Accounting for uncertainty in the quantification of the environmental impacts of Canadian pig farming systems

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ABSTRACT

The different environmental impacts of commercial pig production for two regions (Eastern and Western) in Canada were compared in a cradle to farm gate Life Cycle Assessment (LCA) using Monte Carlo simulations for statistical analysis. For the first time detailed production data from Canadian farms was used to quantify the impacts of commercial Canadian pig systems. The impacts were defined using 5 metrics – Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Abiotic Resource Use (ARU) and Non-renewable Energy Use (NRE). Uncertainties in the model outputs were separated into two types: uncertainty in the data used to describe the system (alpha uncertainties) and uncertainty in impact calculations or background data which affects all systems equally (beta uncertainties). Using this method pig production in these two regions was systematically compared based on the differences in the systems (alpha uncertainties). The environmental impacts for impact categories GWP, EP, AP, NRE and ARU were found not to be significantly different ($P<0.05$) between Eastern and Western system, despite differences in the feed ingredients used and typical pig performance in the systems. The study quantified uncertainty systematically when comparing multiple environmental impacts measures in an LCA for pig systems for the first time.

Keywords: Uncertainty, Pig Production, Monte-Carlo Simulations, Canada

1. Introduction

Several recent LCA studies have quantified the environmental impact of pork supply chains in various farming systems using multiple environmental impact categories (e.g. Reckmann et al. 2013; Wiedemann et al. 2010; Pelletier et al. 2010; Nguyen et al. 2011). A smaller number, whilst quantifying a single impact category (namely Carbon Footprint) have introduced uncertainty in their results using Monte Carlo simulations (Thoma et al. 2011; Macleod et al. 2013). The aim of this study was to quantify the environmental impacts of typical pig production systems in Canada using multiple impact metrics, while integrating uncertainty in the LCA results using Monte Carlo simulations. An LCA was conducted to compare the environmental impacts of typical pork production systems in two regions of Canada; Eastern Canada (Ontario and Quebec) and Western Canada (Manitoba, Saskatchewan and Alberta). In 2012, production in these regions was ~13.5 million marketed pigs in Eastern Provinces and ~13.3 million finished pigs in Western provinces, a combined total representing ~98% of commercial pig production in Canada (Canadian Pork Council 2014). The two systems have several differences in pork production; including the feed ingredients used in typical diets, herd performance measures such as Feed Conversion Ratio (FCR) and mortality rates, as well as farm management practices such as finishing weights.

2. Methods

2.1 Model structure

A cradle to farm gate LCA was conducted to compare the environmental impact of pork production supply chains in Eastern (Ontario and Quebec) and Western (Manitoba, Saskatchewan and Alberta) Canada. The three main compartments of material flow in the Life Cycle Inventory (LCI) were the production of feed ingredients, the use of energy and materials in on farm pig production and the storage and land application of manure. The LCA modelled three separate stages in the pig production system; breeding (including suckling piglets), nursery (up to ~28 kg) and grower/finisher (from nursery to finishing weight). The functional unit of the LCA was 1 kg expected carcass weight at farm gate. For both regions typical diets for each stage of production were devised based on expert advice from Nutreco Canada: the Eastern diets were corn based with the western diets based on Wheat and Barley. LCI data for the major crop ingredients were taken from previous LCA studies of Canadian crops (Schmidt 2007; Pelletier et al. 2008). Using these diets and the herd performance data shown in Table 1 the nitrogen (N), phosphorus (P) and potassium (K) content of the resulting excretion was predicted. N retention in the finished pigs was calculated using an animal growth model using the principles of Wellock et al (2003); P retention was calculated using the method of (Symeou et al. 2014) and K using allometric relationships of body composition ((National Research Council 2012). All N, P, K not retained by the finished pigs was assumed to be excreted in faeces or urine and applied to land as fertilizer once losses during manure storage and spreading were accounted for.

