# Comparison of different calculation procedures and emission factors in the manure management systems of swine production

Edivan Cherubini[1,2,*], Vamilson Prudêncio da Silva Jr[3], Guilherme M. Zanghelini[1,2],
Rodrigo A. F. Alvarenga[1,2,4], Bruno M. Galindro[2], Cristiane M. de Léis[5],Sebastião R. Soares[1]

[1] Universidade Federal de Santa Catarina, Life Cycle Assessment Research Group (CICLOG).
[2] EnCiclo Soluções Sustentáveis
[3] Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (EPAGRI), Florianópolis, Brazil.
[4] Funded by Programa Ciência Sem Fronteiras and CAPES / Brazil
[5]Universidade de São Paulo (USP).
[*] *Corresponding author. E-mail: edivan.cherubini@posgrad.ufsc.br*

**ABSTRACT**

The aim of this paper was to perform a sensitivity analysis of different calculation procedures and emission factors to estimate methane ($CH_4$) and nitrous oxide ($N_2O$) emissions applied to a case study of slurry management of swine production in southern Brazil. The manure management system (MMS) defined was the slurry tank without a natural crust cover. The calculation procedures used were: (i) GES'TIM; (ii) Static mass flow model from Hutchings et al. (2013); (iii) Calculation procedure described by Hamelin et al. (2011); and three variations of the IPCC guideline (IPCC 2006): (iv) IPCC with European default parameters, IPCC (DF-EU); (v) IPCC with Latin American default parameters, IPCC (DF-LA); (vi) IPCC with parameters adjustment to represent Brazilian reality, IPCC (BR). Finally, it was proposed a model guide for future estimations of MMS emissions in Brazil for slurry tanks (Baseline). Results showed significant differences between the upper and lower $CH_4$ and $N_2O$ estimative.

Keywords: Emissions, calculation procedure, emission factor, $CH_4$, $N_2O$.

## 1. Introduction

Life cycle assessment (LCA) is a methodology widely used to predict the environmental profile of livestock and other agricultural products. Studies from literature (Basset-Mens; van der Werf 2005; Flysjö et al. 2011; Reckmann et al. 2013; Prudêncio da Silva et al. 2010; Prudêncio da Silva et al. 2014; Williams et al. 2006) have shown that the environmental impacts of these activities are mainly due to ammonia ($NH_3$), nitrous oxide ($N_2O$), carbon dioxide ($CO_2$), nitrate ($NO_3$) and methane ($CH_4$) emissions from crops cultivation by fertilizer usage, enteric fermentation from animal rearing, and manure management systems (MMS).

Regarding to swine production, manure handling is an important stage to mitigate the environmental impacts of this activity. According to Chadwick et al. (2011), the MMS selected by the farmers has a direct influence on the magnitude of gaseous losses and consequently the potential to reduce those emissions. For climate change, MMS represents 18-26% of total $CO_2$ eq. emissions (Kool et al 2009; Nguyen et al. 2011) which highlights the importance of having reliable data for $CH_4$ and $N_2O$ emissions.

However, these emissions are difficult to be measured on field because of economic costs and the long period to measure it (Javon 2012). Therefore, many LCA studies uses mathematical models and emission factors (EF) to estimate $CH_4$, $N_2O$, $NO_3$ and $NH_3$ (Basset-Mens et al. 2007; Dalgaard et al. 2008; Flysjö et al. 2011; Nguyen et al. 2010; Prudêncio da Silva et al. 2014; Ruviaro et al. 2014; ten Hoeve et al. 2014; Wesnæs et al. 2009). There are a few calculations procedures and EFs in literature to estimate these emissions (Deltour et al. 2009; Gac et al. 2007; Hamelin et al. 2011; Hutchings et al. 2013; IPCC 2006; Rigolot et al. 2010), which may generate different results. Thus, it is not easy to choose the procedure and EF that better applies in the product system under analysis since these emissions have a high variability due to differences in system production, temperature, management, soil type, manure composition, windspeed and rainfall (Mkhabela et al. 2009, Sommer et al. 2009).

The aim of this paper was to perform a sensitivity analyzes of different calculation procedures and EFs to estimate $CH_4$ and $N_2O$ emissions applied to a case study of slurry management of swine production in southern Brazil. In addition, we also proposed a calculation procedure for the Brazilian swine production based on the mathematical models and EFs reviewed.

