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A Comparison of the Greenhouse Gas Emissions From the Sheep Industry With Beef Production in Canada

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Abstract

Sheep production in Canada is a small industry in comparison to other livestock systems. Because of the potential for expansion of the sheep industry in Canada, the GHG emissions budget of this industry was assessed in this paper. The GHG emissions from Canadian lamb production were compared with those from the Canadian beef industry using the ULICEES model. The GHG emission intensity of the Canadian lamb industry was 21% higher than lamb production in France and Wales, and 27% higher than northern England. Enteric methane accounts for more than half of the GHG emissions from sheep in Canada. The protein based GHG emission intensity is 60% to 90% higher for sheep than for beef cattle in Canada. The GHG emission intensity for sheep in Eastern Canada is higher than for sheep in Western Canada. Protein based GHG emission intensity is more sensitive to the difference between sheep and beef than LW based emission intensity. This paper demonstrated that protein based GHG emission intensity is a more meaningful indicator for comparing different livestock species than live weight (LW) based GHG emission intensity.

Keywords: sheep, lambs, beef, greenhouse gas emissions, carbon footprint, livestock crop complex, protein, live weight

1. Introduction

In Canada the main livestock-based industries are beef, pork, dairy, eggs and poultry. In comparison to beef and pork, sheep-based products play only a minor role in the Canadian agri-food sector (Statistics Canada, 2009). Consequently, Canada's contribution to the global market for lamb is very small (Walker, 2008). The small size of the Canadian sheep population, the low volume of exports and the growing global demand for protein suggest an opportunity to expand the sheep industry in Canada. Impending climate change will introduce more variability to food production (Bonatti, Schlindwein, de Vasconcelos, Sieber, & D'Agostini, 2013). It is important for land use policies, including livestock, to be diverse and to leave a minimal carbon footprint. Since both beef cattle and sheep are ruminants, the carbon footprint of sheep production can be defined most effectively by using the beef industry as a benchmark (Edwards-Jones, Plassmann, & Harris, 2009). Whether the current approach to raising sheep in Canada, which is relatively intensive, has a greater GHG emission intensity than beef production needs to be determined. If this was found to be true, then, from the perspective of GHG emissions, the land needed to expand sheep would be better used to support additional beef cattle.

In addition to being the largest livestock industry in Canada, and the largest agricultural emitter of Greenhouse Gases (GHG) (Vergé et al., 2012), beef production is the most GHG-intensive source of protein of Canada's five major livestock industries (Dyer, Desjardins, & Worth, 2010a). Considerable information is available regarding the GHG emissions from the Canadian beef industry (Beauchemin, Janzen, Little, McAllister, & McGinn, 2010; Desjardins et al., 2012; Vergé, Dyer, Desjardins, & Worth, 2008a). Unlike the grain-fed hogs and poultry, the reliance of beef production on roughages makes enteric methane a major term in the GHG emissions budget of beef cattle (Capper, 2012; IPCC, 2006). There is currently no effective mitigation for enteric methane emissions (Cottle, Nolan, & Wiedemann, 2011). However, there is widespread dependence on feedlot operations in both the Canadian and U.S. beef industries, where more grain in the cattle diet reduces the intensity of enteric methane emissions (Capper, 2012; Vergé et al., 2008a).

Quantifying the GHG emissions from the Canadian sheep industry was the main goal of this paper. The other agro-ecological benefits were excluded from this assessment. The GHG emissions budget of sheep was determined using the Unified Livestock Industry and Crop Emissions Estimation System (ULICEES) described by Vergé et al. (2012). Comparing the carbon footprints of the Canadian beef and lamb industries was the second goal of this paper. Since ULICEES has already been applied to the Canadian beef industry, it facilitated a comparison of this industry with the Canadian beef industry on the same computational basis. To verify that ULICEES was an appropriate model for Canadian sheep production, the GHG emissions budget of sheep was compared to several offshore national sheep industry GHG emission estimates.