The on-farm energy consumption data were based on studies of conventional pig housing systems in North America (Lammers et al. 2010). The mix of electricity generation in the LCA was the national mix for the Canadian grid (Statistics-Canada 2012); this was assumed for all Canadian unit processes in the LCA. The housing/manure model of important enteric emissions as well as those during manure storage and spreading was based on the principles of the IPCC guidelines for greenhouse gas inventories, using a tier 2 methodology. The model estimated the emissions of CH_4, NH_3, N_2O and NO during storage and application as well as the leaching of NO_3 and PO_4. The proportional mix of manure stored and spread using different techniques was based on the Statistics Canada records regarding the storage and application of swine manure (Statistics-Canada 2003; Beaulieu 2004). The calculated available N, P and K to the soil in the manure after land application were credited to the pig system by offsetting the need to apply synthetic fertilizers to land. As such the LCA modelled the net difference in emissions caused by applying manure instead of inorganic fertilizer, while accounting for the avoided burdens of fertilizer production. The proportional mixture of synthetic fertilizers applied to land in each region was derived from sales figures in a Canadian fertilizer shipments survey (Korol 2004).

2.2. Herd Performance data

The herd performance data used is shown in Table 1 and based on benchmark data from farms in Eastern and Western Canada. The Eastern data covered the performance of 73,880 sows, 1.47 million nursery pigs and > 1 million finished pigs, the Western data were based on 58,886 sows, 63,757 nursery pigs and 26,910 finished pigs. Using this data the model calculated the feed intake at each production stage per finished pig accounting for mortality at all stages and the flow of gilts to replace culled sows.

2.3. Environmental impact calculations

The environmental impact of the systems was quantified using the following metrics: Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), Non-Renewable Energy (NRE) and Abiotic Resource Use (ARU). GWP was quantified as CO_2 equivalent: with a 100 year timescale 1 kg CH_4 and N_2O are equivalent to 25 and 298 kg CO_2 respectively. EP, AP and ARU were calculated using the method of the institute of Environmental Sciences (CML) at Leiden University (http://www.leidenuniv.nl/interfac/cml/ssp/index.html). NRU was calculated based on the IMPACT 2002+ method. The impacts were calculated for a functional unit of 1 kg of pig carcass weight (CW) at farm gate, using a Canadian definition regarding yield (including head and trotters), meaning typical carcass yield was 80% (+/- 2%). The LCA calculations and Monte Carlo simulations were conducted using the SimaPro 7.2 software package.

2.4 Separating impacts

The results for each impact metric were assigned to the following material (and energy) flow categories to demonstrate their relative contribution to the overall impacts:

1) Feed: production of crops and additives, feed processing and transport. This category also includes the water consumed during housing.
2) Electricity: direct electricity consumption at the farm (breeding, nursery and grower/finisher stages) not including feed production, processing and transport.
3) Fuel: direct fuel consumption at the farms, not including feed production, processing and transport.
4) Housing: direct emissions of NH_3, CH_4, NO and N_2O from housing and manure storage
5) Manure: Emissions of NH_3, CH_4, NO and N_2O resulting from field spreading. This category also includes credits from replacing synthetic fertilizers.

Table 1. Mean, maximum and minimum values for key herd performance parameters

Indicator	East mean 2012	East min	East max	West mean 2012	West min	West max
Feed conversion Ratio Nursery	1.57	1.38	1.80	1.58	1.40	1.86
Feed conversion Ratio Grower/finisher	2.74	2.50	3.09	2.90	2.77	3.16
Average Daily Gain Nursery (g/d)	428	335	515	455	363	515
Average Daily Gain Grower/Finisher (g/d)	882	752	983	836	801	953
Start weight (kg)	6.32	5.50	7.30	6.22	5.40	7.00
Weight end Nursery (kg)	27.4	21.0	34.0	28.8	22.0	34.0
Weight Finish (kg)	123.6	118	130	118	114	126.6
Average weaned litter size (piglets)	11	9.7	11.6	10.8	10.1	12
Average weaning period (days)	20.0	18.0	23.0	20.6	18.6	26.5
Wean to eastrus (kg)	6.90	5.00	9.50	6.90	5.30	8.90
Litters /sow / year	2.45	2.20	2.55	2.43	2.30	2.50
Gestation feed/ weaned (kg)	28.8	25.0	34.5	28.0	25.6	34.5
Lactation feed / weaned (kg)	11.8	10	15.4	11.4	10	15.4
Creep feed / weaned (kg)	0.1	0.001	0.3	0.1	0.1	1.2
Still born	7.2%	4%	10%	7.6%	5.10%	11.9%
Post birth mortality	12.5%	6.20%	19.2%	13.6%	8.80%	20.4%
Nursery Mortality	2.8%	0.64%	7.50%	3.1%	0.90%	6.00%
Grower/finisher mortality	4.0%	1.50%	9.00%	3.0%	1.80%	5.90%
Sow Mortality	6.8%	3.60%	10.00	5.0%	2.00%	9.00%
Sow culling rate	36.1%	22.0%	58.0%	41.6%	27.7%	55.6%

