrates presupposes a microbial community in the rumen that is adapted to the concentrates and the roughage fed. This community develops together with the rumen growth (e.g. Beharka et al., 1998).

4.1.2 Stepwise calculation – an overview

These facts are accounted for in the following approach to characterize CH_4 emissions from calves in four steps where Steps 1 and 2 describe well defined situations, Steps 3 and 4 close the gap (Figure 1).

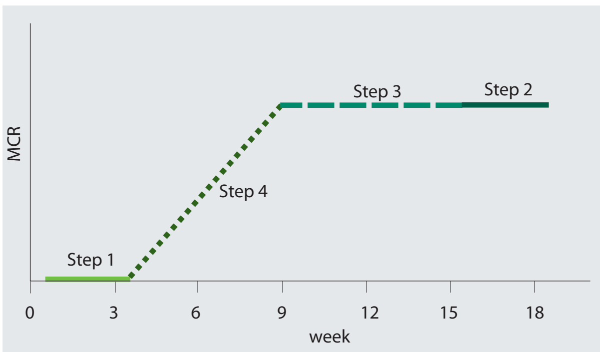

Figure 1

Succession of steps used in the subsequent calculation procedure

Step 1: Milk fed calves. CH_4 emission rates for weeks one to three are zero, as the rumen has not developed. Hence, *MCR* is zero.

Step 2: Fully ruminating calves with weights above 100 kg animal^{-1}. Kirchgeßner et al. (1995) describe the CH_4 emissions from cattle for animals with a weight above 100 kg animal^{-1}. Their methodology is applied to calculate the emission rates for weeks 15 to 18.

Step 3: Fully ruminating calves with weights less than 100 kg animal^{-1}. It is assumed that the efficiency of CH_4 formation during weeks 9 to 15 is not substantially different from that of weeks 15 to 18. Hence it is characterized by the same methane conversion mechanisms, and that the emission rates obtained with the Kirchgeßner et al. (1995) approach can be extrapolated accordingly.

Step 4: Transition from non-ruminant to ruminant calves. It is assumed here that the gradual transition from non-ruminant to ruminant calves can be described using properties described in Step 3 combined with an appropriate efficiency parameter.

4.2 Calculation of methane emission rates of fully ruminating calves above 100 kg animal^{-1} live weight (Step 2)

4.2.1 The method used for German dairy cows

In contrast to the IPCC methodology (IPCC, 1996, 2006), the German approach for dairy cows calculates CH_4 emission rates from feed intake rates and feed properties according to Dämmgen et al. (2012) (using the method proposed in Kirchgeßner et al., 1995) rather than from GE intake rates. The application of this method to calves was desirable.

The CH_4 excretion of the functional ruminant may be described by the approach of Kirchgeßner et al. (1995) (Equation (1)).

$$E_{\mathrm{CH4,\,K}} = a \cdot M_{\mathrm{XFi}} + b \cdot M_{\mathrm{NFE}} + c \cdot M_{\mathrm{XP}} + d \cdot M_{\mathrm{XF}} + e \qquad (1)$$

where

$E_{\mathrm{CH4,\,K}}$ methane emission rate according to Kirchgeßner et al. (1995) (in kg animal^{-1} d^{-1})
a coefficient (a = 0.079 kg kg^{-1})
M_{XFi} intake rate of crude fibre (in kg animal^{-1} d^{-1})
b coefficient (b = 0.010 kg kg^{-1})
M_{NFE} intake rate of N-free extracts (in kg animal^{-1} d^{-1})
c coefficient (c = 0.026 kg kg^{-1})
M_{XP} intake rate of crude protein (in kg animal^{-1} d^{-1})
d coefficient (d = – 0.212 kg kg^{-1})
M_{XF} intake rate of ether extract (crude fat) (in kg animal^{-1} d^{-1})
e constant (e = 0.063 kg animal^{-1} d^{-1})

and

$$M_{\mathrm{XFi}} = M_{\mathrm{DM}} \cdot \sum_{\mathrm{i}} \eta_{\mathrm{XFi,i}} \cdot x_{\mathrm{i}} \qquad (2)$$

where

M_{XFi} intake rate of crude fibre (in kg animal^{-1} a^{-1})
M_{DM} dry matter intake rate (in kg animal^{-1} a^{-1})
$\eta_{\mathrm{XFi,\,i}}$ crude fibre content of feed constituent i (in kg kg^{-1})
x_{i} share of diet constituent i (in kg kg^{-1})
etc.

