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Chapter 17

Changes in Greenhouse Gas Emissions from Displacing Cattle for Biodiesel Feedstock

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/60047

1. Introduction

The adoption of biodiesel as a fossil fuel reduction strategy in Europe has created a demand for vegetable oil as a biodiesel feedstock and a new market for the canola oil grown in the Canadian Prairies. Canola is a variety of rapeseed developed in Canada which contains reduced levels of erucic acid, making its oil palatable for human consumption, and reduced levels of a toxic glucosin, which makes its meal a potential livestock feed. Because of the extracted canola oil being suitable for use as cooking oil, canola is considered to be a new and distinct crop from rape seed in Canada.

The market acceptability of canola oil as a biodiesel feedstock in Europe depends on the Carbon Footprint (CF) of its production being significantly lower than that of conventional diesel fuel [1]. In October 2012, The European Commission amended its directive relating to the quality of petrol and diesel fuel and the promotion of the use of energy from renewable sources. These amendments set mandatory margins for the amount of fossil CO_2 required to be offset by biofuels. For biofuel installations in operation on or before 1 July 2014, biofuels must achieve a greenhouse gas emission savings of at least 35% until 31 December 2017 and at least 50% thereafter. If the physical production of biofuels starts after 1 July 2014, the greenhouse gas emission saving from the use of biofuels must be at least 60% of the fossil CO_2 emissions of the equivalent petro-fuel energy.

These Directives also proposed a provision to address changes in the indirect land use given that current biofuels are mainly produced from crops grown on existing agricultural land. Therefore, if the demand for canola biodiesel continues to increase, questions arise about where the additional feedstock would be grown. The first goal of this chapter was to assess the impact of expanding canola production on beef production in the Prairie Provinces of Canada. The scope of this assessment excludes any substitution of beef with non-ruminant livestock in response to canola expansion. The second goal was to determine the feedback effect from this impact on the Greenhouse Gas (GHG) emission cost of canola biodiesel.

2. Background

The primary impact of canola expansion was expected to be the displacement of other grains and oilseeds from the land most capable of growing annual crops. The assessment in this chapter did not consider the small areas of canola that might be seeded into lower quality land because the expectation is that most of that land would not support the cultivation of canola. Since the expansion of canola between 1986 and 2006 happened concurrently with, and possibly as a consequence of, the shrinkage of summerfallow [2], there is little indication that canola expansion to date has caused the direct conversion of land under permanent year-round cover into annual crops.

Without this conversion of perennial forage areas to canola, a potential decrease in soil carbon could be ignored. However, the converse cannot be ruled out if beef production is forced to shift to a more forage (roughage) based diet. Because ruminants have the option of feeding on roughages, the land base that supports these livestock is likely to shift to more permanent cover if their feed grain supply is displaced by canola. Although beef cattle are the dominant ruminants in Canada, some consideration has been given to the potential expansion of sheep production [3]. The impacts of canola expansion on ruminant livestock production can be treated as secondary effects. An environmental effect is considered secondary when one environmental component is affected by another environmental component when the second component has been affected by a human activity [4, 5]. The activity being assessed in this chapter is the continued expansion of canola in Western Canada at the expense of livestock feed grains.

The Western Canadian beef industry is an intensive system that relies on finishing animals destined for slaughter in feedlots with a diet that is high in feed grains [6, 7]. Canadian lamb production is similarly intensive in this regard [3]. The conversion of these systems to extensive systems that are mainly based on grazing and hay consumption could be one of the indirect effects of canola expansion [8]. The main impact on the CF of beef production will be greater enteric methane emissions due to a higher share of roughage in the diet [7]. While Dyer et al. [8] qualitatively assessed the impacts on biodiversity from this potential land use change, a quantitative assessment of the GHG emissions from beef cattle displaced from a highly grain based diet into improved pasture or rangeland, and greater dependence on hay has not yet been carried out.

