**The Canadian Society for Bioengineering**
*The Canadian society for engineering in agricultural, food, environmental, and biological systems.*

**La Société Canadienne de Génie Agroalimentaire et de Bioingénierie**
*La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement*

CSBE | SCGAB

**Paper No. CSBE09-512**

# Baseline scenario for gas, odor, dust and particulate matter emissions from swine buildings in Québec-Part I : emissions inventory

**L. Hamelin*[1,2], S. Godbout[1], S.P. Lemay[1]**

[1]Research and Development Institute for the Agri-Environment (IRDA), 2700 Einstein, Quebec (QC), G1P 3W8.

[2]Institute of Chemical Engineering, Biotechnology and Environmental Technology (KBM), Faculty of Engineering, University of Southern Denmark, Campusvej 55, 5230 Odense M., Denmark.

*Corresponding author. Email : loha@kbm.sdu.dk

**Written for presentation at the**
**CSBE/SCGAB 2009 Annual Conference**
**Rodd's Brudenell River Resort, Prince Edward Island**
**12-15 July 2009**

***Abstract.*** *A rapidly changing and increasing livestock production has entailed, worldwide, fruitful efforts in terms of innovations and technologies in order to minimize the environmental impacts of meat production at both the local, regional and global scale. This is especially true for the pig sector. This context of innovation has brought up the need, among the leading stakeholders of the pig sector of the province of Quebec, to assess and compare the environmental performances of the technologies and practices implemented in-barn. This means that the progresses and shortcomings need to be measured and compared to a reference situation. The aim of this project was to define such a baseline scenario for the province of Quebec as regarding gas, odor, dust and particulate matter emissions for the specific case of the pig building, looking at year 2006 as the "reference year". All stages of production of a typical farrow-to-finish farm were considered, and such a "typical" Quebec barn was defined. This study details a methodology based on emissions inventory in order to define this baseline scenario, presents the results of the application of this methodology and discusses its main limitations.*

**Keywords.** Swine, barn, gas, odor, emission, inventory, baseline.

## 1. Introduction

A rapidly changing and increasing livestock production has entailed, worldwide, fruitful efforts in terms of innovations and technologies in order to minimize the environmental impacts of pig production at both the local, regional and global scale. According to Oenema et al. (2005), the main solution in order to reverse the trend of increasing emissions from animal production systems lies in the management of animal wastes, the others parameters being too difficult to control. Yet, an important part of the manure management takes place in animal facilities. In Quebec, the pig building has been particularly targeted by such technological innovations. Among the different technologies investigated and/or tested in Quebec barns are the in-barn manure separation technologies (Lachance et al., 2005; Guimont et al., 2007; Lemay et al., 2007), odors and ammonia reducing technologies such as optimized diet composition (Godbout and Lemay, 2006) and air cleaning systems (Lemay et al., 2008), improvements as regarding floor design and building materials (Pelletier et al., 2005; Hamelin, 2009) or dust-reducing techniques (Godbout et al., 2001).

The substances targeted by technological improvements for swine houses are : carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), ammonia ($NH_3$), dust, odors and particulate matters ($PM_{10}$ and $PM_{2.5}$). It is desired to decrease the $CO_2$, $CH_4$ and $N_2O$ emissions from pig barns since these gases are greenhouse gases (GHG) and therefore contribute to global warming. In fact, as reported by Steinfeld et al. (2006), livestock activities contribute to nearly 80 % of the total anthropogenic GHG emissions from the agricultural sector. Ammonia is recognized as one of the gaseous emissions from animal production sites having the largest impacts on human health and agroecosystems (Aarnink et al., 1996; Ni et al., 2000), contributing, among others, to soil and water acidification, loss of biodiversity, eutrophication and indirectly to climate change by further transformation into $N_2O$ (Oenema et al., 2005). In Canada, agriculture accounted for 89 % of the total $NH_3$ emissions emitted in the country in 2007, among which 66 % were ascribed to livestock production and 23 % to fertilization activities (Environment Canada, 2009). Odors, as the largest public concern in animal production (Blanes-Vidal et al., 2009), is a priority as regarding technological in-barn innovation. Dust and particulate matter are also substances of concern for their role as regarding health of workers and animals and as a potential vector for odors from the farm to the neighbourhood.

The formation and emission of these substances from pig facilities is influenced by several factors. These factors, as detailed by Blanes-Vidal et al. (2008), are mainly related to animals (e.g. genetics, diet, number and weight, animal activity and behaviour), wastes (e.g. handling, treatment, floor system), and environment (e.g. indoor and outdoor temperature, ventilation flow). However, these factors are seldom specified in published literature where emissions from swine houses are measured (Jungbluth et al., 2001; Arogo et al., 2003). This makes it difficult to compare the emissions reduction obtained from a given mitigation technique to a reference baseline

In Quebec, most of the gas, odors, dust and particulate matter mitigation technologies have been assessed experimentally or in a specific barn as regarding their environmental performance, but how effective would they be if they are implemented in a typical Quebec farm? Answering this question involve that the progresses and shortcomings need to be measured and compared to a reference situation. This study intends to provide a foundation in order to define such a reference situation.

The aim of this project therefore consisted to define a baseline scenario for the province of Quebec as regarding gas, odors, dust and particulate matter emissions from “typical” pig facilities, looking at year 2006 as the “reference year”. This publication describes and discusses the methodology used to establish such a baseline and presents its preliminary results.

# 2. Materials and Methods

## *2.1 Determination of a representative "typical Quebec pig farm"*

As a first step in the determination of a baseline scenario as regarding gas and odors emissions from Quebec's pig barns, a "typical" pig farm needed to be defined for the reference year selected, i.e. 2006. In fact, such a "reference barn" is the very basis for the emissions generation and the subsequent comparison of different technologies implemented in-barn.

In order to define this "typical" farm, national experts from the pig sector were contacted. Thus, in agreement with different representatives of the Quebec pig sector expertise (research, development, producers association, national agricultural ministry) the key parameters of the representative Quebec pig farm for 2006 were defined. It was established, among others, that the representative pig farm must be a farrow-to-finish farm comprising three growing stages. The growing stages considered are: grower finisher, nursery and maternity. The maternity stage comprises both gestating sows and farrowing sows with their piglets. Table 1 presents the different parameters of the "typical" farm that were necessary in order to establish the annual emission of gases, odors and dust from such a "typical" farm. This mostly refers to animal-related parameters. However, it must be emphasized that the reference farm established was much more detailed, defining, among others, the manure management scheme, the manure composition, the feed used, the details about the building and in-barn environment (construction materials, ventilation, temperature, floors system, insulation, etc.). The performance-related parameters were established by a national expert (Richard, 2008) from the Centre de développement du porc du Québec inc. [Quebec Hog Development Centre inc.] (CDPQ, described in Falardeau, 2006). It must also be highlighted that all parameters presented in table 1 (and all other parameters selected for the "typical farm") were validated by an extensive literature review.

It was not the intention, when establishing the "reference pig farm" for this project, to represent an average of all the pig farm systems found in Quebec. The reference farm should rather be seen as representative of "typical" pig farm systems found in Quebec.

**Table 1. Description of the reference pig farm (baseline year: 2006)**

| Growing stage | Parameter | Value | Comment |
|---|---|---|---|
| Maternity | Number of productive sows inventory | 417 | |
| | Boar | 2 | |
| | Litter / sow inventory * year | 2.23 | |
| | Living piglets / litter | 11.2 | |
| | Total born piglets / year | 10 415 | Calculated as : 417 sows inventory x 2.23 litter/sow inventory*y x 11.2 living piglets/litter |
| | Piglets mortality (from birth to wean) (%) | 11.7 | |
| Nursery | Number of entering piglets / year | 9 196 | Calculated as : 10 415 born piglets/y – (10 415 born piglets/y x 11.7 % mortality) |
| | Weight of entering piglets (kg) | 5.8 | |
| | Weight of piglets leaving nursery (kg) | 26.5 | |
| | Mortality (%) | 3.0 | |
| | Number of piglets leaving nursery / year | 8 921 | Calculated as : 9 196 entering piglets/y – (9 196 entering piglets/y x 3.0 % mortality) |
| | Average annual number of piglets in nursery | 9 058 | Calculated as: 8 921 piglets + ((9 196 - 8 921) / 2) piglets |
| Growing-Finishing (GW) | Number of entering pigs / year | 8 921 | Same as leaving piglets from nursery |
| | Weight of entering pigs (kg) | 26.5 | |
| | Weight of pigs leaving (kg) | 111.1 | |
| | Average weight in GW stage (kg) | 68.8 | Calculated as: 26.5 kg + ((111.1 - 26.5) / 2) kg |
| | Mortality (%) | 3.5 | This corresponds to the value found in CRAAQ (2008). The mortality value for 2006 was exceptionally high, i.e. 7 %, as a circovirus crisis occurred on that year, and this was not judged to be representative of a “typical farm” under “typical” circumstances. |
| | Number of pigs leaving / year | 8 608 | Calculated as : 8 921 entering pigs/y – (8 921 entering pigs/y x 3.5 % mortality) |
| | Average annual number of pigs in GW stage | 8 764 | Calculated as : 8 608 pigs + ((8 921 – 8 608) / 2) |

## 2.2 Inventory of emissions and substances of interest

### 2.2.1 Overview of the methodology used

In order to determine what the emissions from the reference barn are, an approach based on the principles of the life cycle inventory methodology (described in ISO, 2006) has been used. Therefore, quantitative and qualitative data about the emissions from swine farms were collected extensively. As described in sections 2.2.2 to 2.2.4, three screening of the data available from the international literature were performed in order to have a set of emissions data that can be related to the reference farm. This includes statistical considerations for handling data variability.