2.5. Quantifying Uncertainty

A Monte Carlo approach was applied to quantify the uncertainties of the impacts in both systems (Leinonen et al. 2012). The LCA was run 1000 times, and during each run a value of each input variable was randomly selected from a distribution for this variable. Distributions were assigned to variables in the LCA based on the data available in each case. For example for major crops, yield data from 2010 to 2014 was used to estimate the average and typical ranges in the yield. In cases such as this or the herd performance benchmark data, triangular distributions were assigned where the position of the mean in the range did not suggest a normal distribution. Many of the distributions in generic unit processes taken from the ecoinvent database (e.g. transport emissions) came with log-normal distributions. The distributions for each impact metric were not assumed to be normal due to the effects of multiplying normal and non-normal distribution curves as part of the LCA uncertainty analysis. The outcome of the analysis was a minimum and maximum level of impact for each metric, which was used to evaluate the statistical significance of the differences between the Eastern and Western at 95% confidence. The uncertainties in the input variables were divided into two groups, namely system “alpha” and calculation “beta” uncertainty (Leinonen et al. 2012).

Alpha errors were considered to vary between systems, and therefore were taken into account in statistical analysis of the differences between the systems. For example, variation in the herd performance parameters seen in Table 1, used to calculate feed intake, were all considered to represent alpha errors. In contrast, beta errors were considered to be similar between the systems, and had no effect in the statistical comparison between the systems, e.g. the emission factor for N_2O from manure. The errors in the emission factors were associated with errors in the models used to generate them, and therefore considered as beta errors (Wiltshire et al. 2009; Leinonen et al. 2012). The error distributions of the emission factors in the manure model followed the IPCC (2006) guidelines as well the recent review by Liu et al. (2013).

3. Results

The LCA showed no significant difference ($P<0.05$) between Eastern and Western systems for ARU, AP, EP, GWP & NRE despite differences between both systems in terms of feed ingredients used and typical herd performance characteristics (Figures 1-5). As can be seen in figure 1-5 the range of results for most of the impact metrics do not reflect perfectly normal distributions.

For all impact categories the grower/finisher production stage accounted for >75% of impacts for both production systems. The nursery phase contributed not more than 11% of impacts for any impact category, with breeding no more than 16% for any impact category (Table 2). The production of feed ingredients accounted for the >90% of ARU and NRE and > 50% of GWP for both systems. Housing emissions from animals and manure storage were the largest contributors to AP in both systems (60 and 56 % respectively), housing and manure was also the largest cause of EP in the East (52%). However in Western systems feed ingredients were the largest cause of EP (49 %) due to the different feed ingredients used in the diet. The Coefficient of Variance (CV) for all impact categories was between 9 – 16 % for both systems. Manure application was associated with credits for ARU, GWP and NRE due to it replacing the production of synthetic fertilizers. For AP and EP the net effect of manure application was considered to increase emissions and leaching associated with these negative impacts.

Table 2**.** Summary of the environmental impacts of 1 kg pork carcass weight at farm gate for Eastern and Western Canadian pig systems (including source of impact in the systems by production stage)

	Abiotic Resource Use		**Acidification**		**Eutrophication**		**Global Warming Potential**		**Non Renewable energy**	
	kg Sb eq		kg SO_2 eq		kg PO_4^{3-} eq		kg CO_2 eq		MJ eq	
	East	West	East	West	East	West	East	West	East	West
Breeding	0.0012	0.0013	0.0088	0.0087	0.0022	0.0025	0.40	0.35	2.63	2.77
Nursery	0.0006	0.0008	0.0058	0.0079	0.0015	0.0022	0.27	0.28	1.69	1.92
Finisher	0.0062	0.0058	0.0492	0.0547	0.0129	0.0162	2.23	2.16	14.7	14.0
Total	**0.0081**	**0.0079**	**0.0638**	**0.0713**	**0.0165**	**0.0208**	**2.90**	**2.80**	**19.0**	**18.7**