The GHG emission budgets of biofuel feedstock and livestock production have already been shown to strongly interact [9]. Instead of converting beef production from intensive to extensive production (as proposed in this chapter), Dyer et al. [9] replaced part of the beef population with hogs which, being non-ruminants, reduced enteric methane emissions. That beef-pork displacement scenario was based on the assumption that total protein supply must be maintained, and that hog and beef populations can be equated on the basis of their contribution to a constant supply of edible protein [10]. Unlike the assessment in this chapter, no change in the area for growing grain was allowed for in the replacement process in that analysis [9].

3. Methodology

While the expansion of canola can also displace baking quality grains or other food crops for humans, this assessment will only deal with the canola that displaces livestock feed grains, which would lead to changes in the livestock diet. The first set of impacts from canola expansion into ruminant livestock production will be on land use. The expected output variables from the analysis of land use changes included the weight and area of feed grain that will be displaced by the expanded canola crop, the areas of roughage crops, including, hay (for winter feed), pasture (improved) and rangeland (unimproved pasture), and the number of displaced grazing animals computed from the roughage crop yields and stocking rates [11, 7]. This chapter also considers the net changes in the GHG emissions budget for canola and the implications for protein supply.

3.1. Rangeland forage availability

If part of the increased forage in the ruminant diets is to come from more grazing, then one of the pools of available land would likely be rangelands. Therefore, the first land use change question addressed in this chapter will be how much rangeland could be allocated to grazing the livestock that are taken off feed grain due to the canola expansion. In addition to the impact on biodiversity [8], overgrazing would make the forage digestibility on rangeland less than the forage digestibility on tame pasture [12], which effectively lowers forage yields. Therefore, it is essential to set stocking rakes at a population density that is sustainable.

The Ecological Sustainable Stocking Rate (ESSR) was an essential indicator in quantifying the rangeland grazing resources. ESSR values have been quantified for rangelands in most of the agro-ecological sub-regions of the Prairie Provinces [11, 13-15]. The fraction of each agro-ecological sub-region in each of the three Prairie Provinces was extrapolated by Dyer et al. [16]. Integrating the ESSR fractions for these regions in each province gave the approximate provincial ESSR values shown in Table 1.

Each ESSR represents the sustainably grazed forage by one Animal Unit Month (AUM) from a given area of rangeland. One Animal Unit (AU) was defined as being equal to one 454 kg cow with calf, or five breeding sheep (ewes and their lambs), based on equivalent forage consumption [11, 17, 18]. One AUM is, therefore, a measure of forage production. Provincial ESSR and rangeland areas were combined to approximate the rangeland forage yields and the Total Sustainable Animal Units (TSAU) in each province shown in Table 2. To determine yields, an AUM must be converted to the required quantity of feed for each AU. The ESSR from Table 1 were converted to the required areas of rangeland per AU over six months (Column 3). The

ESSR (Column 1) were used to derive forage yield estimates for the three Prairie Provinces (Column 4). The hay needed to over-winter one AU (one breeding cow and her calf or five ewes and their lambs) must approximately equal the forage that a typical cow would have grazed from the rangeland during the six-month summer period [19].

Ecoregions	DMG	MG	FF	PNF	
		ESSR (AUM/ha)			
	0.37	**0.84**	**1.68**	**0.88**	**ESSR**
Province	**Share of province in each Ecoregion**				**AUM[1]/ha**
Manitoba				100%	0.88
Saskatchewan	30%	35%		35%	0.71
Alberta	20%	30%	25%	25%	0.97
	Canadian Prairie Ecoregions:				
DMG =	Dry Mixed Grass		FF =	Foothills Fescue	
MG =	Mixed Grass		PNF =	Parkland-Northern Fescue	

[1], AUM = Animal Unit Months

Table 1. Provincial Ecological Sustainable Stocking Rate (ESSR) factors for Canadian Prairie rangeland interpolated from ecoregion ESSR estimates

One AU has a daily requirement of 11.8 kg of dry matter forage [17]. Therefore, one AU-month (AUM) equals 355 kg of dry matter forage (30 days times the daily forage requirement). Six AUM (half year of feed) would equal 2.13 t of dry matter per AU. Forage yields in each province (Column 4 of Table 2), in t per ha, were the product of each provincial ESSR (Table 1) and 0.355 t dry matter. Table 2 also shows the rangeland area needed to support one AU for six months of summer grazing (Column 3), the total rangeland area (Column 2) and the TSAU (Column 5) in each province.