2. Background

Although these two grazing animals have fundamentally different mouth parts (OMAFRA, 2011) and differ in their preference for the type of forage they eat (Van Dyne, Brockington, Sxocs, Duek, & Ribic, 1980), they are both ruminants and emit enteric methane. The dryness of sheep manure compared to beef cow manure (ASAE, 2003) is an important difference between these two ruminants because manure storage is the source of two important types of GHG (Vergé et al., 2012). The storage of dry manure produces large emissions of N_2O while storage of liquid manure produces large emissions of CH_4 (Janzen, Desjardins, Rochette, Boehm, & Worth, 2008). Since sheep manure that is not directly deposited in the pasture is managed mainly by dry storage, emissions of N_2O are the main concern.

While the need for domestic wool made sheep an integral part of Canada's early farming history (CCWG, 2011), easier management has made cattle the dominant farm animal on prairie grazing lands (Vergé et al., 2012). The resulting reduction in sheep numbers coincided with the spread of invasive weeds on western rangelands (Walker, Coffey, & Faller, 2006). Since sheep eat weeds such as leafy spurge, which are toxic to cattle, it has been suggested that producers could use these animals for non-chemical weed control (SMA, 2008).

3. Methodology

Since ULICEES has been described in detail elsewhere (Vergé et al., 2012), this section presents only the main concepts used and the adaptations needed for the sheep industry. ULICEES was created by assembling the four groups of livestock-specific GHG computations from the Canadian beef, dairy, pork and poultry industries (Vergé, Dyer, Desjardins, & Worth, 2007, 2008a, 2008b, 2009) in one spreadsheet model. As well as the direct emissions from livestock, these calculations account for GHG emissions from the crop complex that is used to feed each livestock population, and manure characteristics and storage practices of each livestock type. The ULICEES model accounted for the N_2O emissions from sheep manure which was mainly handled as dry manure. Because 2001 was the most recent year with livestock diet survey data (Elward, McLaughlin, & Alain, 2003), ULICEES was initially applied to 2001 (Vergé et al., 2012). For this analysis, however, ULICEES was updated to 2006, the closest census year to the mid-point of the 2000-2009 study period used in the sheep report for Canada (Statistics Canada, 2009). This update of ULICEES had to allow for the changes in tillage practices, crop areas, fertilizer applications and livestock populations.

3.1 Modeling the GHG Budget of Canadian Sheep

To take into account the complete lifecycle of meat animals, ULICEES calculates the GHG emissions from all age-gender categories of each type of Livestock. The age-gender categories used in ULICEES for sheep in the present study were mature breeding animals (ewes and rams), breeding (replacement) lambs and market lambs (Statistics Canada, 2003). The livestock GHG assessments include fossil CO_2, CH_4 and N_2O emissions. Emissions of CH_4 and N_2O were distributed over age-gender categories within each livestock type based on differences in feed intake and live weight (LW).

3.1.1 Methane Emissions

Emissions from enteric fermentation and manure storage were calculated on a per-head basis using the ULICEES model (Vergé et al., 2012) which relies on IPCC Tier 2 methodology (IPCC, 2006). Because the two sources require different management, ULICEES quantified manure methane separately from enteric methane. Both types of methane emissions from each age-gender category were multiplied by each respective category population.

3.1.2 Nitrous Oxide Emissions

ULICEES also uses the Tier 2 methodology from IPCC (2006), modified for Canadian conditions by Rochette et al. (2008), to estimate nitrous oxide emissions. For sheep, nitrogen (N) excretion rates were based on Dry Matter

Intake (DMI) (Vergé et al., 2012). The Canadian DMI average values (Marinier, Clark, & Wagner-Riddle 2004) were indexed to the average animal weights for the two regions and the age-gender categories before being integrated over the population in each age-gender category.

