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Uncertainty of agricultural CH_4 and N_2O emissions in Switzerland

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Introduction

Uncertainty estimates are an essential element of a complete emissions inventory. They are implemented to help prioritize efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice (IPCC 2000). Leifeld and Fuhrer (2005) accomplished a first estimation of uncertainties for greenhouse gas emissions from Swiss agriculture. Based on this work, a more detailed assessment has been conducted in the present document.

Uncertainty estimates in this document are in general based on expert judgment and literature used for emission calculation. Other literature not used in the calculation process and more recent findings have been considered sporadically. The calculated uncertainty ranges in this document should be understood as a first approximation and a basis for further discussion. More thorough analysis, checks and comparisons will follow as more information is available and reviewed.

The Tier 1 methodology suggested by the IPCC Guidelines (2000) has been applied here to obtain an improved approximation of uncertainties. Uncertainty ranges for the single parameters of the IPCC equations were combined according to the error propagation laws. For some livestock characteristics, uncertainty information is available on a disaggregated level i.e. for individual livestock categories. For reasons of simplicity and in order to evade problems with possible error correlations, weighted overall uncertainty rates have been calculated in these cases. Following this procedure, uncertainty ranges of livestock related emissions might be somewhat higher than when calculated on a more disaggregated level.

Uncertainties are presented as upper (97.5 percentile) and lower (2.5 percentile) ranges of a 95% confidence interval and expressed as percent of the mean. Error propagation has been calculated independently once for the lower range and once for the upper range. Therefore, eventual asymmetric uncertainties of the individual parameters are reflected in the result. At present no specific information on the type of probability distribution functions (PDF) is provided for overall uncertainties. Nevertheless large discrepancies between the upper and lower range are indications for a skewed distribution. In these cases lognormal or triangular PDF’s can be used. When upper and lower values are close or equal, a normal distribution can be assumed. Winiwarter et al. (2004) argue that the exact shape of a probability function is not important and that the subjective selection of literature information available causes a more significant effect.

Possible systematic errors are not accounted for in this study.

To put the following uncertainty analysis into a broader context, the corresponding chapters in the QA/QC document should be consulted (Bretscher 2008), where more information on the data sources and further cross checks are available.

1. Uncertainties - Livestock Population

The accuracy of animal livestock numbers was assessed by expert judgment. According to personal communication with R. Grüter (2007), the officer in charge for livestock data at the Swiss Farmers Union, the respective uncertainties lie within ±1-2%. Correspondingly, the uncertainty range was defined as ±2.0% for all animal species except cattle, where a value of ±1.5% has been adopted due to a more detailed and reliable data source (Grüter 2007). Since livestock statistics are collected at a single point in time of the year the respective numbers do not necessarily reflect average annual populations (IPCC 2000). Therefore an additional 4.5% uncertainty is assumed accounting for seasonal population fluctuations. This value is derived from monthly cattle livestock data provided by the Swiss Farmers Union (SBV 2007a). As a result the overall uncertainty in livestock population data is estimated to be ± 6.0% for cattle and ±6.5% for all other livestock categories. These values are considerably smaller than the ±20% that has been used until 2007. They are now closer to values reported by other countries such as Germany (6%), the Netherlands (5%) or Denmark 7-10%. Austria (10%), the USA (<10%) and the CORINAIR Emission Inventory Guidebook 2006 (10%) estimate slightly higher uncertainties. However, small ranges for Switzerland are justified by the rigorous and reliable livestock population data assessment. Monni et al. (2007) also report small uncertainties of ±3% for cattle with individual earmarks and ±5% for other animal numbers and the NIR of Denmark quotes that uncertainty for cattle with ear tags is almost nonexistent.

Although absolute uncertainty of animal numbers might seem negligible compared with uncertainties in emission factors, it may be important for the calculation of trend uncertainties (Kelliher et al. 2007, Leifeld and Fuhrer 2005).

2. Uncertainties 4A - Enteric Fermentation

Uncertainty of the emission factor

Methane emission from enteric fermentation is based on IPCC equation 4.14 IPCC 2000: p. 4.26.

$$EF = \frac{GE * Y_m * 365\, days / y}{55.65\; MJ / kg\, CH_4}$$

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

Uncertainties have been estimated for the two variables GE and Y_m and have then been combined according to the error propagation rules to calculate overall emission factor uncertainty. Coefficients shown as numbers in the equation are assumed to be known with high precision and are therefore neglected in the analysis.

Gross Energy Intake GE

For livestock energy requirements as assessed by the Swiss Farmers Union (SBV 2007b), an uncertainty of ±10% has been estimated by expert judgment (Grüter 2007). The same range is also adopted for cattle livestock data although the respective energy requirements are calculated separately (see Soliva 2006 for detailed methodology). For all animal categories an additional uncertainty of -5.1 and +3.5% is assumed for the conversion from energy required for maintenance and performance to gross energy intake. These numbers correspond to the average energy density of feed (mean: 18.5 MJ/kg dm; range: 17.5-19.1) given by Minonzio et al. (1998). The importance of accurate conversions between different diet energy levels is also emphasized in the 2006 IPCC Guidelines. The development towards a broader range of production intensities bears additional uncertainty with respect to the utilization of metabolisable energy in low quality roughage (RAP 1999). However, this tendency is of minor importance because the use of such feed is still limited.