It should be emphasized that the methodology described hereby is only a first step that will be supplemented by many subsequent steps. In fact, it only focuses on emissions, which are then related to the reference farm. However, concentrations data were also inventoried. In the subsequent steps, these inventoried concentrations data will be transformed into emissions in accordance with the parameters defined for the reference farm (e.g. ventilation flow) and this will be compared to the data presented here. This comparison will allow to make adjustments in the emissions and concentration data, when needed, in order to present final concentrations and emissions data for the reference barn that are in accordance with mass balances principles.

### 2.2.2 Screening 1

The first screening consisted to inventory all published literature available where in-barn emissions are mentioned for swine buildings. Only publications describing barn types similar to those of the reference farm (described in 2.1) were kept (e.g. data referring to organic barn or extensive farming were not considered). Data concerning animal kept on litter were also not retained since the "typical" Quebec barn defined does not involve litter.

The data were then separated in two main categories: those referring to concentrations and those referring to emissions. The present study will only treat the results regarding the emissions category. In these categories, the data were regrouped by regions and growing stages. Four regions were identified, namely: Europe, Quebec, Canada and United States. The growing stages considered are in accordance with those of the reference farm, i.e. growing finishing, nursery and maternity. The maternity stage comprises both gestating sows and farrowing sows with their piglets.

In the selected publications, all data related to substances generated in-barn were methodically compiled, as well as all qualitative and quantitative data that may have an influence on the emission of these substances (e.g. in-barn manure management system, floor system, number of animal, animal density, weight of animals, ventilation system and flow, interior and exterior temperature, total experiment duration, frequency of sampling, etc.). All data related to uncertainty or variability for a given parameter were also compiled. This voluminous amount of qualitative and quantitative supporting data will however not be presented here, for obvious practical reasons.

### 2.2.3 Screening 2

The second screening consisted to convert all inventoried data into similar units. The units chosen for expressing the emission data for a given substance have been chosen according to the most frequently used unit from the data compiled for that substance (in all growing stages). The conversions were made in accordance to the data provided in the publications. However, for some data, some hypothesis needed to be taken in order to carry up the conversions, especially as regard with animal weight. There were, withal, some data that were rejected at this stage as there were not enough data in the publication to enable any reasonable hypothesis to be taken for converting the data into the selected unit.

### 2.2.4 Screening 3

Screening 3 consisted to remove all extreme values for a given growing stage (including the data from all regions). This was done by building, for each substance within a given growing category, a quartile diagram. The quartiles (Q1 and Q3) were determined using Microsoft® Office Excel® 2007 software and the limit values at both ends of the distribution were determined according to equation 1 (inferior end of the distribution) and equation 2 (superior end of the distribution). Both equation 1 and 2 were taken from Hines and Montgomery (1990).

$$IL > Q1 - 1.5(Q3 - Q1)$$ **Equation 1**

$$SL < Q3 + 1.5(Q3 - Q1)$$ **Equation 2**

Where :

*IL* : Inferior limit. Smallest value that can be considered in the distribution. Values below IL are considered as extremes values.

*Q1* : Quartile 1

*Q3* : Quartile 3

*SL* : Superior limit. Highest value that can be considered in the distribution. Values above SL are considered as extremes values.

### 2.2.5 Determination of estimates and confidence intervals for each substance

Once the extreme values of each distribution were removed, the following descriptive statistical parameters were calculated for each substance, within a given growing stage: average, median and standard deviation. Confidence intervals, i.e. an interval including the parameter being estimated with a known degree of uncertainty, were then calculated for each substance. This degree of uncertainty is referred to as the confidence level, which corresponds to 100 (1-α) %, where α is the signification level. In this project, the confidence level chosen was 95 %, which means that α was set to 0.05. The confidence interval (CI) was calculated according to equation 3, which was taken from Bendat and Piersol (2000):

$$CI(95\%) = t_{0.05,\nu} \frac{s}{\sqrt{N}}$$ **Equation 3**

Where :

*CI(95%)* : Confidence interval with a 95 % confidence level.

$t_{0.05,\nu}$ : Value from the t (Student) distribution at a signification level of 0.05 with $\upsilon$ degrees of freedom (with $\upsilon$ = N-1)

*s* : Standard deviation of the data set

*N* : Number of data in the data set from which a confidence interval is calculated

This step was performed, within a given growing stage, for both the entirety of the inventoried data as well as for data separated per region. This will allow to compare the data from the experiments held in Quebec against those held in other parts of the world.

### *2.3 Scaling up of the inventory data to the reference farm*

This step simply consists to apply the different estimates obtained for all substances and growing stages to the reference farm described in section 2.1. This was done with the estimates obtained from the overall data rather than those obtained from the “Quebec” region only. The reason for that is explained and discussed in the discussion section.

## 3. Results

For the nursery stage, the number of data remaining after the 3 screenings were : 7 for $NH_3$, 16 for odors, 7 for $CH_4$, 6 for $CO_2$, 7 for $N_2O$ and 1 for respirable dust (Table 2). The data from Quebec’s literature account for the greatest proportion of the data for most substances, except for odors and respirable dust for which there is no data.

For the maternity stage, only data from the regions labeled “Europe” and “Canada” remained after the 3 screenings (Table 3). The same substances as for the nursery stage were inventoried, with the addition of the total dust. Odors is the most document substance for this growing stage, with 29 data.

The growing finishing stage was the stage where the greatest numbers of data were obtained (Table 4). The most document substance was $NH_3$, with 77 data. All the substances documented in the maternity stage were also documented for this stage, with the addition of hedonic character, $H_2S$, $PM_{10}$ and $PM_{2.5}$.

In tables 2 to 4, the number of digits should not be seen as a measure of the precision, but is only included as the values are the foundation for further calculations. Also, all blank cells in table 2 to 4 indicate that there are no data for the parameter to which that cell corresponds.

An insight of the overall inventory is presented in Appendix A, where converted data for all growing stages are presented per reference and region (Tables A1 to A3).

**Table 2. Inventory results for the nursery stage**

| Growing Phase: Nursery | | | | | | | |
|---|---|---|---|---|---|---|---|
| Region | Parameter | Substance | | | | | |
| | | NH3 g/d*head | Odors $OU_E$/s*head | $CH_4$ g/d*head | $CO_2$ kg/d*head | $N_2O$ g/d*head | Resp. dust mg/h*head |
| All | Average | 0.39 | 8.50 | 2.77 | 0.55 | 0.01 | 6.40 |
| | St. dev | 0.35 | 7.94 | 4.11 | 0.03 | 0.01 | |
| | Median | 0.28 | 4.60 | 0.56 | 0.55 | 0.01 | |
| | N | 7 | 16 | 7 | 6 | 7 | 1 |
| | CI | 0.32 | 4.23 | 3.67 | 0.04 | 0.01 | |
| | CI as % of Avg | 82 | 50 | 132 | 6 | 67 | |
| Europe | Average | 0.56 | 10.69 | 10.68 | | | 6.40 |
| | St. dev | 0.76 | 8.05 | | | | |
| | Median | 0.56 | 7.35 | | | | |
| | N | 2 | 12 | 1 | | | 1 |
| | CI | 6.82 | 5.11 | | | | |
| | CI as % of Avg | 1211 | 48 | | | | |
| Quebec | Average | 0.33 | | 0.49 | 0.56 | 0.010 | |
| | St. dev | 0.14 | | 0.10 | 0.02 | 0.002 | |
| | Median | 0.28 | | 0.53 | 0.56 | 0.010 | |
| | N | 5 | | 5 | 5 | 5 | |
| | CI | 0.17 | | 0.13 | 0.02 | 0.003 | |
| | CI as % of Avg | 53 | | 26 | 4 | 27 | |
| Canada | Average | | 2.50 | 6.30 | 0.49 | 0.00 | |
| | St. dev | | 0.69 | | | 0.00 | |
| | Median | | 2.50 | | | 0.00 | |
| | N | | 2 | 1 | 1 | 2 | |
| | CI | | 6.21 | | | 0.00 | |
| | CI as % of Avg | | 248 | | | | |
| USA | Average | | 1.36 | | | | |
| | St. dev | | 1.23 | | | | |
| | Median | | 1.36 | | | | |
| | N | | 2 | | | | |
| | CI | | 11.03 | | | | |
| | CI as % of Avg | | 810 | | | | |