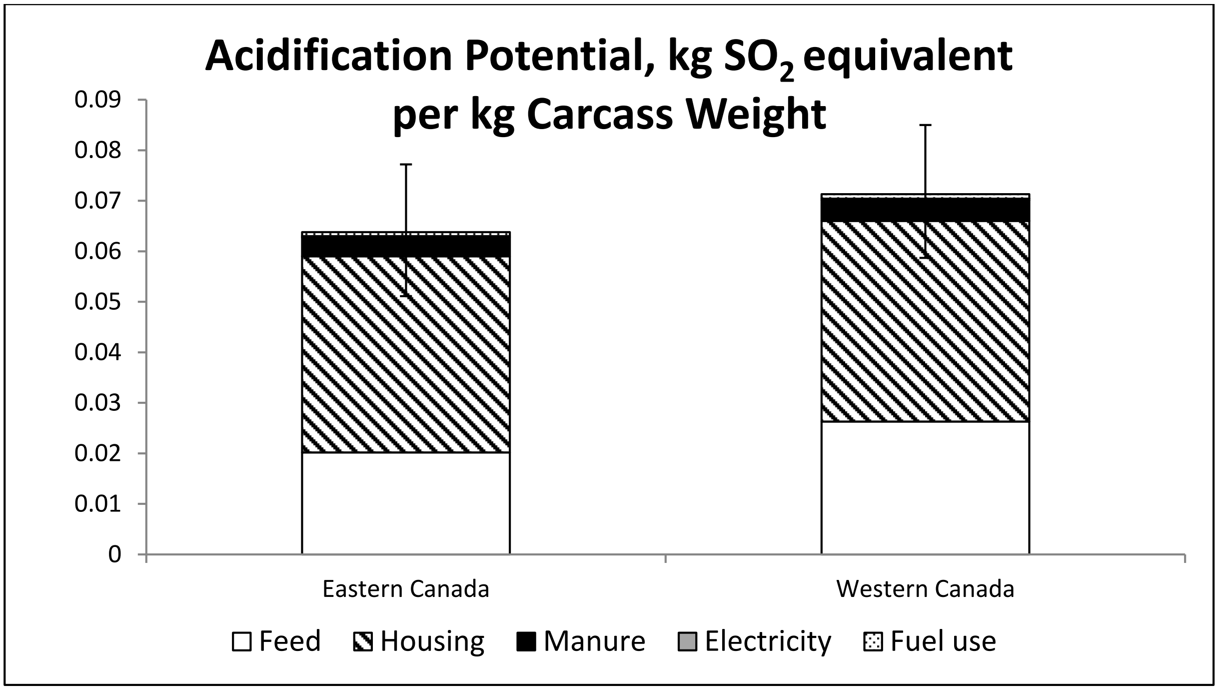

Figure 1. The Acidification Potential for typical Eastern and Western Canadian pig production. The error bars indicate standard deviations based on alpha uncertainties