This approach is valid for cattle whose weights exceed 100 kg animal^{-1}. Hence the feed composition for weeks 15 to 18 (inclusively) is used to estimate a mean daily CH_4 emission rate. This amounts to 0.032 kg animal^{-1} d^{-1} CH_4.

4.2.2 Deriving a national methane conversion rate for fully ruminating calves

Within the IPCC methodology, it is customary to relate CH_4 emission rates as an energy loss to the GE intake rate using the methane conversion ratio MCR [4] which is defined as follows:

$$MCR = \frac{E_{\mathrm{CH4}} \cdot \eta_{\mathrm{CH4}}}{GE} \cdot \varepsilon \qquad (3)$$

where

MCR methane conversion ratio (in kJ MJ^{-1})
E_{CH4} methane emission rate (in kg animal^{-1} d^{-1})
η_{CH4} energy content of methane (η_{CH4} = 55,65 MJ kg^{-1})
ε energy units conversion factor (ε = 1000 kJ MJ^{-1})
GE gross energy intake rate (in MJ animal^{-1} d^{-1})

For weeks 15 to 18, the mean daily GE intake rate amounts to 48.3 MJ animal^{-1} d^{-1} GE. Application of Equation (1) and the data provided in Tables 1 to 3 results in a mean CH_4 emission rate of 0.047 kg animal^{-1} d^{-1}, and an MCR of 54 kJ MJ^{-1}. The value is lower than the ones proposed in IPCC (1996) and IPCC (2006) which is due to the comparatively high shares of concentrates. This results in lower MCR (see Kurihara et al., 2002; Schönhusen et al., 2003; the reasoning of the MCR of feedlot cattle in IPCC, 2006, pg 10.30; also Dämmgen et al., 2012).

4.3 Calculation of methane emission rates of fully ruminating calves below 100 kg animal^{-1} live weight (Step 3)

Kirchgeßner's approach is not valid for animals whose weights fall below 100 kg animal^{-1}. It is obvious from Equation (1) that constant *e* will dominate emissions for low feed intake rates. In order to close the gap, we assume that physiological conditions between week 9 and week 15 are similar to those in subsequent weeks, and apply the MCR determined for weeks 15 to 18 to the preceding weeks nine to fifteen. Therefore, the MCR of 54 kJ MJ^{-1} obtained for weeks 15 to 18 is then applied to weeks nine to fifteen. GE intake rates are derived from ME requirements and feed properties, as listed in Tables 3 and 4.

4.4 Methane emissions during the transition period (Step 4)

The transition from a pre-ruminant newborn calf to a ruminant calf weighing 100 kg animal^{-1} is described using an interpolation procedure. This is done by adding an effectiveness parameter P to describe rumen function, with P = 0 for a newborn calf and P = 1 for a fully functional ruminant:

[4] The IPCC terminology calls this entity methane conversion rate Y_m.

$$E_{CH4,\,trans,\,j} = P_j \cdot E_{CH4,\,rum} \quad (4)$$

with

$$E_{CH4,\,rum} = E_{CH4,\,K} \quad (5)$$

where

$E_{CH4,,\,trans,\,j}$ methane emission rate (factor) for week j in the transition period (in kg animal^{-1} d^{-1})

P_j effectiveness parameter for week j ($0 \leq P \leq 1$, dimensionless)

$E_{CH4,\,rum}$ methane emission rate (factor) for a functional ruminant (in kg animal^{-1} d^{-1}) as obtained by the application of Equation (1)

$E_{CH4,\,K}$ methane emission rate according to Kirchgeßner et al. (1995) (in kg animal^{-1} d^{-1})

Experimental data values for P are not available. Hence, assumptions have to be made for the amounts of P as a function of time. These are listed in Table 5. Here, variant 1 is a simple linear interpolation, whereas variant 2 may represent a more realistic approach that takes the non-linear growth of the rumen into account (Kirchgeßner et al., 2008; Coverdale et al., 2003; Pennstate College of Agricultural Sciences, 2011).