The resulting uncertainty ranges for gross energy intake (+11.2% / -10.6%) might seem relatively low. Austria, for example, uses a ±20% uncertainty for gross energy intake in its National Inventory Report. Nonetheless, the regularly validated energy requirement values and the cross-checks with annual feed production and feed import surpluses conducted by the SBV suggest a high data quality.

Methane conversion rate Y_m

Uncertainties for the methane conversion rate Y_m are taken from a literature review in Minonzio et al. (1998) and are presented in Table 1.

Table 1 Uncertainty ranges for methane conversion rates

Type	**mean**[a]	**low**	**high**	**uncertainty** **lower**	 **upper**	 **IPCC**
	%	%	%	%	%	%
Mature dairy cattle	6	5.5	6.7	8.3	11.7	8.33
Mature non-dairy cattle	6	5.5	7.6	8.3	26.7	8.33
Sheep	5	4	5.8	20.0	16.0	8.33[b]
Goats	5	4	5.8	20.0	16.0	n.a.
Horses	3.5	2.7	4	22.9	14.3	n.a.
Mules and asses	3.5	2.7	4	22.9	14.3	n.a.
Swine	0.54	0.4	0.9	25.9	66.7	n.a.
Poultry[c]	0.16	n.a.	n.a.	n.a.	n.a.	n.a.
Overall (weighted mean)				**9.4**	**16.5**	

[a] mean values from Minonzio et al. (1998) are not necessarily identical with the values adopted in the Swiss GHG Inventory

[b] uncertainty for lambs (<1 year old) (IPCC 2000; 4.27)

[c] the methane conversion rate given by Hadorn (1996) seems rather low and is therefore relatively uncertain. This uncertainty can, however, be neglected since methane emission from poultry digestion accounts for only 0.1% of overall emissions.

n.a.: not assessed

Swiss methane conversion rate uncertainties are rather large compared to IPCC default ranges. Minonzio et al. (1998) argue that at least some of the 1996 Y_m default values rely on rather weak scientific foundations. This is especially true for goats, horses, mules and asses and for poultry. Moreover, both Soliva (2006) and Minonzio et al. (1998) quote, that values for cattle measured in Switzerland are generally somewhat higher than IPCC default.

The overall methane conversion rate uncertainty as calculated by weighing the individual category values with total methane emission from enteric fermentation in 2005 is -9.4 and +16.5%.

Uncertainty of the emission factor

According to the error propagation rule the aggregated emission factor uncertainty ranges from -14.7 to +19.6%. This is higher than the ±13% used for the Swiss inventory until 2007 (FOEN 2007), but still smaller than default ranges suggested by the IPCC 2000 (±20%) and the CORINAIR Emission Inventory Guidebook 2006 (±30%) or ranges adopted by other countries such as Austria, the Netherlands or the USA. A small uncertainty of the emission factor of enteric fermentation is justified because the coefficients used in the net energy approach are adapted to national circumstances. Furthermore Switzerland's greenhouse gas inventory system counts with an accurate and detailed livestock characterization. A very small uncertainty of 8% is also applied in Denmark.

3. Uncertainties 4B - Manure Management

a) CH_4 emissions

Uncertainty of the emission factor

Methane emission from manure management is based on IPCC equation 4.17 IPCC 2000: p. 4.34.

$$EF = VS * 365\ days / y * B_0 * 0.67\ kg / m^3 * \sum_{jk} MCF_{jk} * MS_{jk}$$

VS = daily volatile solids excreted (kg-dm/day)

B_0 = maximum CH_4 producing capacity for manure

MCF_{jk} = CH_4 conversion factors for each manure management system *j* by climate region *k*

MS_{jk} = fraction of animal species/category's manure handled using manure system *j* in climate region *k*

To calculate the overall emission factor uncertainty, uncertainties have been estimated for the variables *VS*, B_0, *MCF and MS* and combined according to the error propagation rules. Uncertainties for coefficients shown as numbers in the equation are assumed to be of minor importance and are not included in the analysis.

Volatile solids VS

Minonzio et al. (1998) give a range of 0.21 to 0.28 kg VS excretion per kg dry matter intake with a mean value of 0.25 for cattle, sheep and goats. Accordingly an uncertainty range of -16.0 to +12.0% is taken for all animal categories in the Swiss inventory. The IPCC (2006) suggest higher values of ±20% for dairy cows and ±35% for other cattle. Subsequently, VS uncertainty may be underestimated in Switzerland. Minonzio et al. (1998) confirm this statement by arguing that neither the theoretical background nor the experiments to define the parameters and the respective results for VS excretion are sufficiently consolidated. On the other hand, other countries such as the Netherlands report very low uncertainties of 5 to 10%. Due to the lack of further information on the subject at the time being, the above range has been adopted for the Tier 1 analysis but will be revised in an eventual future Tier 2 approach.

B_0

B_0 varies considerably between different animal categories. The respective uncertainties have been estimated based on data from different sources (Table 2). As for the methane conversion rate for enteric fermentation Y_m a single overall uncertainty has been calculated by weighing the individual animal category values with the respective methane emissions in 2005. The resulting values of -15.5 and +14.9% correspond very well to the uncertainty estimate for B_0 presented in the 2006 IPCC Guidelines Table 10A-4 to 10A-9 (± 15%).