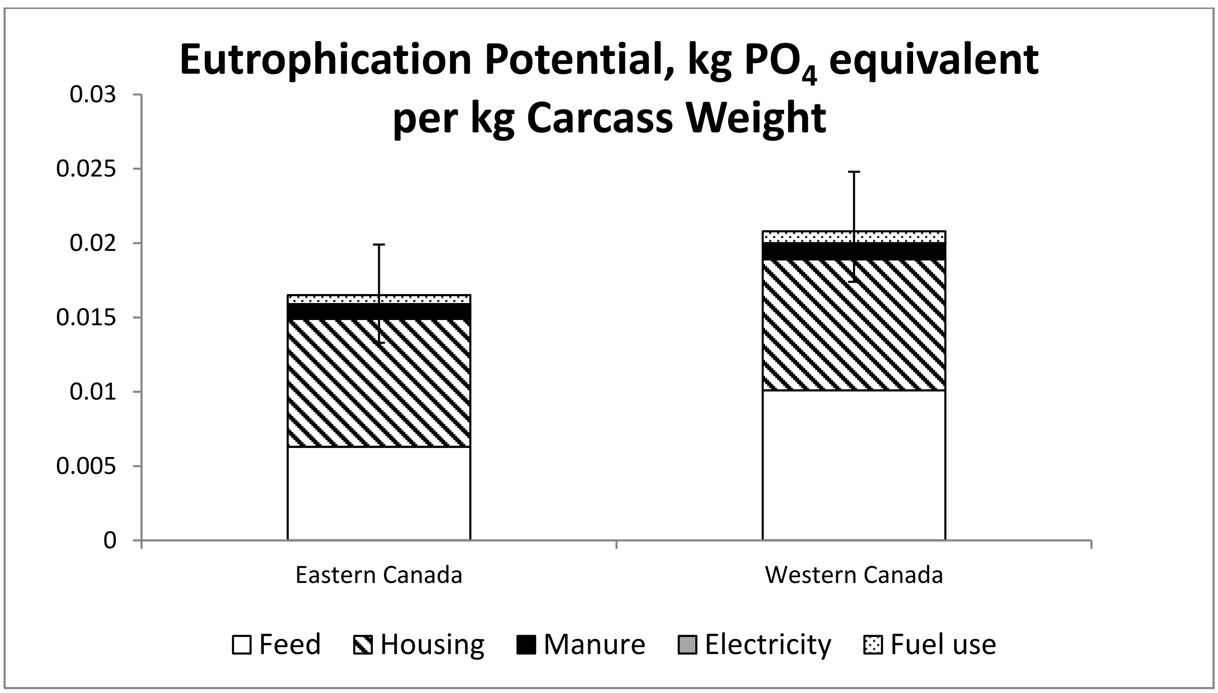

Figure 2. The Eutrophication Potential for typical Eastern and Western Canadian pig production. The error bars indicate standard deviations based on alpha uncertainties

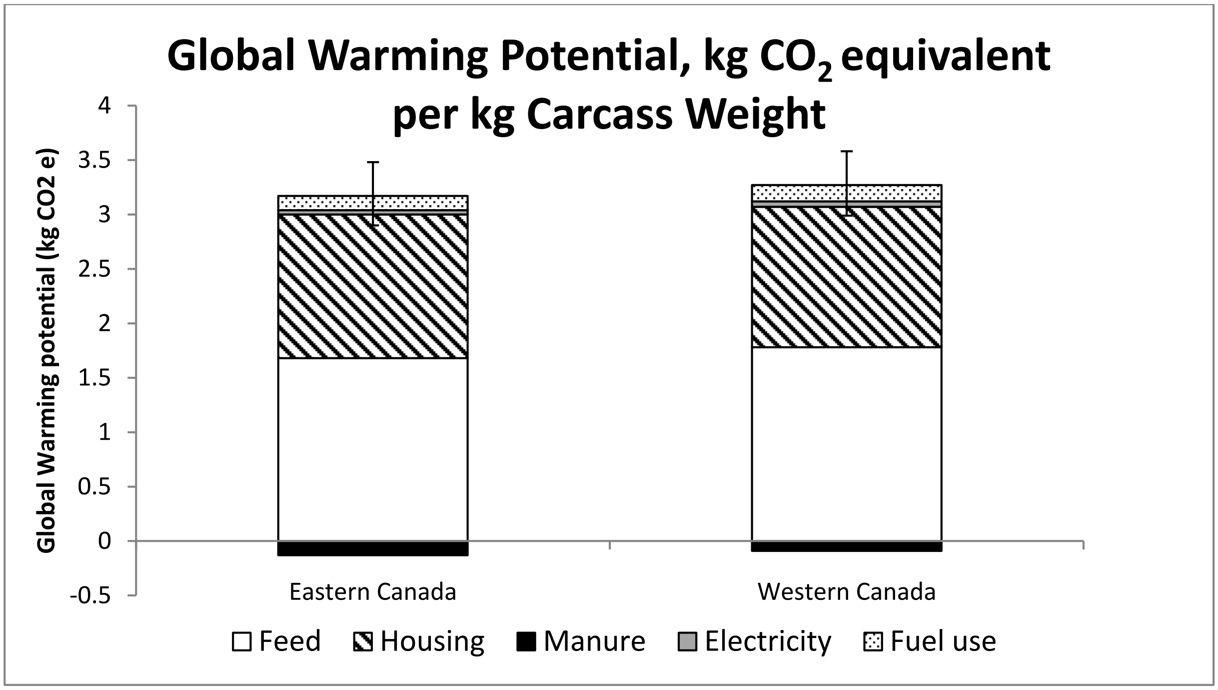

Figure 3. The Global Warming Potential for typical Eastern and Western Canadian pig production. The error bars indicate standard deviations based on alpha uncertainties

