technologies

Fédération des producteurs de porcs du Québec

ASSESSMENT OF THE SCOPE OF AN UPGRADE TO THE FPPQ GREENHOUSE GAS EMISSIONS CALCULATOR IN ORDER TO QUANTIFY THE CABON FOOTPRINT OF PORK PRODUCTION IN QUEBEC

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1. Context

OCO Technologies was commissioned by the Fédération des producteurs de porcs du Québec (FPPQ) to assess the scope of an upgrade to the organization's greenhouse gas (GHG) emissions calculator and make the modifications needed to cover an entire pork production life cycle in Quebec. The upgraded calculator might then be used to quantify a carbon footprint for every pig farm in Quebec.

The objectives of the FPPQ are, first, to learn if it is feasible to expand the range and scope of the GHG emissions calculator and, second, to estimate the carbon footprint for Quebec-grown pork.

To meet these objectives, the following steps have been taken:

- Analysis of the present FPPQ calculator, including:
  - Delimitation of the boundaries of the system covered by the calculator
  - Validation of the emission factors employed
- Review of life cycle assessment (LCA) studies of pork production internationally
- Definition of the boundaries of the system required for a carbon footprint
- Preliminary calculation of the carbon footprint for pork production in Quebec
- A study of solutions and recommendations

2. Determination of the boundaries of a carbon footprint for pork production in Quebec

2.1. Analysis of the FPPQ calculator

The tool developed by the FPPQ for calculating greenhouse gas (GHG) emissions was analysed as part of this study. The protocol established is intended to target GHG emissions reduction projects for pork operations in Quebec.

Three sources of GHG emissions are considered: storage of liquid manure, transportation of liquid manure and mineral fertilizers, and spreading of liquid manure and mineral fertilizers. Data used in the calculator are derived chiefly from the National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS) for agriculture, and from the Intergovernmental Panel on Climate Change (IPCC).

Calculation methodologies and emission factors follow a decision tree which prioritizes those that are (1) specific, (2) are derived from the National Inventory Report (2006) prepared by Environment Canada or (3) from the IPCC or (4) other recognized sources. The tool accounts for three GHGs only: CO_2, N_2O and CH_4.

The boundaries of the present system as defined by the FPPQ calculation tool are the three sources of emissions as well as the three above-mentioned greenhouse gases. To measure the carbon footprint of pork production in Quebec, additional sources of GHG emissions (such as crop production for animal feed) must be included and other greenhouse gases accounted for, as well.

2.2. Review of LCA on pork production and impacts on GHGs

The first step in this study was to conduct a review of various LCA studies of pork production. Four studies from four other countries were considered: Australia (Wiedemann et al., 2010), Denmark (Dalgaard et al., 2007), the United States (Thoma, 2010) and the United Kingdom (Kingston et al., 2009). All these studies take account of crop production required for animal feed. At the other end of the life cycle, however, most studies, by far, end at the farm gate, or on leaving the abattoir. Such studies might be termed “cradle to gate,” while a complete “cradle to grave” study includes processes associated with the sale of pork meat, preservation by consumers prior to use, cooking methods and end-of-life disposal of packaging.

Table 1 shows the carbon footprint revealed in these studies as well as their respective scope.

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Table 1- Principal LCA studies on pork production

Country	Carbon footprint	Scope of study	Reference
Australia‡	4.3 kg† CO_2e	Up to leaving abattoir	Wiedemann et al. (2010)
Denmark	3.4 kg† CO_2e	Up to leaving abattoir	Dalgaard et al. (2007)
	3.6 kg† CO_2e	Includes transportation to the Port of Harwich	
United States	5.08 kg† CO_2e	Up to leaving abattoir (manure lagoon)	Thoma (2010)
	3.00 kg† CO_2e	Up to leaving abattoir (deep pit)	
	8.8 kg* CO_2e	Entire life cycle (weighted average)	
United Kingdom	5.7 kg† CO_2e	Up to leaving abattoir	Kingston et al. (2009)
	8.6 kg* CO_2e	Entire life cycle	

† By carcass weight (kg)
* By deboned weight, boneless meat (kg)
‡ Average of both modes of pork production in Australia