**Table 3. Inventory results for the maternity stage**

| Growing Phase : Maternity (sows) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Region | Parameter | Substance | | | | | | |
| | | NH3 g/d*head | Odors $OU_E$/s*head | $CH_4$ g/d*head | $CO_2$ kg/d*head | $N_2O$ g/d*head | Total dust mg/h*head | Resp. dust mg/h*head |
| All | Average | 14.21 | 29.26 | 30.05 | 5.29 | 0.00 | 0.05 | 53.20 |
| | St. dev | 2.86 | 16.15 | 25.25 | 2.26 | 0.00 | | 66.19 |
| | Median | 13.50 | 30.00 | 25.68 | 4.75 | 0.00 | | 53.20 |
| | N | 5 | 29 | 8 | 8 | 8 | 1 | 2 |
| | CI | 3.55 | 6.14 | 21.11 | 1.89 | 0.00 | | 594.64 |
| | CI as % of Avg | 25 | 21 | 70 | 36 | | | 1118 |
| Europe | Average | 14.21 | 31.16 | 57.74 | | | 0.05 | 53.20 |
| | St. dev | 2.86 | 16.29 | | | | | 66.19 |
| | Median | 13.50 | 33.00 | | | | | 53.20 |
| | N | 5 | 25 | 1 | | | 1 | 2 |
| | CI | 3.55 | 6.72 | | | | | 594.64 |
| | CI as % of Avg | 25 | 22 | | | | | 1118 |
| Canada | Average | | 17.40 | 49.40 | 5.29 | 0.00 | | |
| | St. dev | | 9.63 | 36.71 | 2.26 | 0.00 | | |
| | Median | | 16.12 | 44.84 | 4.75 | 0.00 | | |
| | N | | 4 | 7 | 8 | 8 | | |
| | CI | | 15.33 | 33.95 | 1.89 | 0.00 | | |
| | CI as % of Avg | | 88 | 69 | 36 | | | |

## Table 4. Inventory results for the growing finishing stage

| Growing Phase : Growing Finishing | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Substance | | | | | | | | | | |
| Region | Parameter | $NH_3$ g/d*head | Odors $OU_E$/s*head | Hedonic Character | $CH_4$ g/d*head | $CO_2$ kg/d*head | $N_2O$ g/d*head | $H_2S$ g/d | Total dust mg/h*head | Resp.dust mg/h*head | $PM_{10}$ g/d*AU | $PM_{2.5}$ g/d*AU |
| All | Average | 6.48 | 8.02 | 2.40 | 5.54 | 1.92 | 0.66 | 60.12 | 63.00 | 6.90 | 4.00 | 1.97 |
| | St. dev | 3.81 | 4.63 | 0.08 | 4.72 | 1.05 | 1.39 | 111.16 | 4.12 | | 2.56 | 1.21 |
| | Median | 6.05 | 7.50 | 2.44 | 4.03 | 1.62 | 0.09 | 1.62 | 63.90 | | 3.63 | 2.02 |
| | N | 77 | 57 | 6 | 29 | 32 | 6 | 8 | 3 | 1 | 8 | 6 |
| | CI | 0.86 | 1.23 | 0.08 | 1.79 | 0.38 | 1.46 | 92.93 | 10.25 | | 2.14 | 1.27 |
| | CI as % of Avg | 13 | 15 | 3 | 32 | 20 | 220 | 155 | 16 | | 53 | 64 |
| Europe | Average | 7.49 | 11.72 | | 8.48 | 2.47 | 1.29 | | | 6.90 | 4.71 | 1.97 |
| | St. dev | 4.65 | 4.85 | | 5.33 | 1.13 | 1.92 | | | | 2.50 | 1.21 |
| | Median | 7.65 | 10.50 | | 7.50 | 2.53 | 0.26 | | | | 5.06 | 2.02 |
| | N | 38 | 20 | | 10 | 13 | 3 | | | 1 | 6 | 6 |
| | CI | 1.53 | 2.27 | | 3.81 | 0.68 | 4.76 | | | | 2.62 | 1.27 |
| | CI as % of Avg | 20 | 19 | | 45 | 28 | 369 | | | | 56 | 64 |
| Quebec | Average | 5.48 | 5.90 | 2.40 | 2.26 | 1.40 | | | 63.00 | | | |
| | St. dev | 2.07 | 2.46 | 0.08 | 1.22 | 0.33 | | | 4.12 | | | |
| | Median | 5.83 | 6.25 | 2.44 | 1.69 | 1.28 | | | 63.90 | | | |
| | N | 26 | 26 | 6 | 12 | 14 | | | 3 | | | |
| | CI | 0.83 | 0.99 | 0.08 | 0.77 | 0.19 | | | 10.25 | | | |
| | CI as % of Avg | 15 | 17 | 3 | 34 | 14 | | | 16 | | | |
| Canada | Average | | 4.85 | | 7.41 | 1.88 | 0.04 | | | | | |
| | St. dev | | 2.24 | | 5.40 | 1.78 | 0.04 | | | | | |
| | Median | | 5.95 | | 5.25 | 1.89 | 0.04 | | | | | |
| | N | | 3 | | 5 | 4 | 3 | | | | | |
| | CI | | 5.57 | | 6.70 | 2.84 | 0.09 | | | | | |
| | CI as % of Avg | | 115 | | 90 | 150 | 248 | | | | | |
| USA | Average | 5.52 | 6.83 | | 5.87 | 2.19 | | 60.12 | | | 1.88 | |
| | St. dev | 3.18 | 4.79 | | 1.45 | | | 111.16 | | | 1.59 | |
| | Median | 5.20 | 5.26 | | 5.87 | | | 1.62 | | | 1.88 | |
| | N | 13 | 8 | | 2 | 1 | | 8 | | | 2 | |
| | CI | 1.92 | 4.00 | | 13.07 | | | 92.95 | | | 14.29 | |
| | CI as % of Avg | 35 | 59 | | 223 | | | 155 | | | 762 | |

The results of the "all" rows of tables 2 to 4 for all growing stages were applied to the reference farm presented in table 1 (table 5). For the substances for which the CI(95%) could not be calculated (because there were less than 2 data), a factor of 1 was applied for expressing the uncertainty, meaning that the uncertainty corresponds to the average value multiplied by 1. Table 5 therefore represents the "typical" annual emissions of gases, odors and dust for a typical Quebec swine farm in 2006, as calculated from the emissions inventory.

**Table 5. Annual baseline emissions scenario as calculated from the emissions inventory**

| Parameter | Unit | Growing Stage | | |
|---|---|---|---|---|
| | | Maternity | Nursery | Growing Finishing |
| Odors | ($OU_E$/y) | $(3.87*10^{11}) \pm (4.69*10^{10})$ | $(2.43*10^{12}) \pm (1.21*10^{12})$ | $(2.22*10^{12}) \pm (3.40*10^{11})$ |
| Hedonic character[a] | | n.v[b] | n.v[b] | 2.40 ± 0.08 |
| $NH_3$ | (kg/y) | 2 173 ± 543 | 1 300 ± 1 069 | 20 720 ± 2 766 |
| $CH_4$ | (kg/y) | 4 595 ± 3 228 | 9 166 ± 12 134 | 17 728 ± 5 741 |
| $CO_2$ | (kg/y) | 809 299 ± 288 791 | 1 818 746 ± 117 752 | 6 135 509 ± 1 206 805 |
| $N_2O$ | (kg/y) | 0.00 ± 0.00 | 25 ± 17 | 2 125 ± 4 680 |
| $H_2S$ | (kg/y) | n.v[b] | n.v[b] | 21.94 ± 33.92 |
| Total dust | (kg/y) | 184 ± 184[c] | n.v[b] | 4 836 917 ± 786 612 |
| Respirable dust | (kg/y) | 195 267 ± 2 182 593 | 507 855 ± 507 855[c] | 529 758 ± 529 758[c] |
| $PM_{10}$ | (kg/y) | n.v[b] | n.v[b] | 1 762 ± 942[d] |
| $PM_{2.5}$ | (kg/y) | n.v[b] | n.v[b] | 869 ± 557[d] |

[a] Parameter without unit.
[b] n.v : no value.
[c] A factor of 1 was applied for the uncertainty, meaning that : uncertainty = average value x 1.
[d] The conversion in kg/y was done considering that AU = 500 kg of live weight.

## 4. Discussion

The inventory performed allowed to define a baseline emission scenario for a "typical" Quebec farrow-to-finish swine barn for odors, hedonic character, $NH_3$, $CH_4$, $N_2O$, $CO_2$, $H_2S$, dust (total and respirable) and particulate matter ($PM_{10}$ and $PM_{2.5}$), distinguishing between three growing stages : growing finishing, nursery and maternity. This distinction between the growing stages actually represents an innovative aspect about the present inventory, as opposed to other studies or inventories where a global emission factor is given for the swine sector as a whole (e.g. IPCC, 2006). The inventory performed, however, involves important variation, as it can be seen from confidence intervals presented in tables 2 to 5.