## 2. Methods

The manure management system (MMS) defined was the slurry tank without a natural crust cover with a minimum storage period of 120 days with the land application of the stabilized manure (Fatma 2009). This system represents the most common MMS used in Brazil (Brazilian agroindustry; Higarashi et al. 2013; Kunz et al. 2005). The functional unit (FU) was the manure management generated to produce 1 ton of swine live weight, with the system boundaries set from the manure ex-house until its application on field. Only the emissions of $CH_4$ and $N_2O$ produced from manure were considered. The characterization factors were according to IPCC (2007).

The calculation procedures used were: (i) GES'TIM (Deltour et al. 2009); (ii) Static mass flow model from Hutchings et al. (2013); (iii) Calculation procedure described by Hamelin et al. (2011); and three variations of the IPCC guideline (IPCC 2006): (iv) IPCC with European default parameters, IPCC (DF-EU); (v) IPCC with Latin American default parameters, IPCC (DF-LA); (vi) IPCC with parameters adjustment to represent Brazilian reality, IPCC (BR). Finally, it was proposed a model guide for future estimations of MMS emissions in Brazil for slurry tanks (Baseline). The input parameters for the mathematical models are shown in Table 1. We assumed a slurry tank without a natural crust cover, therefore we did not consider the direct $N_2O$ emissions in storage (IPCC 2006).

Table 1. Input parameters for the mathematical models.

| Parameters/Models | GES'TIM | Hutchings et al. (2013) | Hamelin et al. (2011) | IPCC (DF-EU) | IPCC (DF-LA) | IPCC (BR) | Baseline |
|---|---|---|---|---|---|---|---|
| Sows (no·FU$^{-1}$) | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 |
| Piglets (no·FU$^{-1}$) | 8.40 | 8.40 | 8.40 | 8.40 | 8.40 | 8.40 | 8.40 |
| Swine (no·FU$^{-1}$) | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| Sows (days·FU$^{-1}$) | 142 | 142 | 142 | 142 | 142 | 142 | 142 |
| Piglets (days·FU$^{-1}$) | 38 | 38 | 38 | 38 | 38 | 38 | 38 |
| Swine (days·FU$^{-1}$) | 112 | 112 | 112 | 112 | 112 | 112 | 112 |
| Manure$_{sow}$ (m$^3$·FU$^{-1}$) | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 |
| Manure$_{piglet}$ (m$^3$·FU$^{-1}$) | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Manure$_{swine}$ (m$^3$·FU$^{-1}$) | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Nex$_{sow}^{b}$ (kg N·FU$^{-1}$) | n.a | 1.61 | 1.64 | 2.47 | 3.23 | 1.59 | 1.61 |
| Nex$_{piglet}^{b}$ (kg N·FU$^{-1}$) | n.a | 1.33 | 1.36 | 3.86 | 11.88 | 1.46 | 1.33 |
| Nex$_{swine}^{b}$ (kg N·FU$^{-1}$) | n.a | 17.49 | 17.89 | 57.12 | 175.84 | 17.96 | 17.49 |
| VS$_{sow}^{b}$ (kg VS·FU$^{-1}$) | n.a | 26.52 | 26.52 | 21.95 | 14.31 | 26.52 | 26.52 |
| VS$_{piglet}^{b}$ (kg VS·FU$^{-1}$) | n.a | 13.22 | 13.22 | 95.76 | 95.76 | 13.22 | 13.22 |
| VS$_{swine}^{b}$ (kg VS·FU$^{-1}$) | n.a | 174.23 | 174.23 | 268.80 | 268.80 | 174.23 | 174.23 |

[a] Not applied.

[b] VS = volatile solids; Nex = nitrogen excreted.

The methodological guide GES'TIM was elaborated to be reference for the quantification of gas emissions of livestock, soil, energy consumptions, inputs and compensation by carbon storage. The guide provides a homogenized methodological frame, with EFs that are representative of the French agricultural production sectors (Deltour et al. 2009). This method estimate $CH_4$ and $N_2O$ emissions from manure storage and application in field. Detailed information on GES'TIM model can be found in Deltour et al. (2009), while input parameters considered in this paper are summarized in Table 2. Constant parameters and those that we assume as the same as it was described in the original calculation procedures were not added in this paper. For more details, see Deltour et al. (2009); Hutchings et al. (2013); Hamelin et al. (2011) and IPCC (2006).