3.1.3 Carbon Dioxide Emissions

The fossil CO_2 emissions budget for livestock in ULICEES was based on the six farm energy terms defined by Dyer and Desjardins (2009). Provincial fossil CO_2 emission rate estimates for these six energy terms for 2006 provided by Dyer, Desjardins, McConkey, Kulshreshtha, and Vergé (2013) were incorporated into ULICEES. The farm fieldwork term and fertilizer and machinery supply energy terms were extrapolated from the energy use for all field crops according to Dyer and Desjardins (2009) based on the complex of crop land that supports the sheep industry. The three indirect energy terms, on-farm transport, heating fuels and electricity, could not be related to the livestock crop complexes (Dyer et al., 2013). Instead they were taken from the 1996 Farm Energy Use Survey (FEUS) reported by CAEEDAC (2001). The sheep to beef cattle ratio of total LW was used to scale the FEUS energy quantities for beef to the sheep population because the Canadian sheep industry was too small to be treated as a separate farm type in the FEUS (CAEEDAC, 2001).

3.2 Sheep Crop Complex

The livestock crop complex concept was used in the four previous livestock GHG emission budgets in Canada (Dyer, Vergé, Desjardins, & Worth, 2008; Vergé et al., 2007, 2008a, 2008b, 2009). This concept set the limits of the livestock production systems and has been used to quantify the cropland not used to support livestock in Canada (Dyer, Vergé, Kulshreshtha, Desjardins, & McConkey, 2011). It was used in the present study to describe both the area needed to grow the crops that feed all animals in the sheep and beef industries, as well as the GHG emissions caused by the production of those crops. The crop complex area includes both the roughage and grain crops in the animal diet. A relative comparison of areas in the Sheep Crop Complex (SCC) with the Beef Crop Complex (BCC) on the basis of five crop type groups is shown in Table 1. Corn silage was in a crop category by itself because it is both a roughage and an annual crop. In ULICEES, only improved pasture areas were considered in the GHG emission budgets because un-improved pasture does not receive any farm inputs (Vergé et al., 2012). The crop areas, shown in Table 1 as percent of all areas in each crop complex, were estimated from livestock diets using the ULICEES model.

Table 1. Livestock (LS) crop complexes of the sheep and beef industries in Eastern and Western Canada based on five different feed types during 2006

Feed	Annuals		Alfalfa	Other	Improved	All crop
type	Grain	Silage	mixes	hay	pasture	complex land
	% of area in the crop complex of each LS type					
	Eastern Canada					
sheep	7	2	40	33	18	100
beef	16	3	27	28	25	100
	Western Canada					
sheep	12	0	42	13	32	100
beef	21	0	29	14	36	100

3.2.1 Grain Crop

As was done for the four previous complexes, the grain area in the SCC is the product of the sheep population, their diet and the yield of each feed grain, integrated over all grain crops in the sheep diet. Because Statistics Canada gives livestock rations for a whole year (Elward et al., 2003) these data give the total quantity of feed consumed during the life of market lambs that are younger than one year when slaughtered. The number of market lambs required to determine the annual GHG emissions budget must represent the average yearly population. Therefore, feed intake over the life of these short-lived animals was expanded to obtain the equivalent feed quantity over all sheep that lived during the full year. Rations were multiplied by the ratio of market lamb population slaughtered in 2006 (Statistics Canada, 2009) to the population of all living market lambs at the time of the 2006 agricultural census. The ratio for Canada was 1.92. This high ratio is a reflection of the lives of market lambs only being about 190 days, compared to a full year.

3.2.2 Perennial Forages

To estimate the area of perennial forage in the SCC, the provincial crop areas provided by Statistics Canada (2002) had to be partitioned among the dairy, beef and sheep populations. However, because there were no yield data collected for forage crops in Canada, the forage components of the SCC could not be calculated in the same way as the grain components. Since the harvest from this land was limited to fodder for sheep, beef or dairy cattle, the consumption amounts for each province, forage type and age-gender category (Elward et al., 2003) were used to partition the forage areas among these categories over each of the three ruminant livestock types. The four sources of roughage as defined by the Canadian agricultural census (Statistics Canada, 2002) include tame or seeded pasture, alfalfa and alfalfa mixes, corn silage and all other tame hay and fodder crops (Table 1).