Each of these studies produced a common value of 1 kg per pork carcass leaving the abattoir. That amount will be used as a basis for pork production comparisons in this study. GHG accounting will therefore consider all emissions up to leaving the abattoir, including those associated with:

- Feed production and production of the cereals required for animal feed
- Energy production
- Farrow-to-finish operations
- Transportation
- Manure management
- Carcass management

Readers should bear in mind that these studies vary in their respective methods of calculation and emissions coefficients. Additionally, there are differences in the specific studies and databases used in the pork-producing countries to be borne in mind as well. SimaPro LCA software, which is designed for life cycle assessments of product or production processes, uses several different databases. These databases chiefly provide European figures whose relevance to conditions in Quebec, or even in North America, can vary a great deal. In addition, it is difficult to grade the quality of these databases, since they use many different procedures and give limited information about methodology. Consequently, to assess the precision of the preliminary carbon footprint of pork production in Quebec, this study includes an analysis of the uncertainties.

The different LCA studies make it possible to identify the main sources of GHG emissions, using a “cradle to gate” pork production approach,” grouping emissions into four major processes: crop production required for feed operations, the actual farm operation, management of liquid manure, and transfer to the abattoir and subsequent processing.

All these studies note the importance of animal feed operations in the carbon footprint of pork production. This phase accounts for 67% of GHG emissions in the case of Denmark (Dalgaard et al. 2007), 73% in the United Kingdom (Kingston et al. 2009) and 55% in the United States (Thoma 2010). The lesser impact of feed crops in Australia is attributed to low nitrous oxide emissions from cereals production in that country (Wiedemann et al. 2010). In fact, in the light of local studies, the authors were able to lower the nitrogen emission factor for agriculture from 1.25% to 0.3%, which clearly lowers the impact of feed production on the carbon footprint.

One finding of the study conducted by Gregory Thoma (2010) for the National Pork Board in the United States is that GHG emissions differ greatly depending on manure management methods. The use of large aerobic lagoons greatly increases emissions compared to deep pit storage. The American study basically shows pit emissions due to manure contribute 26% of GHG and this proportion reaches 56% in the case of lagoons. This is confirmed by Wiedemann et al. (2010) in their study of Australian production, where liquid manure management using anaerobic lagoons contributed 73% of the carbon footprint. On the other hand, countries that use recovery and spreading, such as Denmark and the United Kingdom, have reduced the importance of liquid manure in their GHG emissions, particularly by avoiding production, transportation and use of synthetic fertilizers. Even so, these reductions seem overestimated if we refer to the emission factor for production of synthetic fertilizers issued by the Clean Development Mechanism (CDM) (UNFCCC 2010, III.A). In Quebec, liquid manure spreading has been practiced for many years. Given this fact, GHG emissions associated with the **avoidance of synthetic fertilizer production** are not included in the framework for this carbon footprint. In any case, this reduction is not significant, as it is equivalent to **0.068 kg CO_2e.** This hypothesis would only increase the uncertainty of the carbon footprint. In Quebec, investment in uncovered circular concrete tank (about 30 m in diameter by 4 m depth) should help reduce GHG emissions (methane emissions) from liquid manure storage.

Emissions related to farm operations – whether from electricity, heating or direct animal emissions (enteric fermentation) – represent only a small part of the carbon footprint. Available studies do not share assessment methods but reach similar values for such activities: an average contribution of 0.56 kg CO_2e or roughly 11% of the carbon footprint. Types of feedlot operations were also assessed in the United Kingdom, with the conclusion that outdoor feedlots led to more substantial impact in terms of eutrophication and soil acidification but that GHG emissions were roughly the same.

Analysis of the results related to slaughter operations likewise shows weak emissions. In fact, the average figure for emissions from abattoir and processing activities is 8% or 0.38 kg CO_2e. It seems, then, that local realities, particularly energy consumption levels, do not lead to a marked variation in the emissions attributable to energy needs, materials and transportation.