In respect to GES'TIM model, we considered the same EFs for $CH_4$ and $N_2O$ of Deltour et al. (2009) which implicitly assumes that the emissions from swine production in Brazil have the same EFs from swine production in France. These assumptions were also made by Prudêncio da Silva et al. (2014) for broiler chicken production. Therefore, to interpret our results, it should be in mind that there are some differences in the swine production in Brazil and France, such as: in France the manure is stored for some period in housing while in Brazil the manure goes directly to the slurry tanks which decreases the $CH_4$ emissions in housing (not considered in this paper) but could result in more emissions in storage since more volatile solids (VS) are available for decomposition. Another difference is the period of manure storage, i.e., in Brazil this period is 120 days while in France this period can be somewhat higher (Deltour et al. 2009).

The calculation procedure developed by Hutchings et al. (2013) describes the static mass flow of the manure nutrients, i.e. nitrogen and phosphorus (not considered in this paper) and the emissions of $NH_3$, $N_2O$, $N_2$, and $NO_3$. Therefore, to estimate $CH_4$ emissions we used the same model and parameters used in the IPCC (BR). In Hutchings model, the indirect $N_2O$ emissions from $NH_3$-N and $NO_x$-N volatilization are not considered.

The calculation procedure from Hamelin et al. (2011) is based on IPCC (2006), however the authors included the estimative of $N_2$-N and $NO_x$-N and consider a different equation to estimate the $NH_3$-N loss in storage and manure application in field.

The scenarios following the IPCC guide differs from each other by the input parameters considered in the equation used to estimate the excreted N (Nex), and the VS content in manure and methane producing capacity ($B_0$) used to estimate $CH_4$ emissions. For IPCC (BR) different EFs for the $N_2O$ emission in field and the N loss due to $NH_3$-N volatilization were also applied (Table 2).

Table 2. Input parameters to estimate $CH_4$ and $N_2O$.

| **Parameters/Models** | **GES'TIM** | **Hutchings et al. (2013)** | **Hamelin et al. (2011)** | **IPCC (DF-EU)** | **IPCC (DF-LA)** | **IPCC (BR)** | **Baseline** |
|---|---|---|---|---|---|---|---|
| *Input parameters for $CH_4$ emissions in storage/field* | | | | | | | |
| $B_0$ (m$^3$ $CH_4$ (kg VS excreted)$^{-1}$) | n.a[a] | 0.29 | 0.29 | 0.45 | 0.29 | 0.29 | 0.29 |
| MCF (kg·kg$^{-1}$) | n.a | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 |
| Conversion factor of m$^3$ $CH_4$ to kg $CH_4$ (kg·m$^{-3}$) | n.a | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 |
| $EF_{CH4\_St}$ (g $CH_4$·m$^{-3}$·d$^{-1}$) | 61.81 | n.a | n.a | n.a | n.a | n.a | n.a |
| Storage period (days) | 120 | n.a | n.a | n.a | n.a | n.a | n.a |
| *Input parameters for $N_2O$ emissions in storage/field* | | | | | | | |
| $E_1$[b] | n.a | 0 | 0 | 0 | 0 | 0 | 0 |
| $E_2$[c] | n.a | 0.085[d] | 0.05[d] | 0.48 | 0.48 | 0.05[d] | 0.085[d] |
| $E_3$[e] | n.a | n.a | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| $E_4$[f] | n.a | 0.256[g] | 0.149[g] | 0.48 | 0.48 | 0.05[d] | 0.256[g] |
| $E_5$[h] | n.a | 0.013[i] | 0.013[i] | 0.01 | 0.01 | 0.013[i] | 0.013[i] |
| $E_6$[j] | n.a | n.a | 0.0075 | 0.0075 | 0.0075 | 0.0075 | 0.0075 |
| $EF_{CH4\_Field}$ (g $CH_4$·ha$^{-1}$·m$^{-3}$·d$^{-1}$) | 0.078 | n.a | n.a | n.a | n.a | n.a | n.a |
| $EF_{N2O\_Field}$ (g $N_2O$·ha$^{-1}$·m$^{-3}$·d$^{-1}$) | 1.632 | n.a | n.a | n.a | n.a | n.a | n.a |
| Application rate (m$^3$·ha$^{-1}$) | 38.8 | n.a | n.a | n.a | n.a | n.a | n.a |
| $Area_{sow/piglet}$ (ha) | 0.01 | n.a | n.a | n.a | n.a | n.a | n.a |
| $Area_{swine}$ (ha) | 0.14 | n.a | n.a | n.a | n.a | n.a | n.a |

[a] Not applied.