3.3 Animal Population and Production

3.3.1 Animal Populations

Assessing all animal categories during one year would be equivalent to the complete life cycle of the meat produced in that year (Dyer, Vergé, Desjardins, Worth, & McConkey, 2010b). Because ULICEES calculates GHG emissions separately for each age-gender category, the true carbon footprint of slaughtered lambs is defined by the GHG emissions from the whole sheep population. The three age-gender categories used to describe the sheep population are presented in Table 2. Rams were combined with ewes as one category because of the very small number of rams.

Table 2. Eastern and Western Canadian sheep populations by age-gender category recorded on July 1 for the 2006 census

	Head,000			
Region	Rams and Ewes	Replacement lambs	Market lambs	Total population
East	369	52	164	584
West	234	41	164	439
Canada	602	93	328	1,023

3.3.2 Canadian Market Lamb Production

The GHG emission intensity of Canadian sheep was based on the LW at the time of slaughter, rather than the average LW during its growing life span. Since the ideal market LW is 45 to 50 kg (BCMAL, 2013), 48 kg was used as a benchmark LW in the emission intensity estimates. Due to data limitations and the small size of the industry, we did not try to differentiate east-west market lamb LW. Since sheep farmers must cull their oldest ewes every year, 22% of the breeding ewes contribute to the carcasses going to market (Hale, Coffey, Bartlett, & Ahrens, 2010), equivalent to an average of 4.5 reproductive years for the breeding ewe. In comparison, a six year breeding life was used for beef (Vergé et al., 2008a). The LW assumed for the culled ewes was 57 kg (Hale et al., 2010), while the LWs for slaughtered calves, heifers, steers and culled cows were as used in ULICEES (Vergé et al., 2012).

3.3.3 Beef to Lamb Protein Differences

The difference in GHG emission intensities between the beef industry and the sheep and lamb industry was assessed on the basis of protein supply. In this context, protein is taken to include only human edible protein (excluding blood meal, pet food, edible offal and leather). This comparison does not allow for potential nutritional differences between beef and lamb. The LW conversions to protein were 6.4% for slaughter lambs (Pouliot et al., 2009; USDA, 2009) and 8.3% for slaughter steers and heifers (Dyer et al., 2010a; USDA, 2009).

4. Results

4.1 Land Areas and Sheep Populations

There are noticeable differences in the land use shown in Table 1 between the east and west for both the BCC and SCC. Silage is only fed in measurable quantities in Eastern Canada. The areas in the alfalfa mixes (third column) were almost 50% higher in the SCC than in the BCC in both regions. The harvested perennial forage (columns 3 and 4) accounted for relatively more area in the SCC than in the BCC in both the east and the west. The beef industry in the east used 40% more of its crop complex area as improved pasture land (fifth column) than the sheep industry, whereas this difference was only 11% in the west. Most importantly, in both the SCC and the BCC, Western Canada had appreciably more of its land base in feed grains (first column) than did Eastern Canada.

Table 2 shows that breeding sheep are just over half of the whole Canadian population, which is a reflection of the short lifespan of the slaughter lambs. Although these replacement lambs are not counted as breeding stock, these counts include rams which make up 5% of the ewe population. In the 2006, July 1 census records, market lambs are more than two thirds of the ewe population in Western Canada, but are just under half of the ewe population in Eastern Canada. These lamb-to-ewe ratios are only a little lower than the marketing survey records shown in Figure 1 for July 1, 2006 (Statistics Canada, 2009). In Western Canada, the ewe population declined steadily by about 20% throughout the nine years, while in Eastern Canada, the ewe population did not start to decline until after 2004 (Figure 1). Overall, sheep populations are a little lower in the west than in the east, with a little over a million sheep in Canada (Table 2).