Table 2 Uncertainty ranges for B_0

Type	**lower** %	**upper** %	**Reference**
Young cattle	17.6	17.6	Safley et al. 1992, Hashimoto 1981
Mature dairy and non dairy cattle	16.7	16.7	Safley et al. 1992, Morris 1976
Sheep	15.8	15.8	Safley et al. 1992
Goats	17.6	17.6	Safley et al. 1992
Horses	n.a.	n.a.	
Mules and asses	n.a.	n.a.	
Swine	8.9	6.7	Minonzio et al. 1998, Summers and Bousfield 1980, Hashimoto 1983
Poultry	25.0	21.9	Safley et al. 1992
Overall (weighted mean)	**15.5**	**14.9**	

*MCF * MS*

The last parameter in equation 4.34 is determining the uncertainty of CH_4 emissions from manure management. Manure management system distribution *MS* is also identified by Freibauer (2003) and by the IPCC as one of the major sources of uncertainties in national inventories.

The Guidelines do not provide specific uncertainty ranges for the methane conversion factors of the different manure management systems MCF_{jk}. For liquid/slurry in cool climates, however, the 2006 IPCC Guidelines give a set of conversion factors for different temperature regimes and management practices. The values range from 10% (with natural crust cover at ≤ 10°C) to 25% (without natural crust cover at 14°C). This range converts to an uncertainty estimate of ± 43%. For the manure system fractions MS_{jk} an accuracy of ±25.5% can be derived adopting a value of ±50% for the term *MCF*MS*. In comparison IPCC (2006) suggests an uncertainty range of 25 to 50% for management system usage data, depending on the availability of reliable and representative survey data. Considering the high survey quality in Switzerland, a low percentage seems justified. Manure management system usage depends on the animal housing systems. The respective information is of relatively high quality based on a number of studies that were conducted in the context of ammonia emissions from animal husbandry (Menzi et al. 1997, Reidy and Menzi 2005). The minimum and maximum values for *MS* from Menzi et al. (1997) support an uncertainty of approximately ±25%.

Uncertainty of the emission factor

An overall uncertainty of -54.7 and +53.5 is calculated by applying the error propagation laws for the three contributing factors in equation 4.17 IPCC 2000. This uncertainty is higher as compared to default values from the IPCC 1996 (±20%), IPCC 2006 (±30% for Tier 1 and ±20% for Tier 2) and the CORINAIR Emission Inventory Guidebook 2006 (±30%). It is also higher than the former estimates used by Switzerland (±36%; FOEN 2007). On the other hand high uncertainty ranges of 70 to 100% have been adopted by several countries such as Denmark, the Netherlands and Austria. Minonzio et al. (1998) discuss the parameters of the IPCC methodology and show that the underlying data are not yet consolidated sufficiently. They argue that values are mainly based on laboratory results that do not necessarily reflect conditions found in practice. Additionally the use of litter beds, a common practice in Swiss agriculture, is an important source of uncertainty often not accounted for.

b) N_2O emissions

To calculate uncertainty of N_2O emission from manure management the error propagation law is applied on the parameters of IPCC equation 4.18 IPCC 2000: p. 4.42.

$$(N_2O-N)_{(mm)} = \sum_{(S)} \left\{ \left[\sum_{(T)} \left(N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) \right] * EF_{3(S)} \right\}$$

$(N_2O\text{-}N)_{(mm)}$ = N_2O-N emissions from manure management (kg N_2O-N/yr)

$N_{(T)}$ = number of head of livestock species/category *T*

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* (kg N/animal/yr)

$MS_{(T,S)}$ = fraction of total annual excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = N_2O emission factor for manure management system *S* (kg N_2O-N/kgN in manure management system *S*)

S = manure management system

T = species/category of livestock

Uncertainty of activity data

Switzerland distinguishes two manure management systems namely solid storage and liquid systems. Uncertainty analyses are the same for both systems. General uncertainties have been estimated for $N_{(T)}$ and $Nex_{(T)}$ by weighing uncertainties from the individual species/categories with animal numbers and N excretion, respectively. Livestock population ($N_{(T)}$) uncertainty has already been discussed in chapter *1. 1. Uncertainties - Livestock Population*. The adopted range is ±6.4%. Average uncertainty of *Nex* has been estimated using min/max values from Menzi et al. (1997) and ranges from -12.3 to +11.2% (Table 3). These values are considerably smaller than IPCC default (IPCC 2000) even under consideration of accurate in-country statistics on nitrogen intake and nitrogen retention (suggested range: ±25%). Therefore validation of these estimates is clearly needed. Especially the divergence between the theoretical nitrogen excretion derived from standard feeding ratios and the unknown nitrogen excretion in practice should be assessed.

Table 3 Uncertainty ranges for $Nex_{(T)}$ (according to Menzi et al. 1997)

Type	**lower** **%**	**upper** **%**
Mature dairy and non dairy cattle	9.5	9.5
Young cattle	14.8	12.0
Sheep	25.0	25.0
Goats	11.1	33.3
Horses	16.7	16.7
Mules and asses	16.7	16.7
Swine	18.2	13.6
Poultry	10.7	9.5
Overall (weighted mean)	**12.3**	**11.2**

As for methane emission from manure management, the distribution of manure among different management systems is dominating the uncertainty. The respective calculation is conducted in two steps. First the share that is excreted on pasture, range and paddock is subtracted from the total amount. Based on data from Menzi et al. (1997), an uncertainty of -8.7 and + 7.7% is assumed for this parameter (this is consistent with the uncertainty adopted under *4. b) Emissions from animal production (4D2)*). The remaining manure is distributed among solid storage and liquid systems assuming an uncertainty of ±25% as discussed under *a) CH4 emissions*.