	ESSR	**Rangeland**	**Summer forage**	**Yield[1]**	**TSAU[2]**
Province	**AUM/ha**	**ha × 10^6**	**ha/AU {6 months}**	**t/ha**	**AU × 10^6**
Manitoba	0.88	0.72	6.9	0.31	0.10
Saskatchewan	0.71	4.55	8.4	0.25	0.54
Alberta	0.97	5.29	6.2	0.34	0.85

[1], Yield = Dry matter yield of forage from rangeland

[2], TSAU = Total Sustainable Animal Units

Table 2. Areas, carrying capacities and sustainable forage yields of rangeland in the Prairie Provinces of Canada.

http://dx.doi.org/10.5772/60047

3.2. Changes in arable land use

The next phase of this chapter considers the impact of expansion of canola on the areas seeded to livestock feed crops. Since they account for roughly 90% of the grains in cattle diets in western Canada, a mix of barley and oats was taken as representing a typical ration of feed grain in the prairie region. The area currently used to grow feed grain (oats and barley) and canola is shown in Table 3 in each province for the two most recent census years (2006 and 2011). The total provincial production and yields for these crops are also shown in Table 3. The respective yields were used to determine how much feed grain area would be displaced by expanded canola. The dry matter weights of production in Table 3 were used to determine how much new area in perennial forage would be needed the replace the lost livestock feed.

This assessment was based on four scenarios of how expanded canola could impact beef production (described in Section 3.3). The land use changes that are the basis of these scenarios are shown in Table 4. These changes include the expansion of canola, the feed grain displaced by canola and the areas of additional hay needed to replace the displaced feed grain. This table represents a dynamic area balance calculation for testing the quantitative response to assumed expanded areas of canola to be of the crops being displaced by canola. The controlling parameter for this table was the total area of new canola across all three provinces. While this table is a dynamic tool that changes depending on what value for this parameter is selected, the version of this table shown in this chapter assumed a total area of 0.7Mha for both census years. This canola area total was then distributed among the three provinces so that the rangeland in any one province would not be exceeded. The 0.7Mha of expanded canola was the maximum new canola area that the rangeland could have sustainably replaced the required forage.

	Crop area	**Yield**	**Production**	**Crop area**	**Yield**	**Production**
	000,ha	**t/ha**	**000,t**	**000,ha**	**t/ha**	**000,t**
		Canola			**Feed Grain**	
		2006			**2006**	
Manitoba	1,002	1.80	1,803	680	3.13	2,105
Saskatchewan	2,558	1.50	3,836	1,963	2.54	4,975
Alberta	1,728	1.90	3,283	1,716	3.11	5,301
Prairies	5,287	1.71	8,922	4,358	2.88	12,381
		2011			**2011**	
Manitoba	1,064	1.60	1,703	277	2.46	682
Saskatchewan	3,885	1.80	6,993	1,323	3.04	4,020
Alberta	2,438	2.20	5,364	1,475	3.54	5,204
Prairies	7,388	1.93	14,060	3,076	3.26	9,906

Table 3. Crop production comparisons for canola (biofuel feedstock) and barley (livestock feed grain) in the Canadian Prairie Provinces during two census years.

The crop type and year-specific crop yields from Table 3 were used to convert areas to production quantities. The computation sequence in this balance was:

1. set the area to produce canola,
2. let the area of canola define the displaced area of feed grain (barley and oats),
3. convert displaced feed grain area to lost feed grain production,
4. define the required production of forage to replace feed grain, and
5. determine the new forage area from the required forage production.

Since this chapter allowed for the contribution of canola meal to the ruminant diet, the lost feed grain production was reduced by the weight of canola meal from the expanded area of canola. The weight of extractable oil from canola is 39% of the harvested crop weight, which means that 61% of the harvested canola dry matter weight is available as livestock feed supplement [18, 19].

As a general rule for sheep and cattle, 1.8 kg of average quality hay can replace approximately one kg of barley or oats [22-24]. This broadly accepted rule of thumb allowed land under feed grains and under perennial forage to be equated on the basis of nutrient energy for ruminant livestock. This approximation also allowed the land diverted away from the feed grains into canola production to be expressed in terms of the additional tame hay or grazing land that ruminant livestock would need to maintain their dietary energy intake.