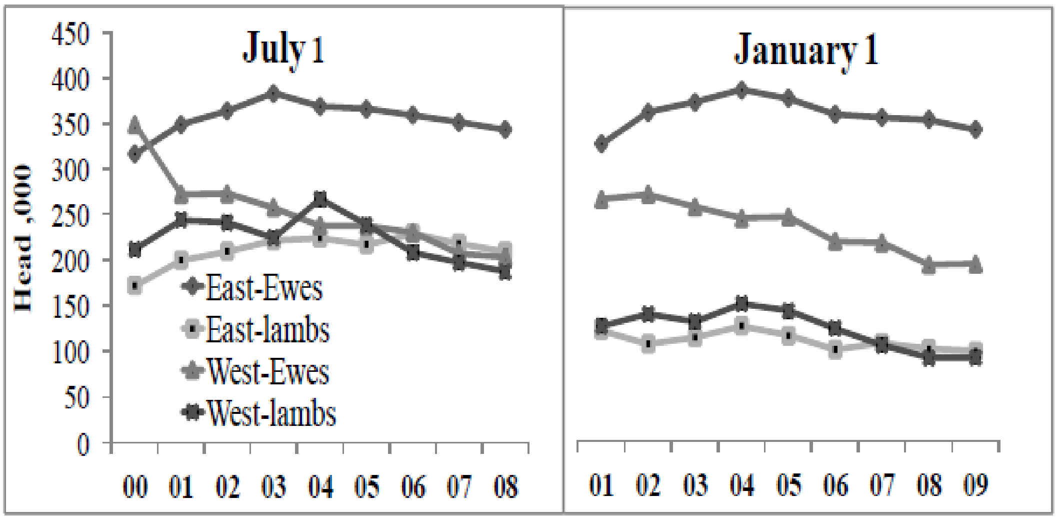

Figure 1. Breeding ewe and lamb populations over Eastern and Western Canada recorded on July 1 and January 1 between July, 2000 and January, 2009

The total GHG emission budgets for sheep and beef cattle are shown in Table 3. The proportion of CH_4, N_2O and fossil CO_2 emissions (in CO_2e) from sheep in Western Canada were 54%, 35% and 11%, respectively, while for beef they were 60%, 28% and 12%, respectively (Table 3). The distribution for beef was similar to the 58%, 33% and 9% distribution of these three GHGs reported for beef on an experimental farm in Alberta between 2008 and 2010 (Basarab et al., 2012). Due to the very small population, around 1 million head in 2006, GHG emissions from raising beef cattle were roughly two orders of magnitude higher than the GHG emissions from raising sheep (Table 3). For beef, the GHG emissions in the west were much higher than in the east, while the east-west distribution of GHG emissions for the sheep industry was consistent with the 60% to 40%, east to west, sheep population split shown in Table 2. In the west the percentages of the total GHG emissions that CH_4 emissions accounted for from the two industries were similar. The CH_4 share of GHG emissions was slightly lower in the east for both industries. For sheep, as well as for eastern beef, N_2O emissions exceeded fossil CO_2 emissions by three and half times.

Table 3. Greenhouse gas (GHG) emissions from the sheep and beef industries in Canada in 2006

	Tg CO_2e							
	CH_4	N_2O	CO_2	Total GHG	CH_4	N_2O	CO_2	Total GHG
	Sheep				Beef			
East	0.10	0.09	0.03	0.22	3.05	1.87	0.66	5.58
West	0.07	0.05	0.01	0.13	18.10	8.07	1.82	27.99
Canada	0.17	0.14	0.04	0.35	21.15	9.94	2.48	33.57

4.2 GHG Emission Intensity

Table 4 shows the comparison of the sheep and lamb industry with the beef industry on the basis of the GHG emissions (in CO_2e) per weight of protein produced. In terms of protein based intensity, fossil CO_2 and CH_4 emissions from sheep exceeded those from beef cattle by 30%. For the N_2O emission intensity, the lamb intensity was 2.2 times as high as that of beef. For total GHG emission intensities, lamb production exceeded beef by factors of 1.31 in the east, 1.65 in the west and 1.65 for Canada. In both lamb and beef production, CH_4 accounted for 50% to 60% of total emissions, while fossil CO_2 accounted for 7% to 11% of the total and N_2O accounted for 30% to 40% of the total. For lamb production, CH_4 emission intensities as a share of the total GHG emissions were slightly lower than for beef, while the lamb N_2O emission intensity share of its total was slightly higher. These differences reflect the differences in manure since differences between sheep and beef manure affects both CH_4 and N_2O emission rates. The spread between CH_4 and N_2O emission intensities was slightly higher in the west than in the east for both industries. This same pattern was seen in the total GHG emission beef-sheep comparisons (Table 3).