For the nursery stage, the confidence interval of all inventoried substances, when expressed as a percentage of the average obtained for these substances, is above 50 %, except for $CO_2$. Methane variation, for example, is 132% of the calculated average for $CH_4$, which means that the uncertainty is superior to the actual reference value.

For the maternity stage, it is also $CH_4$ that presents the highest variation among the inventoried gases and odor parameters (excluding the respirable dust, which, having only two data inventoried, obviously presents a tremendous variance). It is also the only parameter (excluding respirable dust), with a CI superior to 50 % of its average.

The growing finishing stage, where much more data were inventoried, presents slightly different figures. In fact, for this growing stage, the CI of $CH_4$ is only 32 % of the $CH_4$ average. For $NH_3$, odors and $CO_2$, the CI is 13 %, 15 % and 20 % of $NH_3$, odors and $CO_2$ averages, respectively. The CI, expressed as a percentage of the average, is however above 50 % for PM ($PM_{10}$ and $PM_{2.5}$), $H_2S$ and $N_2O$, the latter being 220 % of the $N_2O$ average. Such a high uncertainty range for $N_2O$ is not surprising. In fact, the large uncertainty ranges for $N_2O$ emission estimates in animal production systems is a hugely discussed issue (e.g. Oenema et al., 2005), through not solved. According to Oenema et al. (2005), one of the reasons for these uncertainties with $N_2O$ is the lack of accurate data. Such a lack of reliable data was also highlighted by Jungbluth et al. (2001) as well as Arogo et al. (2003).

As mentioned in section 2.3, it is the data obtained from the overall compilation that were used instead of the data compiled from the “Quebec region” only in order to represent the baseline emissions (table 5). Such a procedure may be criticized, as it is argued, for example, that data obtained from barns in Western Europe may not be so representative of the actual emission data in barns from North America (Arogo et al., 2003). However, it was decided to adopt such a procedure since there are, overall, much more substances and data that can be included than if only the data from the “Quebec region” are considered. Moreover, there are no data for the “Quebec region” for the maternity stage, highlighting that research efforts were not so much driven through this stage in Quebec. Also, it should be mentioned that for the two stages for which there is data for the “Quebec region” (i.e. nursery and growing finishing), the average emission values for the “Quebec region” do not present major discrepancies as compared with the average emission values for the “all region”. Methane, however, is the exception, being more than five-fold lower for the “Quebec region” than for “all region” for the nursery stage, and more than two-fold lower in the case of the grower finisher stage.

These high variations highlight the limit of the current approach for determining the baseline scenario for odor, gases and dust emissions for a “typical” Quebec swine farm. This is why a systematic approach in order to eliminate extreme values was established, and a high confidence level (95 %) was chosen for building the confidence interval. Such confidence interval are, in fact, considered as another innovative element of the present study, as uncertainty ranges were seldom specified in the published literature from which the data were gathered (Appendix A). Even in spite of this, the current methodology still deal with the “apples and pears” problem, since data taken from completely different experimental context are computed to get averages. Another example of the “apples and pears” problems could be illustrated by the case of odors, for which published averages are sometime presented as an arithmetical mean, and sometime as a geometrical mean. In the present study, this was not taken into account, so no distinctions were made between “geometrical” and “arithmetical” odor data and accordingly, these data were computed together to get average emissions (unless discarded if identified as extremes values, based on equations 1 and 2).

Such variation is the reason why the baseline emissions obtained for the reference barn with this methodology will be compared against those derived from the inventory of the concentrations of all substances. The final emissions defined will then be adjusted in order to ensure that proper mass balances relationship can be established between concentrations and emissions data. This two-steps approach will contribute to provide a transparent background for the establishment of the baseline, as generally required when such baseline scenarios are determined (e.g. ISO, 2006b). Also, as described in 2.2.2, a tremendous amount of data, qualitative and quantitative, where gathered for each substance values selected for the inventory, even through not presented here for practical reasons. Nevertheless, the emissions presented in tables 2 to 5 must be interpreted with precaution, and this especially applies for total and respirable dust data, which are based, for all growing stages, on an extremely low number of data. However, when establishing a scenario for environmental assessment purposes, rough data are still better than no data at all, since values that are not provided are often interpreted as “zero-values” (Weidema, 2006).

It should also be emphasized that the inventory approach applied in this study is a simplified approach and as such results of fixed outputs for processes that are rather complex and dependent upon many variables. In fact, this simplified methodology is not capable of handling dynamic modeling. In the present approach, these dynamic emissions phenomenon were thus translated into a set of discrete values, chosen as carefully as possible in order to represent the situation adequately. It is important to keep this in mind when interpreting the emissions results for the baseline emissions scenario (table 5).

More sophisticated approaches in order to define the baseline emissions have also been considered. For instance, an alternative methodology would have consist to get robust data about all nutrients flows involved in a typical Quebec pig farm and perform mass balance calculations accordingly. The different outputs flows would then have been translated into corresponding emissions based on available models. However, the budget constraints did not allowed such a detail assessment. Also, some parameters, e.g. odors, would be difficult to handle with such an approach as intensive research is still on-going on that field in order to understand how the different substances present in-barn are related to a given concentration of odor. The inventory method used in this project was therefore believed to represent a good compromise between accuracy and the possibility to document an acceptable number of relevant parameters.

The inventory made in this study do not pretend to be based on a survey of all published results about gases, odors, dust and particulate matters emissions from swine buildings, but efforts were made in order to gather as much available data as possible. The low number of data obtained for some growing stages (e.g. nursery) is therefore disappointing, but this may be interpreted as an indication that few experimental projects were actually carried out in order to measure these emissions from the barn. This applies particularly for the maternity and nursery growing stages. In fact, a considerable amount of publications were focused on emissions data from pig manure through its management life cycle, but not so much on the emissions from the whole barn. Some studies, as previously mentioned, provided emissions for the barn but these data could not be converted due to a lack of supporting data (i.e. number of animals, etc.).

The inventory performed also allowed to highlight some facts and tendencies about the literature published on gas, odors and dust substances emitted from swine buildings. For example, odors, for both maternity and nursery growing stages, is the parameter with the greatest number of inventoried data, which tends to reflect the concern for odors emissions in the swine sector. For growing finishing, however, it was the second most documented parameter (with 57 data), after ammonia (77 data). Also, $H_2S$ data were obtained only for the growing finishing stage and were not at all documented for the other growing stages.

In the current study, the importance of the data fixed for the “typical” reference barn has not been assessed. This is intended to be done when the final emission baseline will be established (i.e. after comparison with the concentration-based inventory). This will be performed by the mean of a sensitivity analysis, where some of the reference barn parameters that are needed to pass from the inventory data to the baseline scenario can be modified in order to evaluate their importance on the final baseline emission scenario. In the present study, these parameters (i.e. those needed to pass from tables 2 to 4 to table 5) were essentially related to animals (number and weight).

## 5. Conclusions

A baseline emission scenario for a "typical" Quebec pig farm was defined, for the reference year 2006. This "typical" Quebec farm for the selected reference year was established in cooperation with national experts from the pig sector. The baseline emission scenario was defined by making an inventory of all relevant published data concerning emissions of odors, hedonic character, $NH_3$, $CH_4$, $N_2O$, $CO_2$, $H_2S$, dusts and particulate matters for the following growing stages: growing finishing, nursery and maternity. Extremes values were discarded and confidence interval were made for all substances. In order to foster the transparency of the process, it is the intention to compare the emissions results obtained in this study against those obtained by a compilation of the concentrations data, transformed into emission by relating them to the reference barn parameters (e.g. ventilation flow). The main findings of this project can be grouped into four points:

1. The amount of available data related to emissions from swine barn is limited. This is especially true for the nursery and the maternity stage.
2. Overall, odor was the most documented parameter.
3. There are considerable variations among the data inventoried, which lead to particularly large confidence interval. This was particularly emphasized for $CH_4$ for the nursery and maternity growing stages, and for $N_2O$ for the growing finishing stage.
4. In general, there were no major discrepancies between the average data obtained from the "Quebec region" as compared to averages obtained from all data. The only exception was $CH_4$.

## Acknowledgements

The authors gratefully acknowledge the Research and Development Institute for the Agri-Environment (IRDA) who provided in-kind contributions for this study. The authors are also indebted to Johanne Nadeau, Yvonne Richard and Francis Pouliot from the Centre de développement du porc du Québec inc. [Quebec Hog Development Centre inc.] for the professional support they kindly provided**.** The project also highly benefit from discussions with Dr. Nancy Lease of the "Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec" [Quebec Ministry of Agriculture, Fisheries and Alimentation] and Mr. Raymond Leblanc from the "Fédération des producteurs de porcs du Québec" [Quebec Federation of Pig Producers]. Funding was provided by the Fédération des producteurs de porcs du Québec [Quebec Federation of Pig Producers].