	New canola		**Displaced feed grain**		**Required**	**Tame hay/pasture**		**Rangeland**	
	area	**production**	**area**	**production**	**forage**	**yield**	**area**	**yield**	**area**
	000,ha	**000,t**	**000,ha**	**000,t**	**000,t**	**t/ha**	**000,ha**	**t/ha**	**000,ha**
				2006					
Manitoba	109	197	70	218	393	4.22	93	0.31	720
Saskatchewan	315	473	201	511	919	3.43	268	0.25	4,184
Alberta	276	524	171	532	958	4.65	206	0.34	2,792
Prairies	700	1,193	442	1,261	2,269	4.10	567	0.29	7,695
				2011					
Manitoba	63	101	38	94	169	4.22	40	0.31	543
Saskatchewan	301	542	192	584	1,052	3.43	307	0.25	4,164
Alberta	336	739	208	734	1,321	4.65	284	0.34	3,852
Prairies	700	1,382	438	1,412	2,541	4.10	631	0.30	8,559

Table 4. Changes in areas and production resulting from displacement of barley by 700, 000 ha of canola needed for biodiesel feedstock, and the areas of tame hay, improved pasture or rangeland to grow enough forage to replace the lost feed grain for cattle (represented by barley and oats) during two census years in the Prairie Provinces.

Tame hay yields are less accurately reported (by survey) than the yields of annual field crops. A typical yield of about 4.1 t/ha across Canada, however, has been estimated [25]. Bootsma et al. [26] demonstrated that perennial forage yields on improved land vary with regional climate and soil types. For simplicity, it was assumed that the spatial variance among these tame hay yields (Column 6 of Table 4) would be the same as among the rangeland forage yields (Column 8) and that the provincial tame hay and improved pasture yields could be scaled to the rangeland yields (Column 8 of Table 4 or Column 4 of Table 2). The steps in the above computation sequence relate to the column numbers in Table 4 as follows: Step 1 is in Column 1, Step 2 (allowing for canola meal) is in Column 3, Step 3 is in Column 4, Step 4 is in Column 5, and Step 5 is in Column 7 for tame hay and Column 9 for rangeland. Table 4 also shows the canola production in Column 2.

3.3. Defining the canola expansion scenarios

The second goal of this chapter was to determine the change in the GHG emissions budget for the ruminants undergoing a diet. Prior to this determination for livestock, two preliminary scenarios were considered for the additional forage crop resulting from canola expansion. The difference between not including canola meal in the diet of displaced beef cattle (Scenario 1) and including canola meal (Scenario 2) served to demonstrate the feedback effect of canola meal in partially mitigating the secondary effects of canola expansion into the feed supply for beef cattle.

Two additional scenarios were used to assess the secondary impact of the canola expansion on livestock production. The first (Scenario 3) involved relocating the displaced feedlot cattle to pasture and rangeland, and a diet much richer in hay. The second (Scenario 4) assumed that the steers and heifers destined for finishing in feedlots would be butchered as veal at the calf or pre-yearling life stage, rather than being relocated to feedlots, or to pasture and hay. In order to avoid a major drop in protein supply in this scenario, these pre-yearlings would be replaced with sheep to be grazed and wintered on hay.

Six age-gender categories define the lifecycle of western Canadian beef cattle based on the feed intake and live weight differences among these categories [7, 27]. This grouping put breeding bulls and cows in one category. Figure 1 defines the age-gender categories and shows the ages and their intake of annual feed grains. This grouping ignores the newborn calves because at this age these animals do not consume grain. The bottom three categories in Figure 1, which include the animals destined for slaughter, consume proportionally more feed grain than do the replacement categories. This dietary difference was essential to the GHG emission assessment described below.