In a broader context, studies dealing with the entire life cycle of pork production (up to end-of-life disposal of packaging) highlight the small impact from emissions due to transportation, compared to the feed crop and feeder stages. The British study calculated that overall transport operations contribute only 4.2% of carbon footprint emissions (Kingston 2009). The Dalgaard team studied a scenario in which pork produced in Denmark would be shipped by sea to Tokyo. By their assessment, this generated an additional input of 0.25 kg CO_2e, increasing the carbon footprint by 6.9%. By consensus, these authors see impact of the transportation as minor compared to feed and manure operations.

2.3. Definition of the system used here

The different LCA studies mentioned above make it possible to identify which processes ought to be taken into account for a study of GHG emissions associated with Quebec-based pork production. Figure 1 shows the boundaries of a tool that would allow the FPPQ to measure pork production emissions in Quebec. This study focuses on a “cradle to gate” approach, in which measured data on emissions stops at leaving the abattoir. All emissions upstream of this boundary will be taken into account. Data associated with feed production and the cereals required for feed, generation of energy, transportation, manure management and handling of animal carcasses are included within the boundaries of this study. This broader scope may make it possible later to account for GHG emissions avoided by the use of liquid pig manure as a fertilizer (and GHG emissions avoided that would be associated with production of artificial fertilizers) and by the production of biodiesel from animal carcasses (and GHG emissions avoided that would be associated with conventional diesel production).