[b] Emission factor for direct $N_2O$ emissions in storage without a natural crust cover ($EF_3$ in IPCC 2006, Table 10.21, chapter 10).

[c] Emission factor for $NH_3$ emissions in storage ($Frac_{GasMS}$ in IPCC 2006, Table 10.22, chapter 10 / NH3StoreRate in Hutchings et al. 2013 / $NH_3$-N in Hamelin et al. 2011).

[d] Values from Basset-Mens; van der Werf (2005), 0.05 kg $NH_3$-N (kg N)$^{-1}$ or 0.085 kg $NH_3$-N (kg TAN)$^{-1}$.

[e] Emission factor for indirect ($NH_3$-N+$NO_x$-N) $N_2O$ emissions in storage/field ($EF_4$ in IPCC 2006, Table 11.3, chapter 11).

[f] Emission factor for $NH_3$ emissions in field ($Frac_{lossMS}$ in IPCC 2006, Table 10.23, chapter 10 / NH3FieldRate in Hutchings et al. 2013 / $NH_3$-N in Hamelin et al. 2011).

[g] Values from Basso (2003), Basso et al. (2004), 0.149 kg $NH_3$-N (kg N)$^{-1}$ or 0.256 kg $NH_3$-N (kg TAN)$^{-1}$.

[h] Emission factor for direct $N_2O$ emissions in field ($EF_1$ in IPCC 2006, Table 11.1, chapter 11).

[i] Values from Gonzatto (2012), 0.013 kg $N_2O$-N (kg N)$^{-1}$.

[j] Emission factor for indirect ($NO_3$ leaching) $N_2O$ emissions in field ($EF_5$ in IPCC 2006, Table 11.3, chapter 11).

## 3. Results

The results showed that IPCC (DF-LA) has the highest $CO_2$ eq. emissions while lower emissions were estimated through the calculation procedure described by Hutchings et al. (2013), see Table 3 and Figure 1.

Table 3. Results per FU (percentage of the contribution per column are given in parentheses).

| **Emissions per source/Models** | **GES'TIM** | **Hutchings et al. (2013)** | **Hamelin et al. (2011)** | **IPCC (DF-EU)** | **IPCC (DF-LA)** | **IPCC (BR)** | **Baseline** |
|---|---|---|---|---|---|---|---|
| *Emissions in storage (in kg $CO_2$ eq.)* | | | | | | | |
| *$CH_4$* | 865.3 (82.7) | 436.5 (81.7) | 436.5 (69.3) | 1223.6 (77.1) | 773.0 (41.5) | 436.5(73.0) | 436.5 (75.6) |
| *direct $N_2O$* | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) | 0.0 (0.0) |
| *indirect ($NH_3$-N+$NO_x$-N) $N_2O$* | n.c[a] | n.c | 4.9 (0.8) | 142.6 (9.0) | 429.2 (23.0) | 4.9 (0.8) | 5.5 (0.9) |
| *Emissions in field (in kg $CO_2$ eq.)* | | | | | | | |
| *$CH_4$* | 0.1 (0.0) | n.c | n.c | n.c | n.c | n.c | n.c |
| *direct $N_2O$* | 181.6 (17.3) | 97.7 (18.3) | 120.8 (19.2) | 154.5 (9.7) | 465.0 (24.9) | 121.5 (20.3) | 97.7 (16.9) |
| *indirect ($NH_3$+Nox) $N_2O$* | n.c | n.c | 51.5 (8.2) | 30.9 (1.9) | 93.0 (5.0) | 13.9 (2.3) | 15.2 (2.6) |
| *indirect ($NO_3$ leaching) $N_2O$* | n.c | n.c | 16.0 (2.5) | 34.8 (2.2) | 104.6 (5.6) | 21.0 (3.5) | 22.3 (3.9) |
| **Total** | **1046.9 (100.0)** | **534.2 (100.0)** | **629.7 (100.0)** | **1586.4 (100.0)** | **1864.8 (100.0)** | **597.9 (100.0)** | **577.1 (100.0)** |

[a] Not considered.