## References

Aarnink, A. J. A., A.J. van den Berg, A. Keen, P. Hoeksma, and M.W.A.Verstegen 1996. Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. *Journal of Agricultural Engineering Research*, 64: 299-310.

Arogo, J., P.W. Westerman and A.J. Heber. 2003. A review of ammonia emissions from confined swine feeding operations. *Transactions of the ASAE.* 46(3): 805-817.

Bendat, J.S. and A. G. Piersol. 2000. Random Data. Analysis and measurement procedure. 3rd edition, New York, NY : John Wiley & Sons, Inc.

Blanes-Vidal., V., M.N. Hansen, A.P.S. Adamsen, A. Feilberg, S.O. Petersen and B.B. Jensen. 2009. Characterization of odor released during handling of swine slurry : Part I. relationship between odorants and perceived odor concentrations. *Atmospheric Environment*. 43(18) : 2997-3005.

Blanes-Vidal, V., M.N. Hansen, S. Pedersen and H.B. Rom. 2008. Emissions of ammonia, methane and nitrous oxide from pig houses and slurry : Effects of rooting material, animal activity and ventilation flow. *Agriculture, Ecosystems and Environment.* 124: 237-244.

CRAAQ. 2008. Porcs naisseur-finisseur. Budget. [Farrow-to-finish pigs. Budget]. AGDEX 440/821g. Quebec, QC : CRAAQ.

Environment Canada. 2009. National pollutant release inventory. 2007 Total air pollutants emissions for Canada. Version 1, March 2009. [Online]. http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98- Accessed 01/07/2009.

Falardeau, P. 2006. Le rôle du centre de développement du porc du Québec au sein de la filière porcine du Québec. [The role of the Quebec hog development centre in the pig industry of Quebec]. *Journées Recherche Porcine*. 38 : 299-302.

Godbout, S. and S.P. Lemay. 2006. Effects of pig diet on gas emissions. Final report. Quebec, Canada : IRDA.

Godbout, S., S.P. Lemay, R. Joncas, J.P. Larouche, D.Y. Martin, J.F. Bernier, R.T. Zijlstra, L. Chénard. A. Marquis, E.M. Barber and D. Massé. 2001. Oil sprinkling and dietary manipulation to reduce odour and gas emissions from swine buildings – laboratory scale experiment. In *: Proceedings of the 6th International Symposium of Livestock Environment*, 671-678, ASAE Publication, Richard R. Stowell, Ray Buckling and Robert W. Bottcher eds.

Guimont, H., V. Dufour, F. Pelletier, A, Coulibaly, C. Giguère, S. Godbout, S.P. Lemay, D.I, Massé, F. Pouliot and N. Fortin. 2007. Évaluation technique et économique d'un système d'isolement des fèces avec grattes en « V » dans un engraissement commercial. [Technical and economical assessment of a « V » scraper system for isolation of feaces in a commercial fattening barn]. Rapport final. [Final report] Quebec, QC : CDPQ, IRDA, La Coop fédérée and AAC.

Hamelin, L. 2009. Développement de profiles de lattes en béton permettant de réduire les émissions d'ammoniac au bâtiment de croissance-finition porcin. [Development of concrete slats models allowing to reduce ammonia emissions from the growing-finishing swine barn]. M.Sc. Thesis, Department of Soils and Agri-Food Engineering, Laval University, Quebec, QC.

Hines, W.W. and D.C. Montgomery. 1990. Probability and statistics in engineering and management science. 3rd edition, New York, NY : John Wiley & Sons.

IPCC. 2006. IPCC guidelines for national greenhouse gas inventories. Volume 4. Agriculture, Forestry and Other Land Use. Hayama, Japan : Eggleston H.S., Buendia L., Mowa K., Ngara and Tanabe K. (eds).

ISO. 2006. ISO 14044. Environmental management – Life cycle assessment – Requirements and guidelines. Geneva, Switzerland : ISO. International Organisation for Standardization.

ISO. 2006b. ISO 14064-2. Greenhouse gases — Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements. Geneva, Switzerland : ISO. International Organisation for Standardization.

Jungbluth, T., E. Hartung and G. Brose. 2001. Greenhouse gas emissions from animal houses and manure stores. *Nutrient Cycling in Agroecosystems*. 60: 133-145.

Lachance, I., S. Godbout, S.P. Lemay, J-P.larouche and F. Pouliot. 2005. Separation of pig manure under slats : to reduce releases in the environment! Paper no.054159. St-Joseph, MI : ASABE.

Lemay, S. P, M. Belzile, D. Zegan, J. Feddes, S. Godbout and M. Martel. 2008. Système de traitement de l'air provenant des bâtiments porcins. [Air treatment system for air issued from pig buildings]. [Online] http://www.irda.qc.ca/_documents/_Results/149.pdf Accessed 01/07/2009.

Lemay, S.P., S. Godbout, R. Bergeron, M. Belzile, B. Predicala, C. Laguë, A. Marquis, F. Pouliot and F. Rondeau. 2007. Développement d'un nouveau concept d'enclos pour élevages porcins "sans lattes" permettant de séparer les déjections et de réduire les émissions gazeuses et odorants. [Development of a new pen concept without slats allowing to separate slurry phases and reduce gaseous and odorant emissions for pig production]. Rapport final. [Final report]. Quebec, QC : Institut de recherche et de développement inc.

Ni, J.-Q., J. Hendriks, C. Vinckier and J. Coenegrachts. 2000. Development and validation of a dynamic mathematical model of ammonia release in pig house. *Environment International*. 26 : 105-115.

Oenema, O., N. Wrage, G.L.Velthof, J.W. van Groenigen, J. Dolfing and P. J. Kuikman. 2005. Trends in global nitrous oxide emissions from animal production systems. *Nutrient Cycling in Agroecosystems*. 72 : 51-65.

Pelletier, F., A. Marquis, S. Godbout, R. Joncas, J.P. Larouche, D. Massé and P. Bégué. 2005. Gas and Odor Emissions from Swine Building Materials. *Transactions of the ASAE*. 48 (2), 721-728.

Richard, Y. 2008. Personal communication with Yvonne Richard. Quebec, QC, June 10th 2008.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales and C. de Haan. 2006. Livestock's long shadow: environmental issues and options. Rome, Italy : FAO. [Online]. ftp://ftp.fao.org/docrep/fao/010/A0701E/A0701E00.pdf Accessed 01/07/2009.

Weidema, B.P. 2006. The integration of economic and social aspects in life cycle impact assessment. *International Journal of LCA*. 11(1) : 89-96.

# Appendix A

This appendix intends to present an overview of the inventory performed. Unfortunately, it was not possible to present all the inventoried data in a convenient format and appropriate length for the purpose of the present paper. However, in order to ensure the transparency of the process, it was judge relevant to at least present the converted data used as related to the source from which they were taken from. Tables A1 to A3 therefore present, for the nursery, growing finishing and maternity stages, respectively, all the data that are behind the results presented in tables 2 to 4. This means that all excluded data (e.g. extremes values or impossible to convert data) are not presented in tables A1 to A3. For some references, more than one data were retrieved from the publication.

**Table A1. Summary of converted inventory data for nursery**

| Region [a] | $NH_3$ g/d*pig | Odors[b] $UO_E$/s*pig | $CH_4$[c] g/d*pig | $CO_2$[d] kg/d*pig | $N_2O$[e] g/d*pig | Resp. Dust mg/h*pig | Uncertainties[g] | Reference [h] |
|---|---|---|---|---|---|---|---|---|
| E-BE | | 19.00 | | | | | Odors | 4 |
| E-BE | | 15.10 | | | | | Odors | 4 |
| E-BE | | 28.00 | | | | | Odors | 4 |
| E-BE | | 19.70 | | | | | Odors | 4 |
| E-BE | | 11.40 | | | | | Odors | 4 |
| E-BE | | 7.00 | | | | | odors | 4 |
| E-IE | | 3.70[b1] | | | | | | 11 |
| E-IE | 1.10 | 4.30[b1] | | | | | | 11 |
| E-IE | | 4.60[b1] | | | | | | 11 |
| E-IE | | 4.60[b1] | | | | | | 11 |
| E-NL | 0.03 | | 10.68 | | | | | 41 |
| E-NL | | 7.70 | | | | | | 54 |
| E-NL | | 3.20 | | | | | | 54 |
| E-NL | | | | | | 6.40 | | 41 |
| Q | 0.28 | | 0.56[c1] | 0.58[d1] | 0.01[e1] | | $NH_3$,$CH_4$,$N_2O$,$CO_2$ | 53 |
| Q | 0.22 | | 0.56[c1] | 0.59[d1] | 0.01[e1] | | $NH_3$,$CH_4$,$N_2O$,$CO_2$ | 53 |
| Q | 0.18 | | 0.32[c1] | 0.56[d1] | 0.01[e1] | | $NH_3$,$CH_4$,$N_2O$,$CO_2$ | 53 |
| Q | 0.48 | | 0.46[c1] | 0.54[d1] | 0.01[e1] | | $NH_3$,$CH_4$,$N_2O$,$CO_2$ | 53 |
| Q | 0.46 | | 0.53[c1] | 0.55[d1] | 0.01[e1] | | $NH_3$,$CH_4$,$N_2O$,$CO_2$ | 53 |
| Can-SK | | 2.99 | | | 0 | | | 5 |
| Can-SK | | 2.02 | 6.30[c2] | 0.49[d2] | 0 | | | 5 |
| US-IN | | 0.49 | | | | | | 15 |
| US-IN | | 2.23 | | | | | | 15 |