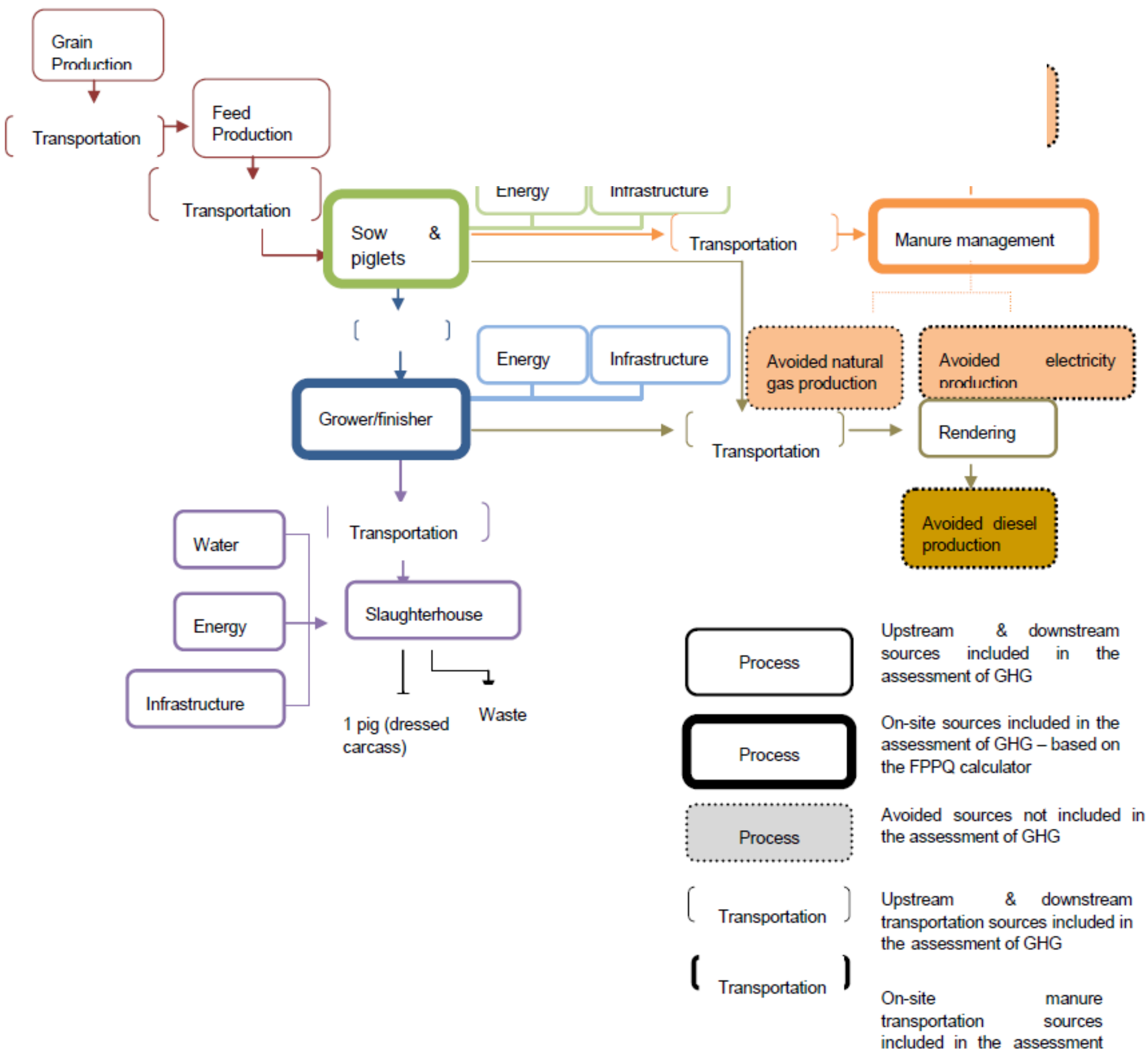

Figure 1. Simplified diagram of the pork production life cycle in Quebec

This approach makes it possible to quantify GHG emissions relative to the production of 1 kg of pork carcass leaving the abattoir. This is a value that can be compared to the results obtained by international studies (see Table 1). The model takes into account four major stages for the pork production life cycle: feed production, farm operations (sows, farrow to nursery and sows, farrow to finish barns), abattoir and liquid manure management. This separation helps to accurately represent the pork production life cycle and also identify major points on the carbon footprint.

The typical farm model in Quebec consists of a conventional farrow-to-finish operation, with feed supplied by off-site mills and sale pig marketed to a processing plant. The piggery is a closed production system, with all pigs bred-on-farm.

The piggery has two distinct production units on the farm. The breeding unit produces weaner pigs that are transferred into nursery. The second unit receives pigs at 6 weeks of age from the breeding unit and houses pigs until finishing age (120 kg). Manure is stored in circular concrete tanks of 30 meter in diameter by 3.6 meter depth.

The model developed here also allows for different mortality rates among piglets and sows as well as the number of farrowings per sow per year. Data provided by the FPPQ Cost of Production Study for 2009 shows mortality rates as 8.6%, 4.3% and 5.3% for sows, piglets and grower-finisher pigs, respectively. In addition, a cull rate of 36% is used for sows (a 44.6% replacement rate), with 10 piglets per farrowing and 2.5 farrowings per year. This data, leads to figures of 0.08 sows and 1.10 piglets for one finisher pig at the abattoir gate.

3. Preliminary carbon footprint calculation

3.1. Methodology

Calculation of GHG emissions from pork production requires input of several different variables. This section shows the methods of calculating the emission sources included in the preliminary carbon footprint as well as the assumptions taken into account in this study.

3.1.1. Feed production

Information on the different types of feeds and ingredients typically used in feeding pigs at different stages of growth was supplied by the FPPQ, which also provided figures for the amounts ingested by pigs while being raised. The information on crops and production, as well as GHG emission factors, come from the international Ecoinvent database.

3.1.2. Farm operations

Several sources are included in sow and breeding barns as well as grower- finisher operations on the farm. A review of the different LCA studies (Table 1) led to the inclusion of energy sources, agricultural infrastructure and emissions due directly to pigs. The propane and energy consumption needed to breed one piglet or raise one finisher pig were determined by the energy expenses on Quebec pork farms in 2006 (Groupe Agéco 2006). It was then assumed that the proportions were still the same in 2009. The emission factors come from the Canadian Greenhouse Gas Inventory (Environment Canada 2010).

Given the lack of information on pig farm infrastructure, the quantities of cement and steel needed to produce one finisher pig derive from international studies (Wiedemann 2010). While there may be some differences between Australia and Canada, the amount of cement and steel required for one pig is considered the same, regardless of location. Methane emissions into the air were treated similarly, as well as sows, farrow to nursery and sows, farrow to finish operations in Canada and Australia.