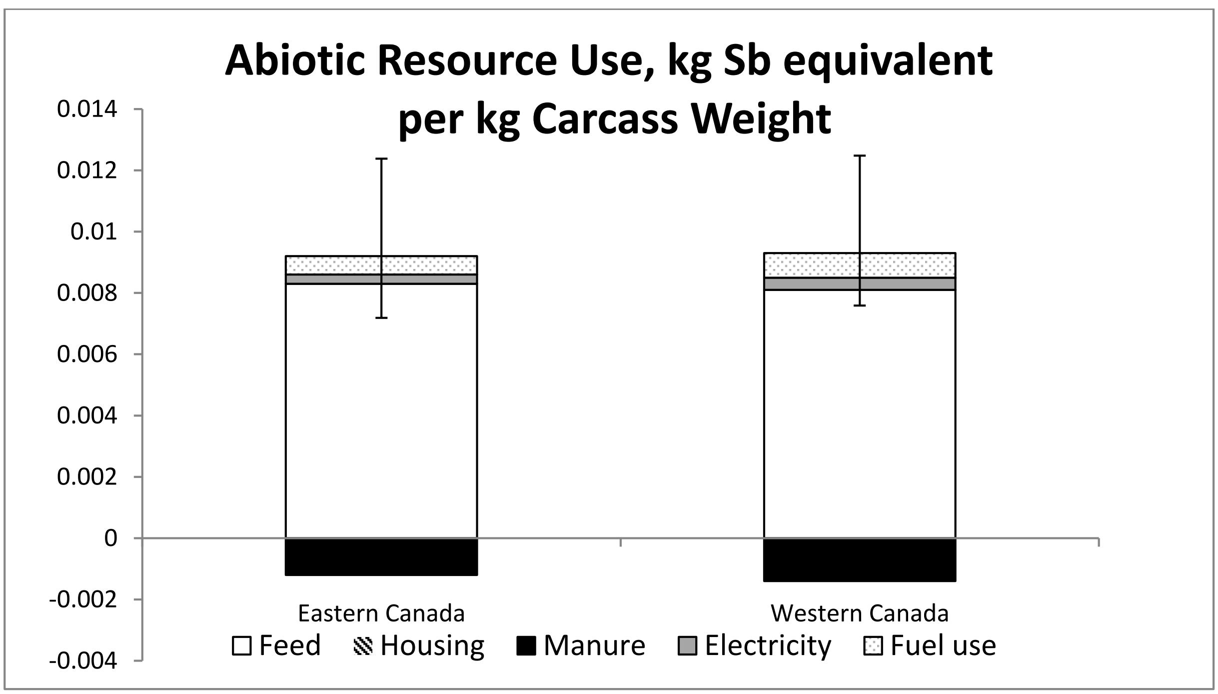

Figure 4. The Abiotic Resource Use for typical Eastern and Western Canadian pig production. The error bars indicate standard deviations based on alpha uncertainties