[a] E : Europe; -BE : Belgium; -IE: Ireland; -NL : Netherlands; Q : Quebec; Can: Canada; -SK : Saskatchewan; US : United Stated; -IN : Indiana.
[b] B1 : Geographical mean.
[c] C1: Middle animal weight of the provided range used for conversion; C2. An animal weight of 16.15 was used for conversion. This is based on the middle weight of the reference farm for the nursery stage.
[d] D1 : Same as C1; D2. Same as C2.
[e] E1 : Same as C1.
[f] Parameters for which an uncertainty or a range is specified.
[g] See table A4 for the correspondence between reference numbers and actual reference.

**Table A2. Summary of converted inventory data for grower finishers**

| Region [a] | $NH_3$[b] g/d*pig | Odors[c] $UO_E$/s*pig | $CH_4$[e] g/d*pig | $CO_2$[f] kg/d*pig | $N_2O$[g] g/d*pig | $H_2S$ g/d | Tot. Dust mg/h*pig | Resp. Dust mg/h*pig | $PM_{10}$ g/d*AU | $PM_{2.5}$ g/d*AU | Uncertainties[h] | Reference [i] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-FR | 11.20 | | | | | | | | | | | 9 |
| E-FR | 9.60 | | | | | | | | | | | 9 |
| E-FR | 6.20 | | | | | | | | | | | 9 |
| E-FR | 9.40 | | | | | | | | | | | 9 |
| E-DK | 3.00 | | | | | | | | | | | 34 |
| E-DK | 3.23 | | | | | | | | | | | 34 |
| E-IE | | 9.30[c1] | | | | | | | | | | 11 |
| E-IE | 3.00 | 9.40[c1] | | | | | | | | | | 11 |
| E-IE | 2.70 | 10.50[c1] | | | | | | | | | | 11 |
| E-IE | | 10.50[c1] | | | | | | | | | | 11 |
| E-NL | 0.74 | | | | | | | | | | | 33 |
| E-NL | 0.70 | | | | | | | | | | | 33 |
| E-NL | 1.20 | | | | | | | | | | | 33 |
| E-NL | 0.86 | | | | | | | | | | | 33 |
| E-NL | 0.78 | | | | | | | | | | | 33 |
| E-NL | 0.78 | | | | | | | | | | $NH_3$ | 35 |
| E-NL | 0.93 | | | | | | | | | | $NH_3$ | 35 |
| E-NL | 5.70 | | | | | | | | | | $NH_3$ | 35 |
| E-NL | 6.40 | | | | | | | | | | $NH_3$ | 35 |
| E-IT | 6.86[b1] | | | 2.76[f1] | 0.11[g1] | | | | | | | 3 |
| E-IT | 4.22[b1] | | | 2.74[f1] | 0.26[g1] | | | | | | | 3 |
| E-DE | 14.00 | | 9.00 | 1.40 | | | | | | | | 2 |
| E-DE | | | 11.00 | 1.60 | | | | | | | | 2 |
| E-DE | 16.00 | | 15.00 | 1.30 | | | | | | | | 2 |
| E-DE | 16.00 | | 6.00 | 1.00 | | | | | | | | 2 |
| E-DE | 10.00 | | 3.00 | 3.00 | | | | | | | | 2 |
| E-DE | 12.00 | | 4.00 | 4.00 | | | | | | | | 2 |
| E-DE | 11.00 | | 5.00 | 5.00 | | | | | | | | 2 |
| E-DE | 12.00 | | 2.00 | 2.00 | | | | | | | | 2 |
| E-BE | | 14.00 | | | | | | | | | Odor | 4 |
| E-BE | | 18.00 | | | | | | | | | Odor | 4 |
| E-BE | | 9.00 | | | | | | | | | Odor | 4 |
| E-BE | | 19.00 | | | | | | | | | Odor | 4 |

**Table A2. Summary of converted inventory data for grower finishers (continuation)**

| Region [a] | $NH_3$[b] g/d*pig | Odors[c] $UO_E$/s*pig | $CH_4$[e] g/d*pig | $CO_2$[f] kg/d*pig | $N_2O$[g] g/d*pig | $H_2S$ g/d | Tot. Dust mg/h*pig | Resp. Dust mg/h*pig | $PM_{10}$ g/d*AU | $PM_{2.5}$ g/d*AU | Uncertainties[h] | Reference [i] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-BE | | 10.00 | | | | | | | | | Odor | 4 |
| E-BE | | 8.00 | | | | | | | | | Odor | 4 |
| E-IE | | 12.10[c1] | | | | | | | | | | 11 |
| E-IE | 6.90 | 16.30[c1] | | | | | | | | | | 11 |
| E-IE | 11.90 | | | | | | | | | | | 11 |
| E-IE | 11.30 | 22.80[c1] | | | | | | | | | | 11 |
| E-IE | | 10.70[c1] | | | | | | | | | | 11 |
| E-NL | 5.69 | | | | | | | | | | | 33 |
| E-NL | 5.87 | | | | | | | | | | | 33 |
| E-NL | 5.70 | | | | | | | | | | | 33 |
| E-DE | | | 17.52[e1] | 2.80[f2] | | | | | | | $CH_4$,$CO_2$ | 40 |
| E-DE | | | 12.26[e1] | 1.93[f2] | 3.50[g2] | | | | | | $CH_4$,$N_2O$, $CO_2$ | 40 |
| E-NL | 9.24 | | | | | | | | | | | 41 |
| E-IE | 8.40 | 7.70 | | | | | | | | | $NH_3$,odor | 46 |
| E-IE | 10.00 | 6.00 | | | | | | | | | $NH_3$,odor | 46 |
| E-IE | | 6.30 | | | | | | | | | Odor | 46 |
| E-IE | | 10.70 | | | | | | | | | Odor | 46 |
| E-DE | 11.94[b2] | | | 2.53[f3] | | | | | | | $NH_3$,$CO_2$ | 51 |
| E-NL | | 18.60 | | | | | | | | | | 54 |
| E-NL | | 5.50 | | | | | | | | | | 54 |
| E-IT | | | | | | | | | 2.97 | 1.87 | | 3 |
| E-IT | | | | | | | | | 0.89 | 0.20 | | 3 |
| E-IT | | | | | | | | | 6.86 | 2.17 | | 3 |
| E-IT | | | | | | | | | 5.86 | 3.37 | | 3 |
| E-IT | | | | | | | | | 7.43 | 3.14 | | 3 |
| E-IT | | | | | | | | | 4.27 | 1.09 | | 3 |
| E-NL | | | | | | | | 6.9 | | | | 41 |
| Q | 8.64 | 7.50 | | | | | 63.9 | | | | | 10 |
| Q | 7.78 | 6.00 | | | | | | | | | | 10 |
| Q | 6.91 | 7.00 | | | | | | | | | | 10 |
| Q | 7.78 | 6.50 | | | | | | | | | | 10 |
| Q | 6.05 | 6.75 | | | | | 58.5 | | | | | 10 |
| Q | 6.05 | 9.50 | | | | | | | | | | 10 |
| Q | 6.05 | 7.50 | | | | | | | | | | 10 |
| Q | 6.48 | 9.00 | | | | | | | | | | 10 |
| Q | 4.75 | 5.75 | | | | | 66.6 | | | | | 10 |
| Q | 4.75 | 7.50 | | | | | | | | | | 10 |
| Q | 5.62 | 8.25 | | | | | | | | | | 10 |
| Q | 4.32 | 7.50 | | | | | | | | | | 10 |