3.1.3. Liquid pig manure

Figures for emissions from the storage or spreading of liquid manure depend on the types of pigs involved. Three sources have been considered: methane emissions, direct nitrous oxide emissions and indirect nitrous oxide emissions. All quantification estimates are based on the FPPQ calculator.

The calculator used the Quantification Protocol for Innovative Feeding of Swine, Storing and Spreading of Swine Manure, Implementation of Manure Treatment Technologies and Cover on Manure Storage Structures, developed by the Fédération des producteurs de porcs du Québec (FPPQ) in 2010, in estimating the annual CH_4 and N_2O emission. This protocol follows the ISO 14064-2 standards and was reviewed by a group of technical experts from various provinces. These consultations were coordinated by the Canadian Standard Association (CSA). Manure is generally spread in pre-seeding (spring) and post-harvest.

Calculations are based on CDM best practices and use values given by the IPCC, among others. In addition, the data measured are integrated into the FPPQ calculations, and this increases the degree of precision.

Volumes of liquid manure coming from sows, farrow to nursery and sows, farrow to finish barns are based on the characteristics of livestock effluents for pigs (CRAAQ 2007). Although the composition of the manure varies with the type of pig, an assumption is made that the methane conversion factor is the same for sows and piglets as for grower-finisher pigs.

3.1.4. Transfer to abattoir

Data from industry experts in Québec provided insight into the structure of transportation from farm to processor. We used an estimate of 75 km transportation distance between the farm and the pork processor. These calculations are based on an estimate of 80 heads with an average weight of 120 kg per truck for delivery of finished pigs.

Although this stage is not directly controlled by pork producers, it must still be included in the carbon footprint calculation. Abattoir operations have been estimated from Ecoinvent database. Emissions from the operations are then calculated with the help of an overall coefficient, which simultaneously includes electricity, combustibles, water treatment and waste. Emissions are assumed to be the same for an abattoir in Denmark and in Canada.

3.2. Preliminary carbon footprint result

The preliminary carbon footprint for pork production in Quebec has been assessed through four stages: feed production, farm operations, liquid manure management and transfer to the abattoir. It works out that **production of 1 kilogram of pork leaving the abattoir generates GHG emissions of 4.16 kg of CO_2e.**

The cradle-to-gate carbon footprint from this scan level study is within the same range as similar studies performed on other swine production systems in Europe, Australia and USA which range from 3 to 5 kg CO_2e / kg dressed carcass. Figure 2 shows the respective contributions depending on the type of production. Feed operations (50% of the carbon footprint) and manure management (37%) are the principal sources of GHG emissions for Quebec-grown pork. Farm operations (6%) as well as activities associated with transfer to the abattoir (7%) also play a minimal contribution in the release of GHG.

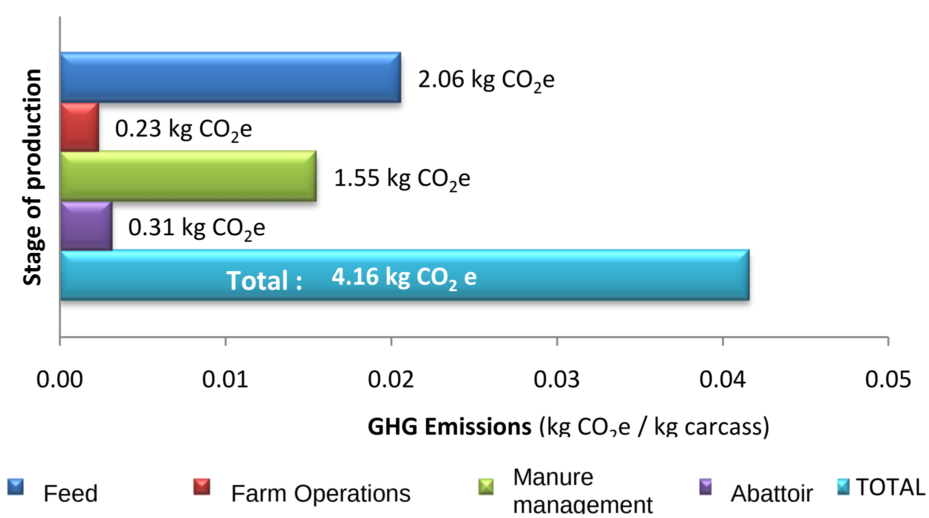

Figure 2. GHG emissions based on stage of production Quebec-grown pork

3.2.1. Feed production

Given that growing one finisher pig requires 257 kg on average, GHG input from feed is obviously significant. The feed production required for 1 kg of pork generates GHG emissions of **2.06 kg CO_2e.**