The combined uncertainty for the activity data according to the Tier 1 methodology is -29.9 to +29.2%.

Uncertainty of the emission factor

Since Switzerland applies the IPCC default emission factors the corresponding default uncertainties are adopted here. The respective estimates are summarized in Table 4.

Table 4 Uncertainty of the emission factor for N_2O emissions from manure management EF_3 According to table 4-22 in the 1996 IPCC Guidelines

Management system	**Medium**	**minimum**	**Maximum**	**lower** **%**	**upper** **%**
Liquid systems	0.001	<0.001	0.001	100	0
Solid storage	0.020	0.005	0.030	75	50
Pasture range and paddock	0.02	0.005	0.03	75	50

4. Uncertainties 4D – Agricultural Soils

a) Direct emissions from soil (4D1)

Calculation of direct N_2O emissions from agricultural soils is based on IPCC equation 4.20 IPCC 2000.

$$N_2O_{direct} - N = \left[\left(F_{SN} + F_{AM} + F_{BN} + F_{CR}\right) * EF_1\right] + \left(F_{OS} * EF_2\right)$$

N_2O_{direct}-N = Emission of N_2O in units of nitrogen (kg N/yr)

F_{SN} = annual amount of synthetic fertilizer nitrogen applied to soils adjusted for the amount that volatilizes as NH_3 (kg N/yr)

F_{AM} = annual amount of animal manure nitrogen intentionally applied to soils adjusted for the amount that volatilizes as NH_3 (kg N/yr)

F_{BN} = amount of nitrogen fixed by N-fixing crops cultivated annually (kg N/yr)

F_{CR} = amount of nitrogen in crop residues returned to soils annually (kg N/yr)

F_{OS} = area of organic soils cultivated annually (ha)

EF_1 = emission factor for emissions from N inputs (kg N_2O-N/kg N input)

EF_2 = emission factor for emissions from organic soil cultivation (kg N_2O-N/ha/yr)

Synthetic fertilizer nitrogen (F_{SN})

Calculations are based on IPCC equation 4.22 IPCC 2000:

$$F_{SN} = N_{FERT} * \left(1 - Frac_{NH3}\right)$$

5% uncertainty has been estimated by expert judgment (Grüter 2007) for commercial fertilizer nitrogen input N_{FERT}. This is identical with an independent estimate of ±5% by Spiess (2005). The respective range suggested by the CORINAIR guidebook (EEA 2007) is ±10%, same as reported by Monni et al. (2007). Thus, Switzerland is applying a considerably high precision. Also Denmark (±3%) and Austria (±5%) report low uncertainties. Since data on the use of commercial fertilizer in Switzerland is based on records about inland production as well as external trade statistics and assessed together with an explicit trust corporation, a high precision is reasonable. Lower and upper limits of 0 and 12%, respectively, have been applied for the share of NH_3 volatilization ($Frac_{NH3}$, mean 6%) assuming an uncertainty range of ±100%. This is a considerably higher estimate than suggested by Menzi et al. (1997, ± 20%) or the CORINAIR Guidebook (EEA 2007, ±50%). The insufficient validation of the ammonia volatilization data suggests, however, a conservative uncertainty. Furthermore, the influence on the total uncertainty of direct N_2O emissions from agricultural soils is very limited. Switzerland does not account for NO_x volatilization in the context of direct soil emissions as is proposed in the IPCC Guidelines. Subsequently an overall uncertainty of ±7.9% can be calculated for F_{SN} applying the error propagation law on the two parameters discussed above.

Animal manure nitrogen (F_{AM})

Calculations are based on IPCC equation 4.23 IPCC 2000:

$$F_{AM} = \sum_T \left(N_{(T)} * Nex_{(T)}\right) * \left(1 - Frac_{NH3M}\right) * \left(1 - Frac_{PRP}\right)$$

In chapter *3. b) N2O emissions* uncertainty of the nitrogen excreted by livestock $N_{(T)}*Nex_{(T)}$ has already been discussed. Menzi et al. (1997) estimated minimum and maximum values for the amount of nitrogen lost as NH_3 from manure for individual animal categories. Based on their data the weighted mean uncertainty for the term ($1-Frac_{NH3M}$) is -24.7 and +17.8%. As for synthetic fertilizer nitrogen NO_x volatilization is not considered here. The uncertainty range for the factor for manure deposited onto soils by grazing animals ($1-Frac_{PRP}$) has also been calculated based on data from Menzi et al. (1997) and adds up to -8.7 and +7.7% (this range is consistent with the respective uncertainty applied under *4. b) Emissions from animal production (4D2)*). Combining the four parameters gives a total Tier 1 uncertainty for F_{AM} of -29.7 and +23.3.

Nitrogen fixed by N-fixing crops (F_{BN})

Based on IPCC equation 4.25 IPCC 2000:

$$F_{BN} = Crop_{BF} * Frac_{NCRBF}$$

Uncertainty for crop yields of nitrogen fixing plants $Crop_{BF}$ has been estimated as ±10% by expert judgment from R. Grüter (2007). $Frac_{NCRBF}$ represents the total nitrogen per kg crop yield that is originating from biological fixation and is associated with an uncertainty of ±20% (Spiess 2005). While the total plant nitrogen content is known with high precision, the most uncertain aspect is the share of nitrogen that is arising from biological fixation. Overall uncertainty for F_{BN} adds up to ±22.4%.