Table 5
Tentative time series of effectiveness parameters P_j

	values of P	
week j	variant 1	variant 2
4	0.00	0.00
5	0.20	0.10
6	0.40	0.20
7	0.60	0.30
8	0.80	0.70
9	1.00	1.00

For each day in week j, the equivalents EE_{CH4} of CH_4 emission rates are assessed using the relation

$$EE_{CH4,\,j} = GE_j \cdot P_j \cdot \frac{MCR_{rum}}{\varepsilon} \quad (6)$$

where

$EE_{CH4,\,j}$ daily energy equivalent of CH_4 emission rate in week j (in MJ animal^{-1} d^{-1})

GE_j GE intake rate in week j (in MJ animal^{-1} d^{-1})

P_j effectiveness parameter for week j

MCR_{rum} methane conversion rate for ruminating calves (MCR_{rum} = 54 kJ MJ^{-1})

ε energy units conversion factor (ε = 1000 kJ MJ^{-1})

Table 6
GE intake rates, effectiveness parameter variants, energy equivalents of CH_4 rates, and CH_4 emission rates

week	GE intake rate	P		EE_{CH4}		E_{CH4}	
	MJ animal^{-1} d^{-1}	variant 1	variant 2	variant 1 MJ animal^{-1} d^{-1}	variant 2 MJ animal^{-1} d^{-1}	variant 1 kg animal^{-1} d^{-1}	variant 2 kg animal^{-1} d^{-1}
1	16.10	0.0	0.0	0.000	0.000	0.0000	0.0000
2	24.14	0.0	0.0	0.000	0.000	0.0000	0.0000
3	25.79	0.0	0.0	0.000	0.000	0.0000	0.0000
4	27.43	0.0	0.0	0.000	0.000	0.0000	0.0000
5	29.07	0.2	0.1	0.313	0.156	0.0056	0.0028
6	32.36	0.4	0.2	0.696	0.348	0.0125	0.0063
7	33.84	0.6	0.3	1.092	0.546	0.0196	0.0098
8	38.55	0.8	0.7	1.658	1.451	0.0298	0.0261
9	38.58	1.0	1.0	2.075	2.075	0.0373	0.0373
10	41.79	1.0	1.0	2.247	2.247	0.0404	0.0404
11	41.82	1.0	1.0	2.249	2.249	0.0404	0.0404
12	39.96	1.0	1.0	2.149	2.149	0.0386	0.0386
13	38.02	1.0	1.0	2.045	2.045	0.0367	0.0367
14	40.88	1.0	1.0	2.198	2.198	0.0395	0.0395
15	38.94	1.0	1.0	2.094	2.094	0.0376	0.0376
16	44.66	1.0	1.0	2.401	2.401	0.0432	0.0432
17	52.02	1.0	1.0	2.797	2.797	0.0503	0.0503
18	57.74	1.0	1.0	3.105	3.105	0.0558	0.0558
Total	MJ animal^{-1}			MJ animal^{-1}	MJ animal^{-1}	kg animal^{-1}	kg animal^{-1}
	4632			190	181	3.41	3.25

The total emission per animal for weeks 4 to 9 is obtained as follows:

$$E_{CH4} = \sum_{j=4}^{9} \left(\sum_{1}^{7} \frac{EE_{CH4,\,j}}{\eta_{CH4}} \right) \quad (7)$$

where

E_{CH4} methane emission per animal (in kg animal^{-1})

$EE_{CH4,\,j}$ daily energy equivalent of CH_4 emission rate in week j (in MJ animal^{-1} d^{-1})

η_{CH4} energy content of methane (η_{CH4} = 55,65 MJ kg^{-1})

4.5 Predicted methane emissions by calves over a production period

Weekly input data are collated in Table 6. *GE* intake rates were obtained from a combination of figures provided in Tables 1 to 4. Using the two effectiveness parameter variants listed in Table 5 allows for the prediction of CH_4 emissions.

Variant 2 leads to slightly lower emissions, as would any variant that depicts a delayed (however likely) rumen development. In order to avoid underestimation of the emission rates, variant 1 should be used for reporting.