Table 4. Protein-based emission Intensity of CH_4, N_2O, fossil CO_2, and total GHG from sheep and beef cattle in Eastern and Western Canada during 2006

	kg CO_2e/kg protein							
	CH_4	N_2O	CO_2	Total GHG	CH_4	N_2O	CO_2	Total GHG
	Sheep				Beef			
East	102	93	27	223	93	57	20	170
West	113	73	21	207	81	36	8	126
Canada	107	85	24	217	83	39	10	131

The GHG emission intensity reported in the LCA for sheep in France (Gac, Ledgard, Lorinquer, Boyes, & Le Gall, 2012) without an adjustment for the wool byproduct was 12.9 kg CO_2e/kg LW. Williams, Audsley, & Sandars (2012) found the GHG emission intensity for lamb production in northern England to be 22 tCO_2e/t edible carcass. Using the percents of carcass per LW and of carcass after fat trim presented for beef by Dyer et al. (2010a), this result was converted to 12.3 kg CO_2e/kg LW (Figure 2). The GHG emission intensity for lamb production was found to be 12.9 kg CO_2e/kg LW in Wales (Edwards-Jones et al., 2009) and 10.0 kg CO_2e/kg LW for the extensive production system in Ireland (Casey & Holden, 2005). The New Zealand (NZ) results reported by Cac et al. (2012) were 8.5 kg CO_2e/kg LW. The much lower intensity was expected for NZ, due to warmer climatic conditions, year-round grazing in perennial pastures and no GHG emissions linked to the production of harvested feed and manure management.

The comparison of this paper with the emission intensities from sheep in other countries required that GHG emission intensities be expressed on a LW, rather than protein, basis. The gas-specific emission factors shown in Table 5 represent close to primary calculations within ULICEES. However, they could not be broken down to the per-number of head basis, because of weight and diet differences among the age-gender categories in each livestock type. Nor could they be broken down by area because the SCC involves three distinct types of land use (pasture, harvested perennial forage and annual feed crops). These emission factors are the components of the LW-based emission intensities for Canadian lambs shown in Figure 2.

Table 5. GHG emission factors for sheep and beef cattle in Eastern and Western Canada during 2006 based intensity of emissions of CH_4, N_2O, and fossil CO_2 per unit of LW[1] of slaughter animals

	kg CO_2e/kg LW					
	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2
Region	Sheep			Beef		
East	6.5	6.0	1.7	7.7	4.7	1.7
West	7.3	4.6	1.3	6.7	3.0	0.7

[1] LW = Live Weight of slaughter animals.

The average GHG emission intensity of lambs from Table 4 (based on 6.4% protein/LW) was 13.9 kg CO_2e/kg LW for Canada, 14.2 kg CO_2e/kg LW for the east, and 13.2 kg CO_2e/kg LW for the west (Figure 2). The Canada-wide LW based GHG emission intensity for lambs exceeded the English and French LW based emission intensities by 13% and 7%, respectively. The emission intensity of the Canadian sheep industry was almost double that of the New Zealand sheep industry. Using 8.3% protein for slaughter steers and heifers, the average Canadian GHG emission intensity of beef from Table 4 was 11.6 kg CO_2e/kg LW. For the eastern and western beef industries, the intensities were 14.2 kg CO_2e/kg LW and 11.2 kg CO_2e/kg LW, respectively. In their LCA for sheep, Gac et al. (2012) proposed two adjustment factors for the wool byproduct in the carbon footprint of lamb production in France. The reduction factor based on economic allocation was considered negligible, at 0.3%, in France, given the low global value of wool. However, if the reduction factor based on mass allocation in France, 10.4%, was applied to the Canadian lamb industry, the GHG emission intensity of lambs would be reduced to 12.4 kg CO_2e/kg LW for Canada.