3.2.2. Farm operations

Emissions associated with farm operations come from electricity and fossil fuel consumption, enteric fermentation and pig barn infrastructure. For Quebec-based production, activities from farm operations generate **0.23 kg CO_2e.** This is lower than pork production in other parts of the world, due mainly to the use of propane and the release of enteric methane. Electricity, most of which is produced in Quebec by hydroelectric power, entails few emissions compared to the use of fossil fuels. The impact of infrastructure (construction materials such as cement and steel) is negligible, since this assessment takes account of the pig barn's useful period of life as well as the number of animals that will live there during that time.

3.2.3. Liquid manure management

The contribution of liquid manure management to the carbon footprint is **1.55 kg CO_2e.** Of this amount, 55% comes from the grower-finisher operation, 38% from sows and 8% from piglets. The figures for sows and piglets are calculated with North American coefficients. That makes these values less accurate than the feeder-to-finish contribution figures from the FPPQ-developed calculator.

Avoiding GHG emissions from the production of synthetic nitrogen fertilizers reduces emissions 0.0678 kg CO_2e for a total footprint of 4.09 kg CO_2e per kilogram of pork carcass. Substituting 1 kg of liquid manure for 1 kg of synthetic fertilizer consisting of 93% nitrogen (UNFCCC 2010, III.A), and using the amounts of nitrogen present in manure from hogs, sows and piglets (CRAAQ 2007), this estimated value for fertilizer not produced is multiplied by the emission factor for its production by the industry – that is, 1.54 kg CO_2e per kilogram of fertilizer (UNFCCC 2010, III.A). Since manure spreading has been standard practice for over 20 years, this reduction has not been taken into account since it would only add to the uncertainty.

3.2.4. Abattoir

The impact of transfer to the abattoir is **0.31 kg CO_2e per kilogram** of pork carcass. This value from the Ecoinvert database accounts for infrastructure, fossil fuel use, electricity and refrigerants, among other things.

3.3. Scenario : Export to Japon

The export of pork to Japan requires expansion of the system considered in this study. After transfer to the abattoir, the meat must be frozen before being transported to the Port of Montreal by truck and shipped by sea to Japan. In this scenario, the pork will travel over 10,933 nautical miles from Montreal to Tokyo.

The freezer stage is carried out by Congébec, which provides upstream transportation services in temperature-controlled trucks from the abattoir to its facilities and, subsequently, to the shipping terminal. The refrigeration units at Congébec use ammonia as a refrigerant, with leakage controlled by a break in the compression process if pressure exceeds 25 mg/L (Milk 2010). GHG emissions associated with electricity consumed for pressurizing the gas are negligible. The refrigeration process used by Congébec can therefore be considered sustainable

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and GHG emissions from the freezing process negligible in the context of shipping by sea to Japan.

The estimated average distance between the abattoirs and Congébec is 80 km, while it is 20 km from the company's freezer centre to the shipping terminal. This extra road transport would generate 0.01 kg CO_2e per kilogram of pork carcass. GHG emissions from shipping by sea were based on a 30,000 metric tonnage ship traveling an average of 14 knots, allowing it to reach Tokyo in 32 days while consuming 1235 metric tons of bunker oil fuel and 49 metric tons of marine diesel. Based on emission factors from the Canadian Greenhouse Gas Inventory for 2008, transportation from Montreal to Tokyo would involve an increase in GHG emissions of 0.14 kg CO_2. Export of Quebec-grown pork to Japan would therefore increase emissions by **0.15 kg CO_2e per kilogram of pork carcass –** an increase of 4.3%, a very small increase for such a long distance.