Nitrogen in crop residues returned to soils (F_{CR})

According to expert judgment from R. Grüter (2007) crop yields are known with an accuracy of ±10%. An additional 15% is assumed for the uncertainty of the fraction of nitrogen that is left on the field as crop residues based on Leifeld and Fuhrer (2005). The total uncertainty for F_{CR} is thus ±18.0%. This is somewhat lower than the range suggested by the CORINAIR guidebook (±25%).

Uncertainty of activity data

The overall uncertainty for all four nitrogen sources in the IPCC equation 4.20 (IPCC 2000) can be calculated applying the error propagation law. On basis of the amounts of nitrogen (F_{SN}, F_{AM}, F_{BN} and F_{CR}) in the year 2005 the range lies between -12.1 and +10.1% (Table 5). These figures confirm the accuracy of ±10% used previously in Switzerland (FOEN 2007).

According to Leifeld and Fuhrer (2005) the area of organic soils cultivated annually F_{OS} is known with a precision of ±29.4%.

Considering the very high uncertainties of the emission factors, the corresponding ranges for activity data for direct emissions from soil might seem negligible. They might, however, be important for trend uncertainty analyses as is true for livestock population numbers.

Table 5 Uncertainties of activity data and emission factors for direct emissions from soils (4D1)

	Amount 2005 **kg N/yr**	**lower** **%**	**Upper** **%**
F_{SN} (commercial fertilizer)	53204	7.9	7.9
F_{AM} (animal manure)	69950	29.7	23.3
F_{BN} (biological fixation)	32919	22.4	22.4
F_{CR} (crop residues)	36303	18.0	18.0
Overall N input		**12.1**	**10.1**
EF_1 (direct soil emissions)		80.0	80.0
F_{OS} (organic soils)		29.4	29.4
EF_2 (organic soils)		75.0	87.5

Uncertainty of the emission factor

Emission factor uncertainties for direct soil emissions are IPCC default. Ranges are ±80% for EF_1 and -75% and +87.5% for EF_2.

b) Emissions from animal production (4D2)

Emissions from animal production are calculated according to IPCC equation 4.18 IPCC 2000: p. 4.42.

$$(N_2O-N)_{(mm)} = \sum_{(S)} \left\{ \left[\sum_{(T)} \left(N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) \right] * EF_{3(S)} \right\}$$

For further specification of the formula see *3. b) N2O emissions*.

Uncertainty of activity data

Uncertainty of $N_{(T)}$ and $Nex_{(T)}$ has already been discussed under *3. b) N2O emissions*. For the fraction of manure excreted on pasture $MS_{(T,S)}$ Menzi et al. (1997) provide minimum and maximum values for the individual animal categories. Based on these estimates a general uncertainty of -52.4% and +59.1% has been calculated. This is consistent with the respective numbers under *3. 3. Uncertainties 4B - Manure* Management and *4. a) Direct emissions from soil (4D1)*. The precision is lower than for the other two management systems (liquid systems and solid storage), but is reasonable, since the respective data is based on a small survey. Applying the error propagation law, the overall uncertainty for the amount of manure dropped on pasture, range and paddock is -54.2 to +60.4%. These values are dominated by the uncertainty of $MS_{(T,S)}$.

Uncertainty of the emission factor

As for the manure management systems under *3. b) N2O emissions* the IPCC default uncertainty value is used for EF_3. An uncertainty of -75 and +50% is adopted based on data provided in table 4-22 in the 1996 IPCC Guidelines (Table 4).

c) Emissions from atmospheric deposition of NO_x and NH_3 (4D3)

Calculation of N_2O emissions from atmospheric deposition is based on IPCC equation 4.31 IPCC 2000.

$$N_2O_{(G)} - N = \left[\left(N_{FERT} * Frac_{GASF} \right) + \left(\sum_T \left(N_{(T)} * Nex_{(T)} \right) * Frac_{GASM} \right) + \left(AA * 1.5kgNH_3 - N/ha \right) \right] * EF_4$$

$N_2O_{(G)}$ = N_2O produced from atmospheric deposition of N (kg N/yr)

N_{FERT} = total amount of synthetic nitrogen fertilizer applied to soils (kg N/yr) (including fertilizer from compost and sewage sludge)

$\Sigma_T(N_{(T)}*Nex_{(T)})$ = total amount of animal manure nitrogen excreted in a country (kg N/yr)

$Frac_{GASF}$ = fraction of synthetic N fertilizer that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N input)

$Frac_{GASM}$ = fraction of animal manure N that volatilizes as NH_3 and NO_x (kg NH_3-N and NO_x-N/kg of N excreted)

AA = area of agricultural soils (ha)

1.5 kgNH₃-N/ha = ammonia emitted during decomposition of organic matter in the soil

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N_2O-N/kg NH_3-N and NO_x-N emitted)

Uncertainty of activity data

Uncertainty of N_{FERT} has already been discussed under *4. a) Direct emissions from soil (4D1)*. $Frac_{GASF}$ consists of the fraction of fertilizer nitrogen that volatilizes as NH_3 and the fraction that is lost as NO_x (Table 6). For ammonia volatilization an uncertainty range of ±100% has been assumed as discussed under *4. a) Direct emissions from soil (4D1)*. The same range is adopted for the NO_x emission factor. Compared with the data provided by the CORINAIR Emission Inventory Guidebook 2006, the uncertainty for ammonia is probably over- and that for nitric oxide underestimated. Due to the much higher importance of NH_3 volatilization the combined uncertainty for $Frac_{GASF}$ (± 90.2) seems reasonable. The fact that the probability density function is probably skewed has not yet been accounted for in this analysis. The IPCC suggest a lower and upper uncertainty value of -70 and +200% respectively (IPCC 2006, table 11.3).