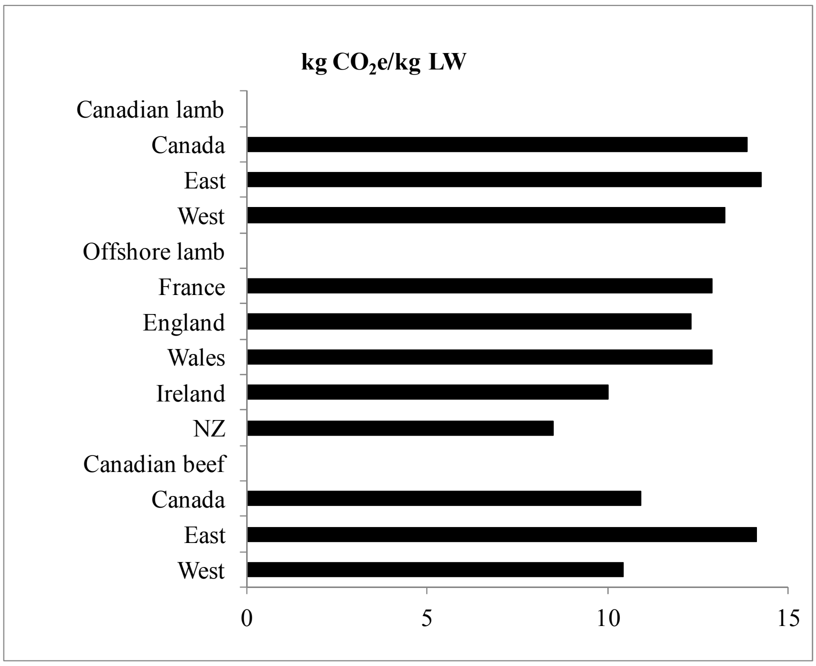

Figure 2. Comparisons of the GHG emission intensities of Canadian beef, lamb and offshore lamb, including France, England, Wales, Ireland and New Zealand (NZ), on the basis of live weight (LW) production for 2006

5. Discussion

The high ratios of ewes and rams to replacement lambs in Table 2 suggest that the reproductive lifespan of a ewe is about 6 years in Canada which is appreciably longer than the 4.3 year lifespan reported by Williams et al. (2012) or the 4.5 years suggested by Hale et al. (2010). Rather than a 6 year breeding life, however, it is more likely that Statistics Canada has miscounted the age-gender categories of sheep. For example, replacement ewe-lambs which have not yet given birth or ewes that are soon destined for slaughter as culls may both have been counted as breeding ewes. The margin by which breeding sheep (rams and ewes) outnumbered the combined replacement and slaughter lambs was 70% in the east and 10% in the west based on the 2006 census data. Also, the ratio of rams and ewes to the replacement lambs in Table 2 is higher in the east. These east-west differences are consistent with Figure 1.

Even though the sheep GHG emission intensities generated by ULICEES (Figure 2) exceeded the French and English sheep industries, these differences were considered to be reasonably close. The higher Canadian GHG intensities are partly due to the more severe climate in Canada. They were also partly due to the intensive production system used in Canada compared to the offshore lamb industries (Edwards-Jones et al., 2009), particularly Ireland. Figure 2 suggests that beef from Eastern Canada has a higher carbon footprint than lamb from the five offshore lamb industries that were compared here. However, due to the differences in protein to LW ratios, emission intensity estimates based on LW mask 33% of the difference between Canadian lamb and beef based on edible protein. Hence, the differences seen in Table 4 give a more realistic comparison of eastern Canadian beef to offshore lamb than shown in Figure 2.

The east-west differences in GHG emissions and emission intensities for both the sheep and beef industries (Tables 3 and 4) were mainly due to higher N_2O emissions related to the more humid conditions and wetter soils in Eastern Canada (Desjardins et al., 2012; Rochette et al., 2008). While they were not allowed for in this analysis, the age and weight of lambs before slaughter, fecundity and breed, may be possible sources of east-west differences. However, with the market for Canadian wool being so low, there is no incentive for Canadian sheep farmers to choose breeds based on wool production rather than meat (Hosford, 2007; Stewart, personal communication).