$CH_4$ emissions in storage contributed with 41.5-82.7% of total $CO_2$ eq. Indirect $N_2O$ emissions in storage had a contribution of 0.8-23.0% of total $CO_2$ eq. Only in GES'TIM model the $CH_4$ emissions due to manure application in field were estimated, however this emission had minor contributions (0.005%). Direct $N_2O$ emissions in manure application represented 9.7-24.9% while the indirect $N_2O$ emissions (i.e. from volatilization of $NH_3$-N+$NO_X$-N and $NO_3$ leaching) participated with 1.9-8.2% of total emissions.

## 4. Discussion

Higher climate change potential was observed in IPCC (DF-LA), as displayed in Figure 1, greater $CO_2$ eq. emissions for this calculation procedure was mainly due to direct and indirect $N_2O$ emissions. This occurred because in this model the default values for N excretion rate used in Equation 10.30 from IPCC (2006) are very high, which results in higher values for the excreted N (Nex in Table 1) when compared to the other models. Comparing to the default values for Western European the N rate for Latin American countries are 3 and 1.3 times (values not showed) higher for the market and breeding swine, respectively. The greater amount of Nex in IPCC (DF-LA) were also the main responsible for higher indirect $N_2O$ emissions due to $NO_3$ leaching in this model. Another issue that resulted in greater indirect $N_2O$ emissions in IPCC (DF-LA) and IPCC (DF-EU) was the default values for N loss due to volatilization of $NH_3$-N and $NO_x$-N considered in IPCC (2006). Ammonia and the nitrogen oxides emissions have greater influence in the results due to the nutrient balance and the indirect $N_2O$ emissions

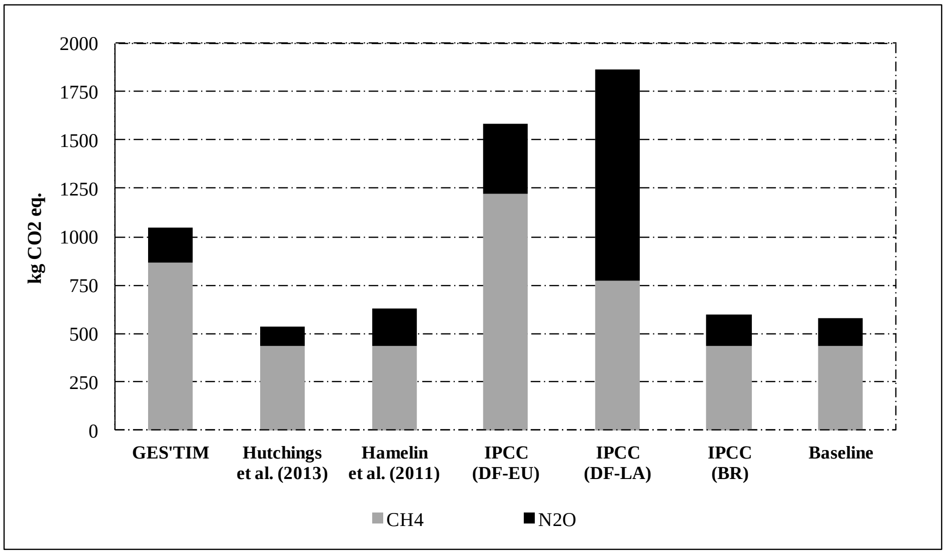

Figure 1. Comparison of mathematical models for $CH_4$ and $N_2O$ emissions in manure management.

The higher $CH_4$ emissions in storage stage for IPCC (DF-EU) (Figure 1), compared to the other models, were mainly due to the methane producing capacity ($B_0$ in Table 1). Most probably, this is also the reason for greater amounts of $CH_4$ emitted in GES'TIM model. The $B_0$ for Latin American countries is lower than for Western European (IPCC 2006). Although we assume the same $B_0$ (i.e. 0.29 $m^3$ $CH_4$ (kg VS excreted)$^{-1}$) in IPCC (DF-LA), Hutchings et al. (2013), Hamelin et al. (2011), IPCC (BR) and Baseline models, IPCC (DF-LA) had higher $CH_4$ emissions due to the VS content used as input parameter.