To help understand the two livestock scenarios, the structure of the beef cattle population in the three Prairie Provinces is shown in Figure 2. The breeding stock included 0.7, 1.6 and 2.1 million head of cattle in Manitoba, Saskatchewan and Alberta, respectively in 2006, making up 46% of the beef cattle population of the Prairie Provinces. Bulls account for 5% of these breeding cattle. The animals that are less than one year old are split almost equally between bull calves and young heifers. About 7% of the animals shown as steers and slaughter heifers category in Figure 2 are slaughter calves. Although the younger age-gender categories

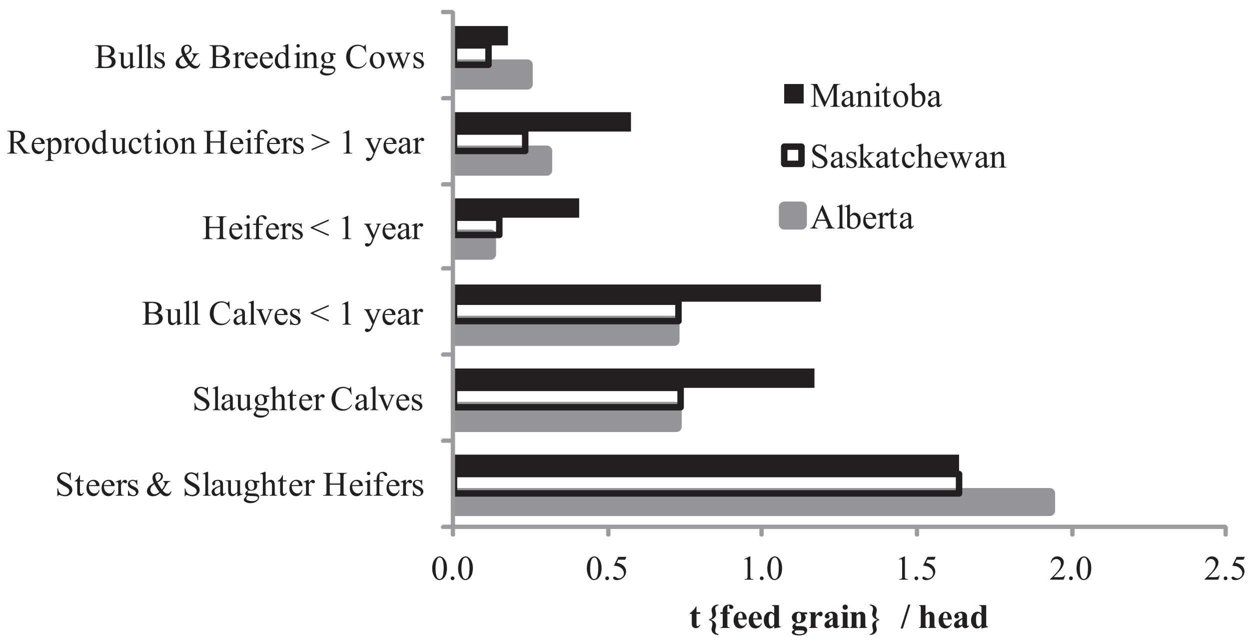

Figure 1. Annual feed grain consumption in each age-gender category of beef in the Prairie Provinces.