The accuracy of the term $N_{(T)}*Nex_{(T)}$ has been discussed under *3. b) N2O emissions*. The uncertainty for $Frac_{GASM}$ has been calculated using data from Menzi et al. (1997) as described under *4. a) Direct emissions from soil (4D1)* for NH_3 and assuming a 100% uncertainty for NO_x volatilization. Ammonia volatilization is the dominating factor. The calculated range of -36.1 and +53.3% is close to the 30% uncertainty proposed by the CORINAIR Guidebook 2006. Total uncertainty of $Frac_{GASM}$ (-35.4 / +52.3) is however considerably lower than IPCC (2006) default (-75% / +150%). The accuracy of this parameter might therefore be overestimated. Currently the methodology for calculating ammonia volatilization in Swiss agriculture is revised and better estimates should be available in the future.

The area of agricultural soils *AA* is known with a precision of ±2% (Grüter 2007). Based on Menzi et al. (1997), an uncertainty of -66.7 to +33.3% has been estimated for the corresponding 1.5kg NH_3-N/ha emitted during decomposition of organic material.

Uncertainty ranges for activity data for N_2O emissions from atmospheric deposition is summarized in Table 6. The overall uncertainty for N deposited on soils and water surfaces according to the Tier 1 methodology is -34.6 and +48.3%. These numbers are slightly below the uncertainty range for dry deposition of NH_3 in the CORINAIR emission inventory

Guidebook 2006 (±50%). The relatively high accuracy used previously for the Swiss inventory (±15%) has clearly been overestimated. The greatest influence on the result can be attributed to the fraction of animal manure that volatilizes as ammonia $Frac_{GASM}$ NH_3.

Table 6 Uncertainty for volatilization of NH_3 and NO_X

Factor	lower %	Upper %	Reference
N_{FERT}	4.6	4.6	Grüter 2007
$Frac_{GASF}\ NH_3$	100.0	100.0	own estimate
$Frac_{GASF}\ NO_x$	100.0	100.0	own estimate
$Frac_{GASF}tot$	90.3	90.3	-
$N_{(T)}$	6.4	6.4	Grüter 2007
$Nex_{(T)}$	12.3	11.2	Menzi et al. 1997
$Frac_{GASM}\ NH_3$	36.1	53.3	Menzi et al. 1997
$Frac_{GASM}\ NO_x$	100.0	100.0	own estimate
$Frac_{GASM}tot$	35.4	52.3	-
AA	2.0	2.0	Grüter 2007
$kgNH_3$-N/ha	66.7	33.3	Menzi et al. 1997
Overall activity data	**34.6**	**48.3**	

Uncertainty of the emission factor

The IPCC default emission factor uncertainty based on table 4-23 in the 1996 IPCC Guidelines is used. The lower and upper ranges are -80 and +100%.

d) Emissions from leaching and runoff (4D3)

Calculation of N_2O emissions from leaching and runoff follows IPCC equation 4.34 IPCC 2000.

$$N_2O_{(L)} - N = \left[N_{FERT} + \sum\nolimits_T \left(N_{(T)} * Nex_{(T)}\right)\right] * Frac_{LEACH} * EF_5$$

$N_2O_{(L)}$ = N_2O produced from N lost as leaching and runoff (kg N/yr)

N_{FERT} = total amount of synthetic nitrogen fertilizer applied to soils (kg N/yr) (including fertilizer from compost and sewage sludge)

$\Sigma_T(N_{(T)}*Nex_{(T)})$ = total amount of animal manure nitrogen excreted in a country (kg N/yr)

$Frac_{LEACH}$ = fraction of nitrogen lost as leaching and runoff (kg N/kg of N input)

EF_5 = emission factor for N_2O emissions from leaching and runoff (kg N_2O-N/kg N)

Uncertainty of activity data

The terms N_{FERT} and $\Sigma_T(N_{(T)}*Nex_{(T)})$ have already been discussed earlier under *4. a) Direct emissions from soil (4D1)* and *3. b) N2O emissions*. According to Prasuhn et al. (2003) the uncertainty of the fraction of nitrogen lost as leaching and runoff $Frac_{LEACH}$ is ±20%. IPCC (1997) suggests a much higher range of -66.7 and +166.7% respectively. However, a high precision is justified for Switzerland due to numerous studies conducted on this issue (Braun et al. 1994; Prasuhn and Braun 1994; Schmid and Prasuhn 2000; Spiess 1999). $Frac_{LEACH}$ has the strongest influence on overall uncertainty of the activity data which amounts to -22.2 and +21.9% respectively.