Transportation of the pork could also go through Vancouver before shipment by sea to Japan. In that case, transport by train between Montreal and Vancouver, based on the emission factor developed by CN (2010), would generate 0.07 kg CO_2e and transport by ship 0.06 kg CO_2e for a total of 0.13 kg CO_2e. These results show the extra carbon footprint would be about the same and would remain small compared to the rest of the pork production chain.

3.4. Assessment of uncertainty

3.4.1. Sources of uncertainty

Some data sources and emission factors cannot be used conclusively (without establishing a variance in the value of the data).

The sources of uncertainty are twofold. The first includes all data supplied by the FPPQ. The FPPQ could reduce the uncertainty by verifying and referencing its data. The second part includes values from external databases over which the FPPQ has no control. Table 2 summarizes uncertainty parameters for data in Quebec's study.

Feed operations

<u>Animal feed</u>: Volumes and ingredients of animal feed required for each phase of pork production were supplied by the FPPQ. As the data are specific to Quebec, no error is associated with these values.

<u>Emission factors</u>: The emission factors associated with each ingredient of animal feed come from databases assembled and made available with the help of the SimaPro program. Some of these values are averaged from data specific to the United States, while others are based on a European average. Uncertainty is therefore inherent in the use of these databases, since many factors can influence agricultural modes. Climatic conditions or existing regulations on the use of fertilizers are just two examples. In view of such possible variations, a 25% margin of error has been assigned to emission factors from these databases.

Farm operations

<u>Energy</u>: The FPPQ has supplied data on the annual energy cost in 2009 per sows, farrow to nursery barns and grower-finisher barns. But this cost includes electricity and propane with no percentage breakdown for each type. Data on costs per type of energy area available are for 2006. The percentages deduced from these energy costs are applied to the costs for 2009. But the costs vary so there is major uncertainty on energy percentages. The fact that propane is a greater polluter than electricity would certainly affect the carbon footprint in this sector. The

average percentage of propane use is 50%. Mixed energy use, including 20% propane, would represent the most optimistic scenario and 80% propane use the worst-case scenario.

Infrastructure: Emission factors for infrastructure were taken from studies done in Quebec. The required amounts of cement and steel come from an Australian study. The estimated margin of error is 25%, since the data are not specific to Quebec. There is no need to reduce this uncertainty, though, as infrastructure does not contribute significantly to the carbon footprint.

Enteric fermentation: The emission factor used for enteric fermentation is a specific emission factor for Quebec. For this reason, the level of uncertainty associated with this data is not very high and was estimated at 10%.

Manure management

Direct emissions: Data on manure management are obviously necessary to estimate methane emissions, which reach their maximum if the manure is stored for more than one year. If the pit is emptied more than once a month, however, the methane emissions are minimal.

Ammonia capture: Ammonia capture influences the amounts of nitrous oxide emitted. If the capture level is low, the emissions will also be lower, and vice versa.

Volatilization and surface runoff: The maximum deviation in uncertainty for volatilization and surface runoff during manure spreading can be applied for a worst-case figure of GHG emissions in the form of indirect N_2O. The opposite also applies.

Abattoir sector

No data on activities in an abattoir were provided – whether direct GHG emissions, indirect GHG emissions from energy consumption, volume of water used, etc. That makes it impossible to determine an accurate carbon footprint specific to Quebec. The carbon footprint has been estimated using the SimaPro program. Again, this footprint is not specific to Quebec, but is based instead on emission factors representing an average from several other countries. For these reasons, the estimated margin of error is 25%.

Table 2- Uncertainty parameters for data in this study

Fluctuation	Type of distribution	Value		
		Minimum	Most probable	Maximum
Feed operations Emission factors for animal feed	Triangular	Coefficients -25%	Coefficients	Coefficients +25%
Farm operations Energy used in the form of propane	Triangular	20%	50%	80%
Farm Operations Enteric fermentation	Triangular	0.109 kg*	0.121 kg*	0.133 kg*
Manure management[1]	Triangular	0.69 kg*	1.57 kg*	2.86 kg*
Abattoir	Triangular	0.24 kg*	0.31 kg*	0.51 kg*

***** kg CO_2e/kg pork carcass

3.4.2. Uncertainty simulations

Afin d'analyser l'influence des fluctuations possibles dans les données, une série de simulations d'incertitudes a été réalisée en utilisant les distributions de probabilités établies à la section précédente. Les résultats ont été obtenus en réalisant des simulations à l'aide la méthode de

To analyse the influence of possible data fluctuations, uncertainty simulations were conducted using probabilities established in the preceding section. Results were based on the Monte Carlo method. Simulations were conducted for each type of sector.