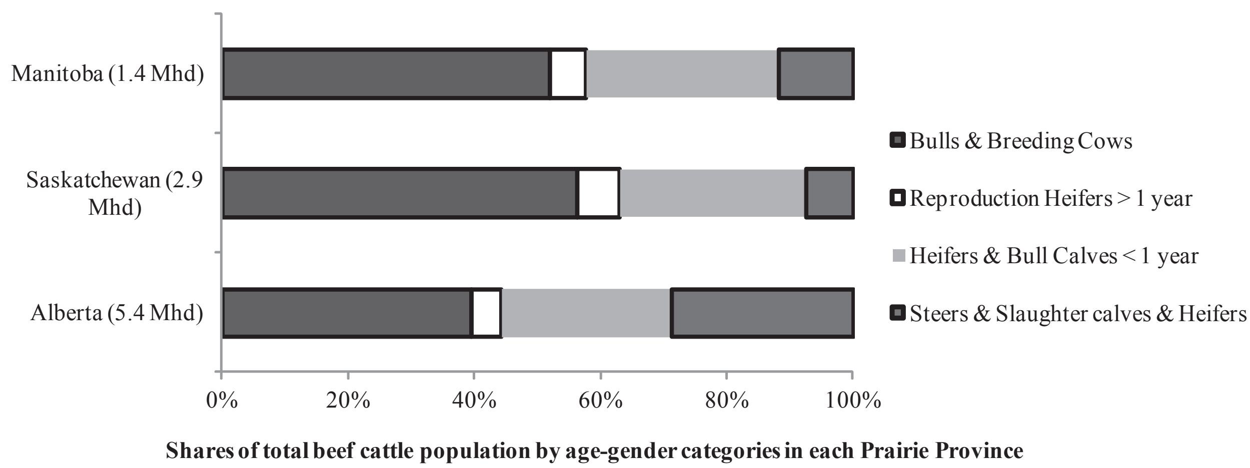

Figure 2. Age-gender based population distributions and total cattle populations (in millions of head (Mhd)) of the beef industry in the three Prairie Provinces of Canada during 2006.

fluctuate depending on market prices, the relative populations of the steers and slaughter heifers indicate that there is a net flow of these animals to the feedlots which are mostly located in southern Alberta.

In order to fully understand the full impact of livestock production on GHG emissions, the GHG emissions from the areas that provide livestock feed, not just emissions of enteric methane, must be included in this budget. The Livestock Crop Complex (LCC) defines the crop areas required to feed Canada's livestock populations [27, 28]. Five specific crop complexes have been defined in Canada, including the BCC, DCC, PCC, ACC and SCC, respectively, for beef, dairy, pork, poultry (avian) farms [7, 20, 29, 30] and, most recently, for sheep

[3]. The LCC concept has been used to quantify the cropland that was not used to support livestock in Canada [28]. This LCC-excluded land concept is similar to the LCC application in this chapter, since the land designated for canola expansion was removed from the BCC.

The crop complex area includes both the roughage and grain crops in the animal diet. Only the BCC, DCC and SCC in the Prairie Provinces include land in perennial forage. The grain area in each LCC is the product of population, diet and the yield of each feed grain, integrated over all grain crops in the livestock diet, although (as in Table 3) feed grain in this region is mostly a mix of barley and oats. In this chapter the potential changes in the BCC due to anticipated canola expansion were assessed for each of the three Prairie Provinces and for the Prairie Province region of Canada.

3.4. GHG emissions budget for ruminants

The GHG emissions for the two livestock scenarios were simulated for 2006 with the Unified Livestock Industry and Crop Emissions Estimation System (ULICEES) model [27]. ULICEES was created by assembling the five sets (discussed above) of livestock-specific GHG computations from the Canadian beef, dairy, pork and poultry industries [7, 20, 29, 30] in one spreadsheet model. Figure 3 shows the total GHG emissions for beef production in each prairie province calculated by ULICEES for 2006. The livestock GHG emission assessments include fossil CO_2, CH_4 and N_2O. Since these calculations provided a baseline for Scenarios 3 and 4, separate totals for the three GHGs are shown in Figure 3. These emissions are expressed as fossil CO_2 emission equivalent quantities.