**Table A2. Summary of converted inventory data for grower finishers (continuation)**

| Region [a] | $NH_3$[b] g/d*pig | Odors[c] $UO_E$/s*pig | C.H[d] | $CH_4$[e] g/d*pig | $CO_2$[f] kg/d*pig | $N_2O$[g] g/d*pig | $H_2S$ g/d | $PM_{10}$ g/d*AU | Uncertainties[h] | Reference [i] |
|---|---|---|---|---|---|---|---|---|---|---|
| Q | 5.30[b1] | 3.90[c2] | 2.30 | 1.65[e2] | 1.35[f1] | | | | | 37 |
| Q | 2.85[b1] | 3.68[c2] | 2.44 | 1.16[e2] | 1.13[f1] | | | | | 37 |
| Q | 2.70[b1] | 3.63[c2] | 2.44 | 1.36[e2] | 1.27[f1] | | | | | 37 |
| Q | 3.21[b1] | 4.04[c2] | 2.29 | 1.61[e2] | 1.29[f1] | | | | | 37 |
| Q | 2.69[b1] | 3.42[c2] | 2.47 | 1.33[e2] | 1.17[f1] | | | | | 37 |
| Q | 2.71[b1] | 3.09[c2] | 2.43 | 1.31[e2] | 1.20[f1] | | | | | 37 |
| Q | 2.88 | 3.35 | | 1.87 | 1.04 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 2.88 | 4.25 | | 1.73 | 1.02 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 4.61 | 1.80 | | 2.59 | 1.23 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 6.05 | 5.05 | | 4.46 | 1.48 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 8.35 | 8.75 | | 4.03 | 1.74 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 6.48 | 2.00 | | 4.03 | 1.97 | | | | $NH_3$, $CH_4$, $CO_2$ | 38 |
| Q | 9.81[b1] | 6.56[c2] | | | 2.04[f1] | | | | $NH_3$ | 43 |
| Q | 6.84[b1] | 11.25[c2] | | | 1.65[f1] | | | | $NH_3$ | 43 |
| Can-SK | | 2.27 | | 5.25[e3] | | 0.08 | | | | 5 |
| Can-SK | | 5.95 | | | | 0.00 | | | | 5 |
| Can-SK | | 6.32 | | | | 0.04 | | | | 5 |
| Can-SK | | | | 3.51[e2] | 0.38[f1] | | | | $CH_4$, $CO_2$ | 43 |
| Can-SK | | | | 3.15[e2] | 0.30[f1] | | | | $CH_4$, $CO_2$ | 43 |
| US-IL | | 9.84[c3] | | | | | | | Odors | 23 |
| US-IN | 9.18[b1] | | | | | | | | $NH_3$ | 25 |
| US-TX | 6.48[b6] | 11.83[c4] | | | | | | 3 | $NH_3$, odors | 16 |
| US-IA | 9.72[b6] | 14.58[c4] | | | | | | 0.75 | $NH_3$, odors | 16 |
| US-IL | 7.13 | | | | | | 288 | | | 29 |
| US-IL | 5.20 | | | | | | 180 | | | 29 |
| US-IN | 2.24 | 3.00 | | | | | 0.50 | | | 32 |
| US-IN | 4.36 | 5.48 | | | | | 1.10 | | | 32 |
| US-IN | 4.12 | 5.04 | | | | | 1.80 | | | 32 |
| US-IN | 1.72 | 0.44 | | | | | 0.70 | | | 32 |
| US-IN | 2.16 | | | | | | 1.44 | | | 32 |
| US-IN | 2.24 | 4.44 | | | | | 7.40 | | | 32 |
| US-NC | | | | 6.90 | | | | | | 44 |
| US-IL | 11.50[b1] | | | | | | | | $NH_3$ | 50 |

[a] E : Europe; -FR : France; -DK: Denmark; -IE: Ireland; -NL : Netherlands; -IT : Italy; -DE: Germany; - BE : Belgium; Q : Quebec; Can: Canada; -SK : Saskatchewan; US : United Stated; -IL: Illinois; -IN : Indiana; -TX : Texas; -IA : Iowa; -NC : North Carolina.
[b] B1: Middle animal weight of the provided range used for conversion; B2. Calculated with 432 pigs; B3. Calculated with an animal weight of 81 kg, which is the average weight for grower-finisher in the US in the inventoried data (for weight provided as a range, the middle value was used to compute this average).
[c] C1. Geometrical mean; C2. Same as B1; C3. For conversion, it was considered that AU corresponds to 500 kg of live weight. The animal weight was based on the middle value of the range provided from the other source from Illinois (source 30); Same as B3.
[d] C.H : Hedonic character.

[e] E1. This data represents a maximum. For conversion, the average weight in inventoried data for finition in Europe has been used, i.e. 73 kg (for weight provided as a range, the middle value was used to compute this average); E2. Same as B1; E3. The animal weight was based on the middle value of the range provided from the other source from Saskatchewan (source 43).
[f] F1. Same as B1; F2. Same as E1; F3. Same as B2.
[g] G1. Same as B1; G2. Same as E1.
[h] Parameters for which an uncertainty or a range is specified.
[i] See table A4 for the correspondence between reference numbers and actual reference.

### Table A3. Summary of converted inventory data for maternity

| Region [a] | $NH_3$ g/d* pig | Odors[b] $UO_E$/s* pig | $CH_4$[c] g/d*pig | $CO_2$[d] kg/d*pig | $N_2O$ g/d*pig | Tot. Dust mg/h*pig | Resp. Dust mg/h*pig | Uncertainties[e] | Reference [f] |
|---|---|---|---|---|---|---|---|---|---|
| E-BE | | 21.00 | | | | | | Odor | 4 |
| E-BE | | 53.00 | | | | | | Odor | 4 |
| E-BE | | 33.00 | | | | | | Odor | 4 |
| E-BE | | 17.00 | | | | | | Odor | 4 |
| E-IE | | 16.40[b1] | | | | | | | 11 |
| E-IE | 13.50 | 20.40[b1] | | | | | | | 11 |
| E-IE | 10.60 | 24.10[b1] | | | | | | | 11 |
| E-IE | | 10.90[b1] | | | | | | | 11 |
| E-NL | 12.84 | | 57.74 | | | | 6.40 | | 41 |
| E-IE | | 12.00 | | | | | | Odor | 46 |
| E-IE | | 10.90 | | | | | | Odor | 46 |
| E-NL | | 39.60 | | | | | | | 54 |
| E-NL | | 31.40 | | | | | | | 54 |
| E-BE | | 43.00 | | | | | | Odor | 4 |
| E-BE | | 51.00 | | | | | | Odor | 4 |
| E-BE | | 30.00 | | | | | | Odor | 4 |
| E-BE | | 36.00 | | | | | | Odor | 4 |
| E-BE | | 33.00 | | | | | | Odor | 4 |
| E-IE | | 35.70[b1] | | | | | | | 11 |
| E-IE | 17.80 | 37.50[b1] | | | | | | | 11 |
| E-IE | 16.30 | 33.20[b1] | | | | | | | 11 |
| E-IE | | 66.40[b1] | | | | | | | 11 |
| E-IE | | 35.00 | | | | | | Odor | 46 |
| E-IE | | 66.40 | | | | | | Odor | 46 |
| E-NL | | 12.20 | | | | | | | 54 |
| E-NL | | 9.80 | | | | | | | 54 |
| E-UK | | | | | | 0.050 | 100 | | 36 |
| Can-SK | | 28.14 | 119.70[c1] | 9.35[d1] | 0.00 | | | | 5 |
| Can-SK | | 22.93 | 19.00[c1] | 6.99[d1] | 0.00 | | | | 5 |
| Can-MB | | | 69.92[c1] | 6.29[d1] | 0.00 | | | | 20 |
| Can-MB | | | | 4.40[d1] | 0.00 | | | | 20 |
| Can-SK | | 9.21 | 51.30[c1] | 3.99[d1] | 0.00 | | | | 5 |
| Can-SK | | 9.31 | 13.30[c1] | 5.11[d1] | 0.00 | | | | 5 |
| Can-MB | | | 44.84[c1] | 4.38[d1] | 0.00 | | | | 20 |
| Can-MB | | | 27.74[c1] | 1.83[d1] | 0.00 | | | | 20 |

[a] E : Europe; - BE : Belgium; -IE: Ireland; -NL : Netherlands; -UK: United Kingdom; Can: Canada; -SK : Saskatchewan; -MB : Manitoba.
[b] B1. Geometrical mean.
[c] C1. Calculated with an animal weight of 190 kg, based on the average weight of the reference farm.
[d] D1. Same as C1.
[e] Parameters for which an uncertainty or a range is specified.
[f] See table A4 for the correspondence between reference numbers and actual reference.