4.6 Resulting national annual emission rates and methane conversion rates

The combination of emission per animal with the number of animal rounds yields the emission per place per year, the so-called emission factor EF_{CH4}:

$$EF_{CH4} = E_{CH4} \cdot n_{round} \quad (8)$$

where

EF_{CH4} CH_4 emission factor (in kg place^{-1} a^{-1} CH_4)

E_{CH4} methane emission per animal (in kg animal^{-1} d^{-1})

n_{round} number of animal rounds (in animal place^{-1} a^{-1})

For E_{CH4} = 3.41 kg place^{-1} a^{-1} and n_{round} = 2.77 animal place^{-1} a^{-1}, the resulting emission factor for German standard calves is 9.43 kg place^{-1} a^{-1} CH_4.

It is mandatory within the reporting to UNFCCC to indicate respective *MCR* in the Common Reporting Format. Application of Equation (3) yields an *MCR* for calves of 41.0 kJ MJ^{-1} or 4.1 %.

5 Nitrogen and volatile solids release rates

N and *VS* release rates are depending on feed intake, diet composition and – for N – on animal weight gained during the life span considered. IPCC (1996, 2006) as well as EMEP (2009) provide calculation procedures.

5.1 Relevant feed properties

Feed properties are derived as weighted means from the relevant feed ingredients. Properties of the ingredients are taken from Beyer et al. (2004) (Table 7). The relevant amounts are listed in Tables 1 and 2, the relevant properties in Tables 3 and 7. For simplification, the amounts of colostrum are incorporated in the amounts of milk fed.

Table 7

Relevant feed properties for the calculation of N and VS excretion rates

		contents related to DM			
		N content	digestibility of N	ash content	digestibility of OM
		X_N	X_{DN}	X_{ash}	X_{DOM}
feed ingredient	unit	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}
milk, 4.2 % fat		0.0411	0.95	0.073	0.98
hay		0.0288	0.70	0.120	0.73
grass silage		0.0259	0.63	0.100	0.71
maize silage		0.0128	0.45	0.080	0.74
linseed expeller		0.0608	0.85	0.065	0.79
oat		0.0208	0.74	0.035	0.73
barley		0.0216	0.74	0.025	0.86
wheat		0.0224	0.75	0.025	0.89
maize		0.0171	0.73	0.017	0.90
wheat bran		0.0280	0.75	0.055	0.71
sugar beet pulp		0.0088	0.50	0.050	0.90
soya bean extraction meal		0.0792	0.90	0.065	0.89
rape seed extraction meal		0.0592	0.84	0.080	0.77
minerals		0.0000	0.00	1.000	0.00

5.2 Annual nitrogen release rates

N release rates are obtained from the N mass balance:

$$m_{\text{excr}} = m_{\text{feed}} - m_{\text{g}} \quad (9)$$

$$m_{\text{excr, TAN}} = m_{\text{feed}} \cdot (1 - X_{\text{N}}) - m_{\text{g}} \quad (10)$$

where

m_{excr} annual nitrogen release rate (in kg place^{-1} a^{-1} N)
m_{feed} annual nitrogen intake rate with feed (in kg place^{-1} a^{-1} N)
m_{g} amount of nitrogen retained in the animal (in kg place^{-1} a^{-1} N)
$m_{\text{excr, TAN}}$ total ammoniacal nitrogen (TAN) excretion rate (in kg place^{-1} a^{-1} N)
X_{N} digestibility of nitrogen (in kg kg^{-1})

The N intake rate is the product of feed intake rate and N content of feed constituents for all constituents i and all time spans (weeks):

$$m_{\text{feed}} = n_{\text{round}} \cdot \sum_{\text{k}} \left(\sum_{\text{i}} m_{\text{feed, i, k}} \cdot X_{\text{N, i}} \right) \quad (11)$$

where

m_{feed} annual nitrogen intake rate with feed (in kg place^{-1} a^{-1} N)
n_{round} number of animal rounds (in a^{-1}) (see Chapter 3.5)
k running index of feeding days within one round ($1 \le \text{k} \le 126$) (for 18 weeks)
$m_{\text{feed, i, k}}$ daily intake rate of feed constituent i (dry matter) on day k (in kg d^{-1})
$X_{\text{N, i}}$ N content of feed constituent i (in kg kg^{-1})

The amount of **N taken in** with feed can be obtained by combining the information provided in Tables 1, 2 and 7 as expressed in Equation (11). The overall N input is 9.4 kg animal^{-1} N or 26.0 kg place^{-1} a^{-1} N.