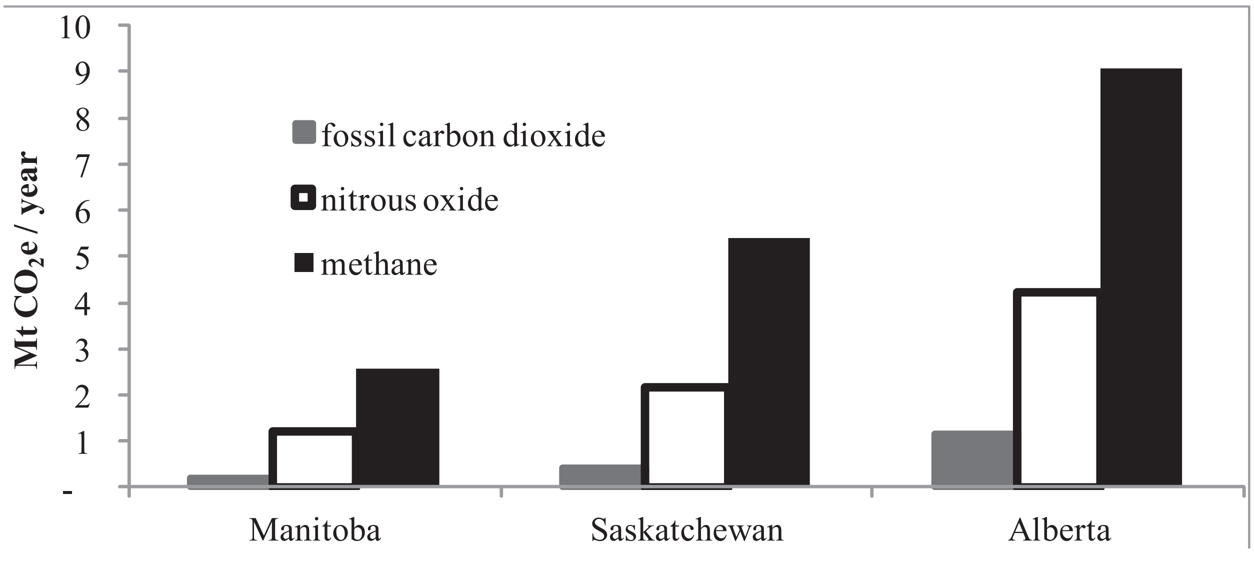

Figure 3. Total Greenhouse Gas (GHG) emissions from the beef industry in the Prairie Provinces of Canada during 2006.

ULICEES uses the Tier 2 methodology from IPCC [31], modified for Canadian conditions [32], to estimate nitrous oxide emissions for each age-gender livestock category. Methane emissions from enteric fermentation and manure storage were calculated separately by ULICEES [27].

Both methane source estimates also relied on IPCC Tier 2 methodology [31]. Both types of methane emissions were then calculated on a per-head basis for each age-gender category and multiplied by each respective category population. Using the six farm energy terms defined in [33], the provincial fossil CO_2 emission rates for 2006 were simulated by Dyer et al. [34]. These estimates were incorporated into ULICEES [27]. Unlike the CH_4 and N_2O mission estimates, the fossil CO_2 emission estimates were not distributed over age-gender categories within each livestock type.

Three ULICEES simulations for beef and lamb production in the three Prairie Provinces were required to describe the two livestock scenarios. The first ULICEES simulation was the baseline set of GHG emissions by the beef industry with no assumed changes in the population structure of the industry. To run the two additional ULICEES simulations, the changes in the age-gender livestock populations described above were implemented in the inputs to the ULICEES model. For ULICEES to implement the grass beef scenario (#3), the replacement heifers were used as an analog for grass beef because their diet is mostly forage [7, 27]. This meant that in the grass beef scenario (#3) the populations of steers, slaughter heifers and slaughter calves in ULICEES were transferred to the replacement heifer age-gender category. To apply ULICEES to the veal/lamb scenario (#4), the populations of steers, slaughter heifers and slaughter calves were transferred to the newly born calves' category, to which ULICEES attributes no GHG emissions [27]. In addition, the sheep populations had to be expanded to consume the forage no longer consumed by those animals that were converted to veal production. This was achieved by inflating the sheep populations by the ratios of meat animals in the beef industry to the sheep population expressed as protein in each province.

Before the reallocation of steers and slaughter heifers to the reproduction heifer category (Scenario 3), these populations were redistributed to match the distribution of breeding cows among the provinces. This was done to remove the influence of the concentration of feedlots in southern Alberta, to which the cattle destined for finishing for market before slaughter tend to gravitate. Before inflating the sheep populations in Scenario 4, the GHG emissions from sheep were redistributed to match the distribution of GHG emissions from beef cattle given by ULICEES. This was done to reduce instability caused by the populations of sheep in western Canada being very small relative to beef cattle.

3.5. Changes in the Carbon Footprint (CF) of canola

The CF of expanded canola must combine initial GHG emission costs of actually growing the canola crop with the secondary impact assessment of the crops being displaced by the canola. In addition, it must include potential benefits stemming from the shift from annual to perennial ground cover for both scenarios. The change in beef production (from feed grain to hay) would mean that the soil surface is never bare between crops which would cause atmospheric CO_2 to be sequestered as soil carbon. For the Prairie Provinces the average yearly carbon storage would be approximately 0.55 t{carbon}/ha [35], or 2.02 t/ha of sequestered CO_2. In this chapter when the CF determination takes all of these terms into account, it is then deemed to be the net CF of canola.