**Table A4. Correspondence between reference number (RN) and actual reference**

| RN | Reference |
|---|---|
| 2 | Gallmann, E., E. Hartung and T. Jungbluth. 2003. Long-term study regarding the emission rates of ammonia and greenhouse gases from different housing systems for fattening pigs – final results. In : *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities,* 122-130. Horsens, Denmark. June 1-4. |
| 3 | Guarino, M., C. Fabbri, P. Navarotto, L. Valli, G. Moscatelli, M. Rossetti and V. Mazotta. 2003. Ammonia, methane and nitrous oxide emissions and particulate matter concentrations in two different buildings for fattening pigs. In : *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities,* 140-149. Horsens, Denmark. June 1-4. |
| 4 | Defoer, N. and H. Van Langenhove. 2003. Determination of odour emissions from pig farms for regulatory purposes in Flanders. In : *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities,* 152-160. Horsens, Denmark. June 1-4. |
| 5 | Godbout, S., C. Laguë, S.P. Lemay, A. Marquis and T.A. Fonstad. 2003. Greenhouse gas and odour from swine operations under liquid manure management in Canada. In : *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities,* 426-443. Horsens, Denmark. June 1-4. |
| 9 | Guingand, N. and R. Granier. 2001. Comparaison caillebotis partiel et caillebotis intégral en engraissement. [Comparison between fully and partly slatted floors in fattening buildings]. *Journées Recherche Porcine*. 33 : 31-36. |
| 10 | Godbout, S., S.P. Lemay, R. Joncas, J.P. Larouche, D.Y. Martin, J.F. Bernier, R.T. Zijlstra, L. Chénard. A. Marquis, E.M. Barber and D. Massé. 2001. Oil sprinkling and dietary manipulation to reduce odour and gas emissions from swine buildings – laboratory scale experiment. In *: Proceedings of the 6th International Symposium of Livestock Environment*, 671-678, ASAE Publication, Richard R. Stowell, Ray Buckling and Robert W. Bottcher eds. |
| 11 | Hayes, E.T., T.P. Curran and V.A. Dodd. 2006. Odour and ammonia emissions from intensive pig units in Ireland. Bioresource Technology. 97: 940-948. |
| 15 | Lim, T.T., A.J. Heber, J.Q. Ni, A.L. Sutton and D.T. Kelly. 2001. Characteristics and emission rates of odor from commercial swine nurseries. *Transactions of the ASAE.* 44(5) : 1275-1282. |
| 16 | Jacobson, L.D., A.J. Heber, S.J. Hoff, Y. Zhang, D.B. Beasley and J.A. Koziel. 2006. Aerial pollutants emissions from confined animal buildings. In : *Proceedings of the Workshop on Agricultural Air Quality. Ammonia emissions in agriculture*, 309-310. Washington, District of Colombia. June 5-8. |
| 20 | Zhang, Q., X.J. Zhou, N. Cicek and M. Tenuta. 2007. Measurement of odour and greenhouse gas emissions in two swine farrowing operations. *Canadian Biosystems Engineering*. 49 : 6.13-6.20. |
| 23 | Heber, A.J., D.S. Bundy, T.T. Lim, J. Ni, B.L. Haymore, C.A. Diehl and R. K. Duggirala. 1998. Odor emission rates from swine finishing buildings. In : *Proceedings of Animal Production Systems and the Environment*, 305-310. Des Moines, Iowa. July 19-22. |
| 25 | Heber, A.J., P-C. Tao, J.Q. Ni, T.T. Lim and A. M. Schmidt. 2005. Air emissions from two swine finishing building with flushing : ammonia characteristics. In : *Proceedings of the 7th International Symposium of Livestock Environment*. ASAE Publication Paper no. 701P0205. St-Joseph, MI : ASAE. |
| 29 | Ni, J-Q., A.J. Heber, C.A. Diehl and T.T. Lim. 2000. Ammonia, hydrogen sulphide and carbon dioxide release from pig manure in under-floor deep pits. *Journal of Agricultural Engineering Resources*. 77(1) : 53-66. |
| 32 | Lim, T.T., A.J. Heber, J-Q. Ni, D.C. Kendall and B.T. Richert. 2004. Effects of manure removal strategies on odor and gas emissions from swine finishing. *Transactions of the ASAE.* 47(6): 2041-2050. |
| 33 | Aarnink, A.J.A., A. Keen, J.H.M. Metz, L. Speelman and M.W.A. Verstegen. 1995. Ammonia emission patterns during the growing periods of pigs housed on partially slatted floors. *Journal of Agricultural Engineering Resources.* 62 : 105-116. |
| 34 | Osada, T., H.B. Rom and P. Dahl. 1998. Continuous measurement of nitrous oxide and methane emission in pig units by infrared photoacoustic detection. Transactions of the ASAE. 41(4) : 1109-1114. |
| 35 | Aarnink, A.J.A., A.J. van den Berg, A. Keen, P. Hoeksma and M.W.A. Verstegen. 1996. Effect of slatted floor area on ammonia emisison on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Resources. 64 : 299-310. |
| 36 | Phillips, V.R., M.R. Holden, R.W. Sneath, J.L. Short, R.P. White, J. Hartung, J. Seedorf, M. Schröder, K.H. Linkert, S. Pedersen, H. Takai, J.O. Jonhsen, P.W.G. Groot Koerkamp, G.H. Uenk, R. Scholtens, J.H.M. Metz and C.M. Wathes. 1998. The development of robust methods for measuring concentrations and emission rates of gaseous and particulate air pollutants in livestock buildings. *Journal of Agricultural Resource*. 70 : 11-24. |
| 37 | Godbout, S., M. Belzile, I. Lachance, S.P. Lemay, M.J. Turgeon, V. Dufour, F. Pouliot and A. Marquis. 2006. Évaluation technico-économique d'un système de séparation solide/liquide des déjections à la source dans un bâtiment porcin et les impacts sur l'environnement – Volet II [Technico-economical assessment of an in-barn solid/liquid separation systemfor pig slurry and impacts on the environment- phase II]. Rapport final [Final report]. Quebec, QC : Institut de recherche et de développement en agroenvironnement inc. |

**Table A4. Correspondence between reference number (RN) and actual reference (continuation)**

| RN | Reference |
|---|---|
| 38 | Guimont, H., V. Dufour, F. Pelletier, A, Coulibaly, C. Giguère, S. Godbout, S.P. Lemay, D.I, Massé, F. Pouliot and N. Fortin. 2007. Évaluation technique et économique d'un système d'isolement des fèces avec grattes en « V » dans un engraissement commercial. [Technical and economical assessment of a « V » scraper system for isolation of feaces in a commercial fattening barn]. Rapport final. [Final report] Quebec, QC : CDPQ, IRDA, La Coop fédérée and AAC. |
| 40 | Gallman, E. and E. Hartung. 2000. Evaluation of the emission rates of ammonia and greenhouse gases from swine housings. In : *Proceedings of the 2nd International Conference on Air Pollution from Agricultural Operations*, 92-99. Des Moines, Iowa : ASAE. |
| 41 | Groot Koerkamp, P.W.G. and G.H. Uenk. 1997. Climatic conditions and aerial pollutants in and emissions from commercial animal production systems in the Netherlands. In : *Proceedings of the International Symposium of Ammonia and Odour Control from Animal Production Facilities*, 139-144. AB Rosmalen : Netherlands. |
| 43 | Lemay, S.P., S. Godbout, R. Bergeron, M. Belzile, B. Predicala, C. Laguë, A. Marquis, F. Pouliot and F. Rondeau. 2007. Développement d'un nouveau concept d'enclos pour élevages porcins "sans lattes" permettant de séparer les déjections et de réduire les émissions gazeuses et odorants. [Development of a new pen concept without slats allowing to separate slurry phases and reduce gaseous and odorant emissions for pig production]. Rapport final. [Final report]. Quebec, QC : Institut de recherche et de développement inc. |
| 44 | Sharpe, R.R., L.A. Harper and J.D. Simmons. 2001. Methane emissions from swine houses in North Carolina. *Chemosphere – Global change science*. 3: 1-6. |
| 46 | Hayes, E.T., T.P. Curran and V.A. Dodd. 2003. Odour and ammonia emissions from pig and poultry units. Paper no. 034082. St-Joseph, MI : ASABE. |
| 50 | Heber, A.J., J.Q. Ni, T.T. Lim, C.A. Diehl, A.L. Sutton, R.K. Duggirala, B.L. Haymore, D.T. Kelly and V.I. Adamchuk. 2000. Effect of a manure additive on ammonia emission from swine finishing buildings. *Transactions of the ASAE*. 43 : 1895-1902. |
| 51 | Hinz, T., and S. Linke. 1998. A comprehensive experimental study of aerial pollutants in and emissions from livestock buildings. Part 2 : Results. *Journal of Agricultural Engineering Research*. 70 : 119-129. |
| 52 | Ni, J-Q., A.J. Heber, T.T. Lim, P. C. Tao and A.M. Schmidt. 2008. Methane and carbon dioxide emission from two pig finishing barns. *Journal of Environmental Quality*. 37 : 2001-2011. |
| 53 | Godbout, S. and S.P. Lemay. 2006. Effects of pig diet on gas emissions. Final report. Quebec, Canada : IRDA. |
| 54 | Verdoes, N. and N.W.M. Ogink. 1997. Odour emission from pig houses with low emission. In : *Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities, 317-325*. CIGR and EurAgEng publication. Rosmalen : The Netherlands. In : ITP. 1998. Odeurs et environnement. Cas de la production porcine. [Odors and environment. Case of pig production]. France : Institut Technique du Porc. |