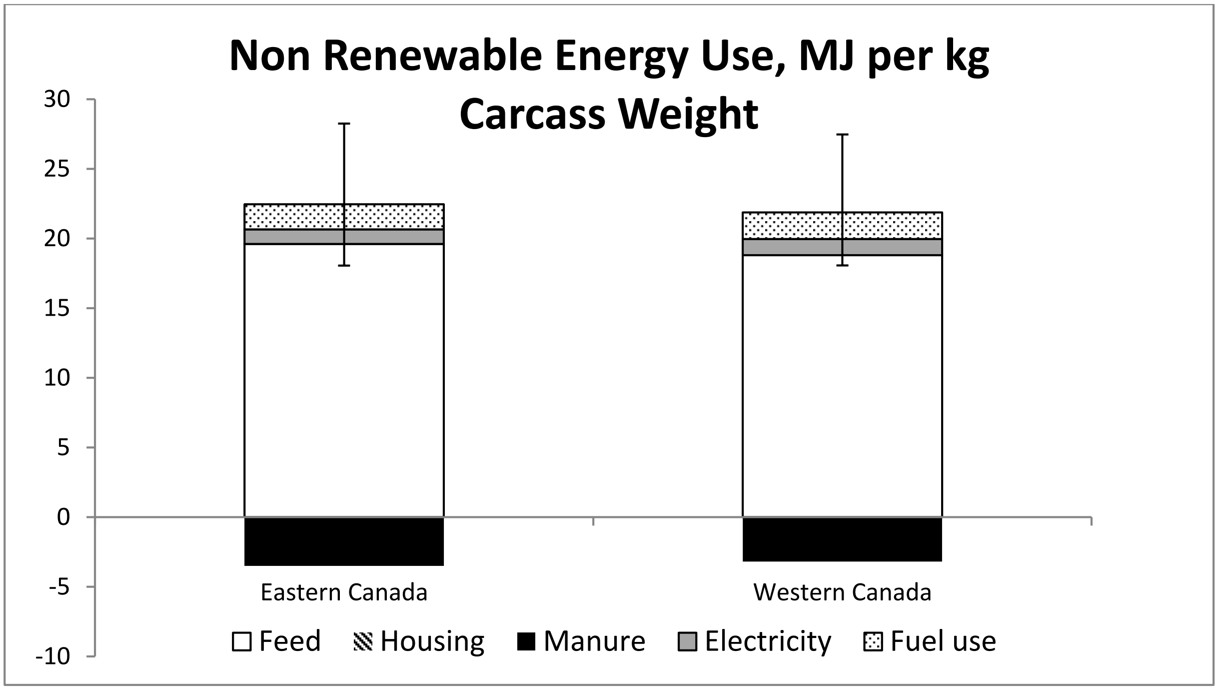

Figure 5. The Non Renewable Energy Use for typical Eastern and Western Canadian pig production. The error bars indicate standard deviations based on alpha uncertainties

4. Discussion

In all of the environmental impacts calculated, no significant differences between the Eastern and Western pig production systems were found. This was despite contrasting input data of the feed ingredients, herd performance and the manure applied to land as fertilizer. Although the Western system had numerically higher mean levels of GWP, EP and AP resulting from increased fertilizer requirements of major feed ingredients wheat and barley, in statistical comparison no significant difference in the environmental impact between the two systems was found.

The environmental impacts (particularly GWP) of pig production systems in many different countries have been quantified in previous studies, and summarized recently in the FAO report on Greenhouse Gases (GHG's) which result from monogastric livestock production (Macleod et al. 2013). This report sets out a new methodology to compare the results of pig LCA's in order to correct for differing assumptions and scope. Following this methodology, the results quoted for the three LCA's below are adjusted to represent the same FU and system boundaries as this study. The GWP results of this study do not appear different from the only previous peer reviewed carbon footprint study of Canadian pig production (Vergé et al. 2009), which reported 2.96 kg CO_2/ kg CW in Eastern systems and 2.85 CO_2/ kg CW. Previous LCA studies of US pork production have also reported figures within the range of uncertainty of this study for GWP of conventional pig production systems: 3.08 CO_2/ kg CW reported by Pelletier et al (2010) and 3.56 by Thoma et al (2010). It should be noted however that comparing results of LCA studies in a systematic manner is not feasible where the uncertainty range in those results is not reported. This is the case for most pig LCAs currently, especially for impact categories other than GWP.

Through separating different error categories in the input data, this study demonstrates a methodology for evaluating the differences between pig production systems in a consistent way. The use of Monte-Carlo simulations allows uncertainty analysis to incorporate the complexities of different types of distribution and incorporate covariance between parameters where this is suitable. Using this baseline model it will be possible to assess whether future changes to Canadian pig production systems such as an increased use of co products from biorefineries in pig diets or potential genetic changes can significantly reduce the environmental burdens of these systems.

5. Conclusion

The LCA examines the environmental impacts of commercial Canadian pig production, quantified for the first time using detailed industry data, multiple impact metrics and a systematic analysis of uncertainty. The study showed the importance of accounting for uncertainty when comparing the impacts of pig production systems. Such analysis has been lacking in previously published peer reviewed LCA's on pig systems. Monte Carlo simulations are a suitable tool for complex models such as LCA's to intrinsically account for uncertainty and allow for the complexity of non-normal distributions in the data. When modelling the systems stochastically the LCA found no significant differences ($P<0.05$) between pig production systems in Eastern and Western Canada for the environmental impact categories assessed. This was despite differences in the LCI of the systems compared regarding the typical feed ingredients used, herd performance data and predicted emission factors.

6. Acknowledgements

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