Regarding the proposed model to estimate $CH_4$ and $N_2O$ emissions from the MMS in Brazil, it can be noticed a need for a more site-specific data for the EF used for direct $N_2O$ emissions in storage stage and for the constant input parameters used to estimate the proportion of organic N mineralized in slurry tanks and the coefficient factor used for $NO_3$ leaching emissions.

## 5. Conclusion

The results showed great differences for both emissions per FU according to the calculation procedure used. The model with lower $CO_2$ eq. emissions was from Hutchings et al. (2013), it showed a reduction of 71.4% when compared to the IPCC (DF-LA). $CH_4$ emissions in Baseline, IPCC (BR), Hutchings et al. (2013), and Hamelin et al. (2011) were 64.3% lower than in IPCC (DF-EU). While for $N_2O$ emissions, the calculation procedure described by Hutchings et al. (2013) represented a 91.1% of reduction when compared to IPCC (DF-LA). The range in terms of $CO_2$ eq. emissions for $CH_4$ was 436.5-1223.6 kg while for $N_2O$ was 97.7-1091.8 kg.

For $CH_4$ emissions, the differences were due to the methane producing capacity ($B_0$) and VS content. For $N_2O$ the amount of excreted N considered and the N loss due to volatilization of $NH_3$-N and $NO_x$-N were the main reasons that significantly increased these emissions in IPCC (DF-EU) and IPCC (DF-LA).

Analyzing the models and based on our judgment, the calculation procedure used in Hutchings et al. (2013) seemed to be the preferable because it considers the effect of the mineralized organic N in the emissions, allowing future comparisons with other MMS, such as composting and biodigester. We suggest that future LCA studies also consider different options to estimate the $CH_4$ and $N_2O$ emissions. Regarding to the Brazilian model proposed in this study, there is a need to develop site-specific data.

## 6. References

Basset-Mens C, van der Werf HMG (2005) Scenario-based environmental assessment of farming systems: the case of pig production in France. Agric. Ecosyst. Environ. 105:127-144

Basset-Mens C, van der Werf HMG, Robin P, Morvan Th, Hassouna M, Paillat JM, Vertès F (2007) Methods and data for the environmental inventory of contrasting pig production systems. J Clean Prod 15:1395-1405

Basso CJ (2003) Perdas de nitrogênio e fósforo com aplicação no solo de dejetos líquidos de suínos. 125p. PhD thesis – Universidade Federal de Santa Maria. (In Portuguese)

Basso CJ, Ceretta CA, Pavinato PS, Silveira MJ (2004) Perdas de nitrogênio de dejeto líquido de suínos por volatilização de amônia. Cienc Rural 34:1773-1778

Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B, Misselbrook T (2011) Manure management: Implications for greenhouse gas emissions. Anim Feed Sci Tech 166-167:514-531

Dalgaard R, Schmidt J, Halberg N, Christensen P, Thrane M, Pengue WA (2008) LCA of soybean meal. Int J Life Cycle Ass 13:240-254

Deltour L, Cariolle M, Dollé JB, Espagnol S, Flénet F, Guigand N, Lagadec S, Le Gall A, Lellahi A, Malaval C, Ponchant P (2009) GES'TIM – Guide méthodologique pour l'estimation des impacts des activités agricoles sur l'effet de serre. Rapport Version 1. 143 p. Institut de l'Elevage, Paris.

Fatma (2009) Fundação do Meio Ambiente. *Instrução Normativa n.º 11*, de 2009. Available from: http://www.fatma.sc.gov.br/images/stories/Instrucao%20Normativa/IN%2011/in_11.pdf [Accessed 10.09.2013]

Flysjö A, Henriksson M, Cederberg C, Ledgard S, Englund J-E (2011) The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. Agr Syst 104:459-469

Gac A, Béline F, Bioteau T, Maguet K (2007) A French inventory of gaseous emissions (CH4, N2O, NH3) from livestock manure management using a mass-flow approach. Livest Sci 12:252-260

Gonzatto R (2012) Injeção de dejetos de suínos no solo em Plantio direto associada a um inibidor de Nitrificação: efeito nas emissões de óxido Nitroso e amônia. 94 p. Master Dissertation – Universidade Federal de Santa Maria. (In Portuguese)

Hamelin L, Wesnæs M, Wenzel H, Petersen BM (2011) Environmental consequences of future biogas technologies based on separated slurry. Environ Sci Technol 45:5869-5877

Higarashi MM, Nicoloso RS, Oliveira PAV, Mattei RM (2013) Greenhouse gases emissions from deep pit stored swine manure in southern Brazil. In: III Simpósio Internacional sobre Gerenciamento de Resíduos Agropecuários e Agroindustriais – SIGER, São Pedro-SP, Brazil.