The amount of **N retained** per round is calculated from the weight gain (84 kg animal^{-1}) and the mean N content of the weight gained per animal. GfE (1997) provide a mean protein content of the empty body of 182.2 g kg^{-1}. The data base covers years between 1980 and 1990 (approximately). For the weight gain used in this work, Robelin and Chiliard (1989) investigating in Holstein Friesians found 193 g kg^{-1}, Flachowsky et al. (1996) report 188 g kg^{-1}. Janssen (2006) measured a mean protein content of German Holstein calves of 178.5 g kg^{-1}. The “official” protein content of 182.2 g kg^{-1} provided in GfE (1997), Table 1, was used in this work. With a mean N content of animal protein of 0.157 kg kg^{-1}, a mean N content of 0.0287 kg kg^{-1} N and a weight gain of 84 kg animal^{-1} lead to an amount of N retained of 2.4 kg animal^{-1} N or 6.7 kg place^{-1} a^{-1} N.

Overall N excretion rates consider intake rates and the amounts of N retained only. Renal N excretion rates are a function of the digestible N entering the animal metabolism (see Table 7).

The following N excretion rates are obtained

total N excretion	7.0 kg animal^{-1} N	19.3 kg place^{-1} a^{-1} N
of which faecal	2.5 kg animal^{-1} N	7.0 kg place^{-1} a^{-1} N
of which renal	4.4 kg animal^{-1} N	12.3 kg place^{-1} a^{-1} N

The share of renally excreted nitrogen is 0.64 kg kg^{-1} rather than 0.60 kg kg^{-1} provided in the UNECE guidebook for “other cattle (young cattle, beef cattle, and suckling cows)” (EMEP, 2009, Table 3-8).

5.3 VS release rate

VS release rates can be obtained from organic matter input rates and ash contents of the feed according to Equation (12) (Dämmgen et al., 2011)

$$VS = n_{\text{round}} \cdot \sum_{\text{k}} \left(\sum_{\text{i}} m_{\text{feed, i, k}} \cdot (1 - X_{\text{ash, feed, i}}) \cdot (1 - X_{\text{DOM, i}}) \right) \quad (12)$$

where

VS *VS* release rate (in kg place^{-1} a^{-1} *VS*)
n_{round} number of animal rounds (in a^{-1}) (see Chapter 3.5)
k running index of feeding days within one round ($1 \le \text{k} \le 126$) (for 18 weeks)
$m_{\text{feed, i,k}}$ intake rate of feed constituent i (dry matter) on day k (in kg place^{-1} d^{-1})
$X_{\text{ash, feed, i}}$ ash content of feed constituent i (in kg kg^{-1})
$X_{\text{DOM, i}}$ apparent digestibility of organic matter of feed constituent i (in kg kg^{-1})

A *VS* release rate of 52.1 kg animal^{-1} or 144.1 kg place^{-1} a^{-1} is obtained for standard calves.

6 Discussion and conclusions

The description of emission rates from calves' enteric fermentation differs in principle from that of the release rates of nitrogen with faeces and urine and *VS* with faeces. The latter are approachable via balance considerations whereas enteric fermentation needs more sophisticated modelling. N excretion rates can be quantified in accordance with the UNECE guidance document (Dämmgen and Hutchings, 2008; EMEP, 2009), the calculations leading to CH_4 emission rates from enteric fermentation and *VS* release rates differ considerably from those recommended in the respective IPCC guidelines (IPCC 1996, 2006).