Uncertainty of the emission factor

Emission factor uncertainty is IPCC default. Based on table 4-23 in the 1996 IPCC Guidelines a range of -92 and +380% has been deducted.

e) Other (sewage sludge and compost used for fertilizing) (4D4)

Calculation of N_2O emissions from application of sewage sludge and compost on agricultural land follows the following equation:

$$N_2O_{SSC} - N = \left(N_{SSC} * \left(1 - Frac_{NH3}\right)\right) * EF_1$$

N_2O_{SSC} = Emission of N_2O in units of Nitrogen (kg N/yr)

N_{SSC} = total amount of N from sewage sludge and compost applied to soils (kg N/yr)

$Frac_{NH3}$ = fraction of N from sewage sludge and compost that volatilizes as NH_3 (kg NH_3-N/kg of N input)

EF_1 = emission factor for emissions from N inputs (kg N_2O-N/kg N input)

Uncertainty of activity data

The uncertainty of activity data for sewage sludge and compost used for fertilization follows the same procedure as described in chapter *4. a) Direct emissions from soil (4D1)*. 5% uncertainty has been estimated by expert judgment (Grüter 2007) for N_{SSC} and for $Frac_{NH3}$ a very conservative uncertainty range of ±100% is assumed. Subsequently an overall uncertainty of ±8.1% can be calculated for the activity data.

Uncertainty of the emission factor

Since the emission factor is the same as for 4D1 direct emissions from soil the, respective IPCC default uncertainty is applied (±80%).

Summary and Conclusions

For a Tier 1 analysis as suggested by the IPCC (1997) small uncertainties (<30%), normal distributed probability distribution functions (PDF) and no covariance of uncertainties are required. All these premises are probably violated by the nature of uncertainties in agricultural greenhouse gas emissions. Nonetheless, the Tier 1 methodology may still be used to obtain an approximate result (IPCC 2000). The results should, however, be interpreted with appropriate caution.

In some cases uncertainty information was available on a disaggregated level, i.e. for individual livestock category data. When using this information for a more detailed analysis, instead of weighted mean uncertainties in the IPCC equations, total uncertainty could possibly be reduced. In contrast to the method applied above, however, more attention would have to be paid to possible correlations.

Application of uncertainty factors to the Emissions 2005

Among agricultural greenhouse gas emission sources in Switzerland, indirect N_2O emissions from soils (4D3) have the greatest single uncertainty followed by emissions from animal production (4D2), emissions from sewage sludge and compost (4D4) and direct emissions from soil (4D1) (Table 7). Due to the low activity of 4D2 and 4D4 (i.e. little nitrogen excreted on pasture, range and paddock and little nitrogen applied as sewage sludge and compost), the significance of these two emission sources in terms of uncertainty is relatively small.

Table 7 Uncertainty of greenhouse gas emission sources in agriculture

		Emissions 2005	lower 2.5%	upper 2.5%	mean 95% uncertainty
		Gg CO_2 eq.	%	%	%
4A Enteric Fermentation	CH_4	2273.42	16.05	20.66	18.33%
4B Manure Management	CH_4	494.97	55.11	53.92	54.52%
4B Manure Management	N_2O	400.06	74.03	52.71	63.09%
4D1 Direct Emissions from Soil	N_2O	1213.64	76.63	76.40	76.51%
4D2 Emissions from Animal Production	N_2O	158.82	92.54	78.45	84.81%
4D3 Indirect Emissions from Soil	N_2O	677.99	68.93	252.46	159.10%
4D4 Other (Sewage sludge and compost)	N_2O	24.04	80.41	80.41	80.41%

Uncertainties are higher for nitrous oxide emissions than for methane emissions. This is especially true for the emission factors. The poor precision of the N_2O emission sources is due to the high temporal and spatial variability of nitrous oxide emissions from manure and soils. Technical measurement of N_2O emissions is costly and time consuming. Therefore the underlying database still does not provide regionalized or otherwise disaggregated emission factors with higher accuracy. Apart from the emission factors the fractions of manure handled in the different manure management systems *MS* and the fractions of nitrogen volatilized as ammonia $Frac_{GASM}$, $Frac_{GASF}$ and $FRAC_{NH3}$ contribute significantly to the overall uncertainty. These parameters are probably associated with strong negative correlations (e.g. a high share of manure managed in "liquid systems" induces low allocation of manure to the "solid storage" compartment). In a future Tier 2 analysis where these correlations will be taken into account, their contribution to the overall uncertainty in agriculture might be smaller than computed in the present analysis. Nonetheless, these parameters should be prioritized in future research programs. Some other factors associated with great uncertainties, such as volatilization of NO_x, have very limited influence on overall uncertainties. This occurs whenever the absolute contributions are small due to low activities.

In all emission sources activity data are more certain than emission factors. This is especially true for methane since activity data are animal livestock populations that are estimated with high precision. Since changes in emissions between the base year and the submission year rely mainly on changes in activity data (livestock populations, amount of manure and mineral fertilizers) (FOEN 2007), emission trends should be associated with lower uncertainties than emission levels. Assuming that the relative uncertainties for each category are within the cited range but constant over time, the trend in agricultural emissions is reliable (Leifeld and Fuhrer 2005).

Some uncertainty ranges are asymmetrical. Asymmetries reflect often the distribution of different literature values or are given by the authors without further explanations. In many cases the impossibility or the high improbability of negative values might be a reason. The skewed probability distribution is especially marked for the emission factors for N_2O emissions from manure management and indirect N_2O emissions from agricultural soils. In the later case this is probably due to the highly variable environmental conditions of the sites where nitrogen is deposited after it is volatilized or lost through leaching and run off. Some of these conditions might be very favorable for nitrous oxide emissions explaining the high values on the upper range.