Hutchings NJ, ten Hoeve M, Jensen R, Brunn S, Søtoft LF (2013) Modelling the potential of slurry management technologies to reduce the constraints of environmental legislation on pig production. J Environ Manage 130:447-546

IPCC (2006) Intergovernmental Panel on Climate Change. IPCC Guidelines for National Greenhouse Gas Inventories: Volume 4, Agriculture, Forestry and Other Land Use. Available from: www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/.pdf [Accessed 01.02.2012]

IPCC (2007) Intergovernmental Panel on Climate Change. Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Chapter 2. United Kingdom: Cambridge University Press Available from: http://www.ipcc.ch/ipccreports/ar4-wg1.htm [Accessed 28.08.2011]

Javon C (2012) Application d'une Méthode Simplifiée en vue d'acquérir des références françaises d'émissions de gaz à effet de serre et d'ammoniac en bâtiments bovin laitier pour des conduites d'élevage contrastées. Agrocampus Quest, CFR Rennes, p.73.

Kool A, Blonk H, Ponsioen T, Sukkel W, Vermeer H, de Vries J, Hoste R (2009) Carbon footprints of conventional and organic pork: Assessment of typical production systems in the Netherlands, Denmark, England and Germany. Blonk Milieu Advies BV. Netherland, November.

Kunz A, Higarashi MM, Oliveira PAV (2005) Tecnologias de manejo e tratamento de dejetos de suínos estudadas no Brasil. Cad Ciencia Tecnol 22:651-665

Mkhabela MS, Gordon R, Burton D, Smith E, Madani A (2009) The impact of management practices and meteorological conditions on ammonia and nitrous oxide emissions following application of hog slurry to forage grass in Nova Scotia. Agr Ecosyst Environ 130:41-49

Nguyen TLT, Hermansen JE, Mogensen L (2010) Fossil energy and GHG saving potentials of pig farming in the EU. Energ Policy 38:2561-2571

Prudêncio da Silva V, van der Werf HMG, Soares SR, Spies A (2010) Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. J Environ Manage 91:1831-1839

Prudêncio da Silva V, van der Werf HMG, Soares SR, Corson MS (2014) Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. J Environ Manage 133:222-231

Reckmann K, Traulsen I, Krieter J (2013) Life Cycle Assessment of pork production: A data inventory for the case of Germany. Livest Sci 157:586–596

Rigolot C, Espagnol S, Robin P, Hassouna M, Béline F, Paillat JM, Dourmad JY (2010) Modelling of manure production by pigs and NH3, N2O and CH4 emissions. Part II: effect of animal housing, manure storage and treatment practices. Animal 4:1413-1424

Ruviaro CF, Léis CM, Lampert VN, Barcellos JOJ, Dewes H (2014) Carbon footprint in different beef production systems on a southern Brazilian farm: a case study. J Clean Prod in press:1-9

Sommer SG, Olesen JE, Petersen SO, Weisbjerg MR, Valli L, Rohde L, Béline F (2009) Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. Glob. Change Biol 15:2825–2837

ten Hoeve M, Hutchings NJ, Peters GM, Svanström M, Jensen LS, Brunn S (2014) Life cycle assessment of pig slurry treatment technologies for nutrient redistribution in Denmark. J Environ Manage 132:60-70

Wesnæs M, Wenzel H, Petersen BM (2009) Life cycle assessment of slurry management technologies. Environmental project no. 1298 Danish Ministry of the Environment, Environmental Protection Agency. Available from: http://www2.mst.dk/udgiv/publications/2009/978-87-92548-20-7/pdf/978-87-92548-21-4.pdf [Accessed 28.09.2013]

Williams AG, Audsley E, Sandars DL (2006) Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities. Cranfield Unverstity and Defra, Bedford [online] Available from: www.silsoe.cranfield.ac.uk.

# Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6