The first simulation studied the effect of uncertainties in the emission factors derived from databases on the animal feed contribution (Table 3).

Table 3- Results of Monte Carlo simulations: Animal feed

Parameters	Data	Units
Average value	1.92	kg CO_2e/kg pork carcass
Minimum value	1.65	
Maximum value	2.17	
Standard deviation	0.105	-
Number of iterations	187	-
Convergence	0.5%	-

These results show clearly that uncertainties about the emission factors have a significant impact on the accuracy of the final result of the carbon footprint for feed operations. The extent of the distribution plainly shows the need for coefficients specific to Quebec. This would make it possible to confirm Quebec's position and orient the choice of animal feed toward crops that emit less CO_2.

In a second stage, simulations examined the influence of uncertainties from enteric fermentation and the percentage of propane used. It was possible to conclude that the uncertainties on infrastructure have a negligible effect on the carbon footprint. Table 4 summarizes the results of the simulation for activities related to operations.

Table 4- Results of Monte Carlo simulations: Farm Operations

Parameter	Variations			Units
	Propane	Enteric fermentation	Overall variation	
Average value	0.23	0.23	0.23	kg CO_2e/kg pork carcass
Minimum value	0.21	0.22	0.21	
Maximum value	0.25	0.24	0.25	
Standard deviation	0.007	0.005	0.008	-
Number of iterations	290	290	290	-
Convergence	0.36%	0.36%	0.37%	-

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Uncertainty over the percentage of propane used has a major impact on the final results. On one hand, it seems the variations in fermentation values have only a negligible effect on the overall footprint. But it also seems that uncertainty over emissions from overall farm operations may be major. Although these emissions contribute little to the total carbon footprint from pork production, there is still a need to verify farm energy consumption. In fact, data measured directly on farms in the control sample help confirm the carbon footprint and clearly identify the position of Quebec-based producers compared to competitors in other countries.

The third simulation studied the effect of uncertainties related to manure management. The results are shown in Table 5.

Table 5- Results of Monte Carlo simulation: Manure management

Parameters	Data	Units
Average value	1.73	kg CO_2e/kg pork carcass
Minimum value	1	
Maximum value	2.65	
Standard deviation	0.31	-
Number of iterations	290	-
Convergence	0.32%	-

Based on these results, the uncertainties related to manure management have major effects on accuracy. According to the Monte Carlo simulation, the carbon footprint may vary between **1.0 and 2.25 kgCO_2e per kilogram of pork carcass.** This fluctuation can be minimized if more exact data are obtained.

Table 6- Summary of Monte Carlo simulation results

	Feed operations	Farm operations		Manure	Units
		Propane	Fermentation		
Average value	1.92	0.23	0.23	1.73	kg CO_2e/kg pork carcass
Minimum value	1.65	0.21	0.22	1.00	
Maximum value	2.17	0.25	0.24	2.65	
Standard deviation	0.105	0.007	0.005	0.31	

The above table (Table 6) summarizes how the various uncertainties affect accuracy. It clearly shows SimaPro uncertainties factors have a major impact so long as no corrective measures are available. The other items in the table belong to the dataset supplied by the FPPQ. Uncertainties associated with this data generate variations of more than 50%.

4. Conclusion

In conclusion, the results of this preliminary carbon footprint suggest that the value for cradle to processing of pork in Quebec has a global warning potential (GWP) similar to other studies presented in the literature and might be in some cases inferior.

The pork industry in Quebec therefore has an opportunity to even improve its carbon footprint by targeting strategic research in feeding strategies and manure management.

The second recommendation relates to sensitivity of greenhouse gas emission factors for the pork industry. More research would be needed to validate these emission factors or propose new factors under Quebec's climatic and soil conditions.

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