The sheep and lamb industry in Canada is very small relative to the sheep industries in England and France (Walker, 2008) and in comparison to the Canadian beef industry (Table 2). It is dispersed over large areas dominated by other farm types. Consequently, it is not surprising that the data on sheep breeds and management needed to make in depth regional comparisons have not been gathered in Canada. Being a small industry dispersed over long distances and a range of climates, wide variances should be expected on the mean Canadian GHG emissions presented in this paper.

The agreement with the distribution of emissions over the three GHGs between the estimated western beef industry (Table 3) with the measured emissions from the beef herd on the Alberta experimental farm was reasonably close. This indirect verification for the beef component of ULICEES, even though it was limited to one site, provided some confidence in the value of ULICEES as a tool for this analysis. The east-west difference in the GHG emissions from the beef industry is consistent with GHG emission assessment reported by Desjardins et al. (2012). Whether using rangeland to graze sheep is sustainable would depend on a range of ecological factors as well as GHG emissions, and all of these factors must be considered in evaluating this land use policy.

6. Conclusion

Perhaps the most surprising aspect of the current Canadian sheep industry was its intensive production practices and the relatively high dependence on grains in the sheep diet. With the GHG emission intensity of the current sheep industry exceeding that of beef throughout Canada and for all three GHGs (Tables 4 and 5), there appears to be little benefit in expanding the sheep industry under the current grain dependent production system in either Eastern or Western Canada, at least from the perspective of the livestock carbon footprint. Differences in the foraging habits of sheep and cattle may mean some ecological benefits in grazing sheep that should be explored. Although the protein basis of comparison was more dramatic, both the LW and protein based GHG emission intensity indicators show the disadvantage of relying on lamb as a protein source, compared to beef.

For more accurate assessment of the role that sheep should play in the Canadian livestock industries, a repeat of the 2001 diet survey of all livestock types (Elward et al., 2003) is needed. The increasing availability of biofuel feedstock byproducts can do much to increase dietary energy and protein and reduce the carbon footprints of all livestock commodities in Canada. This new form of land use adds further incentive to update the livestock diet information base across Canada.

The next step following the research recommended above will be an LCA which would include all of the processing of the meat (lamb), offal, hide and wool products and byproducts. While ULICEES is not an LCA model, it has been interfaced with an LCA for the carbon footprint of the dairy industry (Vergé et al., 2013) and has been applied to an LCA of the vertical integration of the beef industry (Desjardins et al., 2012). Although they were beyond the scope of this paper, ecological and social values need to be integrated with the GHG emission estimates in this LCA. The ULICEES model and the results shown in this paper would provide a basis for an LCA of Canadian lamb production. As the field monitoring research and data upgrades proposed above progress, sensitivity analysis should be done on the ranges in the terms that go into the ULICEES estimates of the GHG emissions from sheep and lambs in Canada.

While both economic and mass allocation would have to be investigated for dealing with wool on an international scale, the very low economic value of this byproduct in France (Gac et al., 2012) and the growing preference for breeds that shed their fleece (Walker, 2008) effectively eliminates wool from the carbon footprint of the lamb industry, at least in Canada. Since the market demand for wool is almost gone, economics was the more meaningful byproduct allocation for both the Canadian and French sheep industries. A more important justification than wool for continued support of lamb production in Canada would be the ability of sheep to digest plant types that are unsuitable as cattle feed, and in some cases (such as leafy spurge) are toxic to cattle. The role that sheep in concert with cattle could play in making sustainable use of rangeland, where a range of plant species must be allowed to grow, should be investigated as a land use policy in Western Canada. This policy, however, would be a departure from the current intensive approach to lamb production. Whether using rangeland to graze sheep is sustainable would depend on a range of ecological factors as well as GHG emissions, and all of these factors must be considered in evaluating this land use policy.

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