The uncertainty analysis presented here should be understood as a momentary estimate. Uncertainties of individual parameters such as MS, $Frac_{NH3}$, N_{ex} or GE can alter over time as agricultural practices change. If the respective inventory data are not adapted simultaneously, the accuracy might decrease due to systematic errors. This fact underlines the need to refine the greenhouse gas accounting model permanently in order to keep track with agricultural development in Switzerland.

Comparison with other countries

Table 8 shows the uncertainties of agricultural greenhouse gas emissions in the national inventories of the European Community and Switzerland. The estimates differ widely between the individual countries especially for N_2O emissions. The Swiss uncertainty ranges for methane emissions are situated in a middle position of the range. For nitrous oxide, however, the estimates presented in this document are clearly on the lower end of the scale. Only a few countries have lower uncertainties for N_2O from manure management and agricultural soils. Reasons for the differences below have not yet been subjected to further investigation and are not clear.

Table 8 Relative uncertainties of agricultural greenhouse gas emissions in the inventories of the European Community and Switzerland (all data except Switzerland from Leip 2007)

Member State	4A Enteric Fermentation CH4 %	4B Manure Management CH4 %	4B Manure Management N2O %	4D Agricultural soils N2O %
Austria	22.4	50.1	100.5	100.0
Belgium	40.3	41.2	90.6	252.0
Denmark	12.8	100.5	100.5	21.0
Finland	16.6	15.7	81.3	115.0
France	40.3	50.2	50.2	200.0
Germany	18.6	28.9	75.3	120.0
Greece	30.4	50.2	111.8	104.0

Ireland	22.6	11.1	100.6	58.0
Italy	28.3	102.0	102.0	67.0
Luxembourg	25.0	50.0	114.4	139.0
Netherlands	19.6	70.4	100.5	83.0
Portugal	38.4	82.0	106.8	234.0
Spain	11.4	11.4	101.3	80.0
Sweden	25.5	53.9	53.9	71.0
United Kingdom	22.4	31.6	425.9	436.0
Switzerland	**18.3**	**54.5**	**63.1**	**68.5**
EU-15*	**17.5**	**28.3**	**58.9**	**120.3**
No correlation	10.8	18.0	37.5	79.5
Full correlation	26.0	43.1	100.9	167.3
Only 4D uncorrelated	26.0	43.1	100.9	79.5
Only 4D correlated	10.8	18.0	37.5	167.3

***most probable correlation level**

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Annex

Error propagation equations

Calculation of Tier1 uncertainties is based on the error propagation equations provided in A.1.4.3.1 (Error Propagation Equations) in the Annex 1 (Conceptual Basis for Uncertainty Analysis) of GPG2000. Equation 5.2.1. in the IPCC Guidelines (2000) can be used to estimate the uncertainty of a product of several quantities:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

U_{total} = percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage)

U_i = percentage uncertainty associated with each of the quantities, i=1, …, n

Where uncertain quantities are to be combined by addition or subtraction, IPCC equation 5.2.2 (IPCC 2000) can be used.

$$U_E = \frac{\sqrt{(U_1 * E_1)^2 + (U_2 * E_2)^2 + \cdots + (U_n * E_n)^2}}{|E_1 + E_2 + \cdots + E_n|}$$

U_E = percentage uncertainty of the sum

U_i = percentage uncertainty associated with source/sink i

E_i = emission/removal estimate for source/sink i

Example

In the case of CH_4 emissions from manure management the calculation looks as follows:

$$EF = VS * 365\ days/y * B_0 * 0.67\ kg/m^3 * \sum_{jk} MCF_{jk} * MS_{jk}$$

Uncertainties for VS, B_0 and MCF_{jk}*MS_{jk} are accounted for. Therefore we find:

$$U_{EF} = \sqrt{U_{VS}^2 + U_{B_0}^2 + U_{MCF*MS}^2}$$

U_{EF} = total uncertainty of the emission factor

U_{VS} = uncertainty of VS

U_{B0} = uncertainty of B_0

U_{MCF*MS} = uncertainty of MCF*MS

This calculation is done once for the lower uncertainty level and once for the upper uncertainty level. For the year 2005 the uncertainty values have been:

U_{VS_low} = 16.0 U_{VS_high} = 12.0

U_{B0_low} = 15.5 U_{B0_high} = 14.9

U_{MCF*MS_low} = 50.0 U_{MCF*MS_high} = 50.0

Therefore:

$$U_{EF\_low} = \sqrt{16.0^2 + 15.5^2 + 50.0^2} = \sqrt{256.0 + 239.9 + 2500.0} = \sqrt{2995.9} = \underline{54.7}$$

$$U_{EF\_high} = \sqrt{12.0^2 + 14.9^2 + 50.0^2} = \sqrt{144.0 + 222.0 + 2500.0} = \sqrt{2866.0} = \underline{53.5}$$

Now the lower uncertainty of the emission factor can be combined with the uncertainty of the activity data to get the lower uncertainty range for methane emission from manure management U_{CH4Man_low}:

$$U_{CH_4Man\_low} = \sqrt{54.7^2 * 6.4^2} = \sqrt{3033.4} = \underline{55.1}$$

$$U_{CH_4Man\_high} = \sqrt{53.5^2 * 6.4^2} = \sqrt{2903.2} = \underline{53.9}$$