In this work, the **CH_4 emission factors EF_{CH4} and the methane conversion rates *MCR*** are obtained using a combination of the cattle methane emission model (Kirchgeßner et al., 1995, see Dämmgen et al., 2012) for live weights above 100 kg animal^{-1} and an adapted IPCC approach (using a national *MCR* for calves) for the animals between birth and a weight of 100 kg animal^{-1}. Bridging the gap between the preruminant calf and the fully ruminating calf requires assumptions that are plausible but nevertheless remain hypothetical. In contrast, the IPCC approach of relating CH_4 emission rates to GE intake rates is not applicable in principle (Dämmgen et al., 2012). Consequently, we recommend not using the IPCC default MCR values for cattle to quantify CH_4 emission rates whenever the animal category "dairy cows and their young" (as in IPCC, 2006, Table 10.12) is divided in subcategories (calves, heifers, dairy cows). However, it would be appropriate to calculate emissions from energy demands, diet composition and feed properties using different MCR for calves on forage and on milk (as may be derived from IPCC, 2006, Table 10 A.2).

The average animal weights and weight gains listed in IPCC (2006), Table 10A.2, are not applicable to the German situation (see Chapter 2). Hence we favour a simple interpolation procedure to obtain adequate MCR for calves based on generally accepted principles, as performed in Chapter 3.5.2. Here, the MCR calculated for variant 1 (linear interpolation) exceeds those obtained potentially reflecting rumen growth (variant 2). Until such time that variant 2 is confirmed using empirical measurements, it is recommended to use the conservative results obtained with variant 1.

At present, the German agricultural emission inventory uses the IPCC Tier 2 methodology (with national energy intake rates and a national MCR) to derive CH_4 emissions from enteric fermentation of calves. Calculations are based on low weights at birth, high weight gains, a final weight of 100 kg animal^{-1} and the application of an expert judgement of MCR of 20 kJ MJ^{-1} (suggested by G. Flachowsky, Institute of Animal Nutrition, former Federal Agricultural Research Center, Braunschweig). It resulted in an emission factor (EF_{CH4}) of 4.3 kg place^{-1} a^{-1} CH_4. The methodology developed in this work describes calves with different properties, i.e. higher weights at birth (41 kg animal^{-1} rather than 36 kg animal^{-1}), a higher final weight (125 kg animal^{-1} rather than 100 kg animal^{-1}) and a lower daily weight gain (670 g animal^{-1} d^{-1} rather than 1066 g animal^{-1} d^{-1}). As shown in Chapter 3, it appears adequate to use an EF_{CH4} of 9.4 kg place^{-1} a^{-1} CH_4 and an MCR of 41 kJ MJ^{-1} to describe the enteric emissions from German standard calves.

With regard to **N release rates with faeces and urine,** the value of 19.3 kg place^{-1} a^{-1} N obtained here is similar to the value previously used in German emission reporting (20.9 kg place^{-1} a^{-1} N; Haenel et al., 2012, Chapter 4.4.6.1). It contradicts the default value of 14 kg place^{-1} a^{-1} N provided in KTBL (2006), pg 428, for 4 animal rounds and a final weight of 100 kg animal^{-1} (see reasoning in Haenel et al., 2012). The TAN content of 0.64 kg kg^{-1} exceeds that previously used (0.60 kg kg^{-1}) based on assumptions for cattle in general (Webb, 2001). This is attributed to the high digestibility of crude protein in milk and the high proportion of concentrates.

The modelling of ***VS* release rates** differs from the IPCC approach in principle: the IPCC methodology is inadequate in general, as it relates VS release rates to GE intake rates (Dämmgen et al., 2011). This is wrong in particular with (partly) milk fed calves as the zero fibre content of milk is not taken into account. The application of the IPCC (1996) methodology (IPCC, 1996, Table B-1: 1.46 kg animal^{-1} d^{-1}) to a standard German calf (using the default ash contents and digestibilities of feeds provided) would yield a VS release rate of about 500 kg place^{-1} a^{-1}.The difference between the IPCC approach and the results described in this work (144 kg place^{-1} a^{-1}) is substantial. Previous, less sophisticated German inventories made use of a VS release rate of 209 kg place^{-1} a^{-1} (with animal performance data as listed above).

The emission factors EF_{CH4} and the MCR as well as the excretion rates of VS with faeces are based on standard descriptions of German calf production and derived using more realistic procedures than those provided in the IPCC guidance documents. The N excretion rates are calculated using more detailed data sets than before. Overall with respect to emission reporting, the new calculation procedures are considered to reflect more faithfully than previously the production conditions for the rearing of calves in Germany, and the accuracy of the description of calves has been improved.

We recommend using the new findings for future emission reporting.

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