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Table 5 shows the GHG emission rates used for all four scenarios normalized to areas of expanded canola so that all of these coefficients have the same area basis. The first two columns show the emission rates for canola and feed grain [36], while the last two columns show the changes in the GHG emission rates of the two livestock scenarios (#3 and #4). Columns 3, 4 and 5 of Table 5 all represent emission rates for the new areas of hay in the expansion scenarios, with Column 3 showing the rates as reported by [36]. Columns 4 and 5 have been normalized to the areas in expanded canola. The differences between these two columns demonstrate the importance of substituting canola meal for part of the displaced feed grain. Column 6 of Table 5 gives the sequestration rate for CO_2 by the conversion to perennial forage normalized from the forage area to the expanded canola area in each province. The negative signs on these values illustrate that sequestration flux direction is apposite that of GHG emissions. Columns 7 and 8 include the increase in GHG emissions compared to the baseline GHG simulations normalized to the area remaining in feed grains in each respective scenario. Columns 7 and 8 do not include the emission cost of growing canola (Column 1) or the benefit of sequestered CO_2 (Column 6).

	Expanded	Displaced	Required forage			Sequestered	Livestock scenarios[5]	
	canola	feed grain	initial[1]	no meal[2]	with meal[3]	soil carbon[4]	grass beef	veal/lamb
	t CO_2e/ha							
Manitoba	1.30	1.19	0.52	0.69	0.44	-1.72	1.91	-2.52
Saskatchewan	1.03	0.68	0.39	0.52	0.33	-1.71	2.65	4.85
Alberta	1.28	0.95	0.53	0.63	0.40	-1.51	0.35	4.44
Prairies	1.16	0.88	0.48	0.60	0.39	-1.63	1.48	3.30

[1], GHG emission intensity of hay per unit area of hay grown and harvested, not normalized to canola.

[2], GHG emission intensity of forage with no substitution by canola meal, normalized to canola area.

[3], GHG emission intensity of forage with substitution by canola meal, normalized to canola area.

[4], fossil CO_2 sequestered by new forage, normalized to canola area.

[5], livestock GHG emission intensities not including areas of expanded canola and not normalized to canola areas.

Table 5. GHG emission intensities per unit area for canola, feed grains (represented by oats and barley combined) and hay, rates of CO_2 sequestration under new forage areas and two ruminant production scenarios, (area basis of intensities shown as footnotes) for the Prairie Provinces during 2006.

Figure 4 shows the changes in GHG emissions that can be attributed to the land use changes induced by the proposed expansion of canola. These changes were measured by the differences between the two scenario simulations and the baseline simulations shown in Figure 3. These differences were expressed as emission rates per unit area of feed grains in the baseline ULICEES simulations. Unlike the emission differences shown in Columns 7 and 8 of Table 5, those in Figure 4 include the cost of growing the expanded canola crop and the new forage crop, and the CO_2 sequestered by the land use change from feed grains to perennial forage.

The rates shown in Figure 4 were also normalized to baseline feed grain areas so that they have the same area base.

The GHG emission cost of growing canola and additional forage, and the sequestration of CO_2 under the new forage area were added to the assessment after the ULICEES simulation process. This was necessary because ULICEES computes the forage component of ruminant diets in the BCC and SCC (as well as the DCC) by partitioning areas from fixed pools of land in hay and in improved pasture to the regional beef, sheep and dairy populations [27]. Unlike the grain components of those diets, ULICEES cannot, therefore, create new areas of forage to meet changes in the BCC. Adding both of these terms to the simulations from ULICEES, required them to be expressed on the basis of the expanded area of canola (as shown in Table 5). Of the 2.3 Mha of feed grain area used in ULICEES to support cattle and sheep in the Prairie Provinces, Scenario 3 converted 44% to expanded canola while Scenario 4 converted 77% to expanded canola.

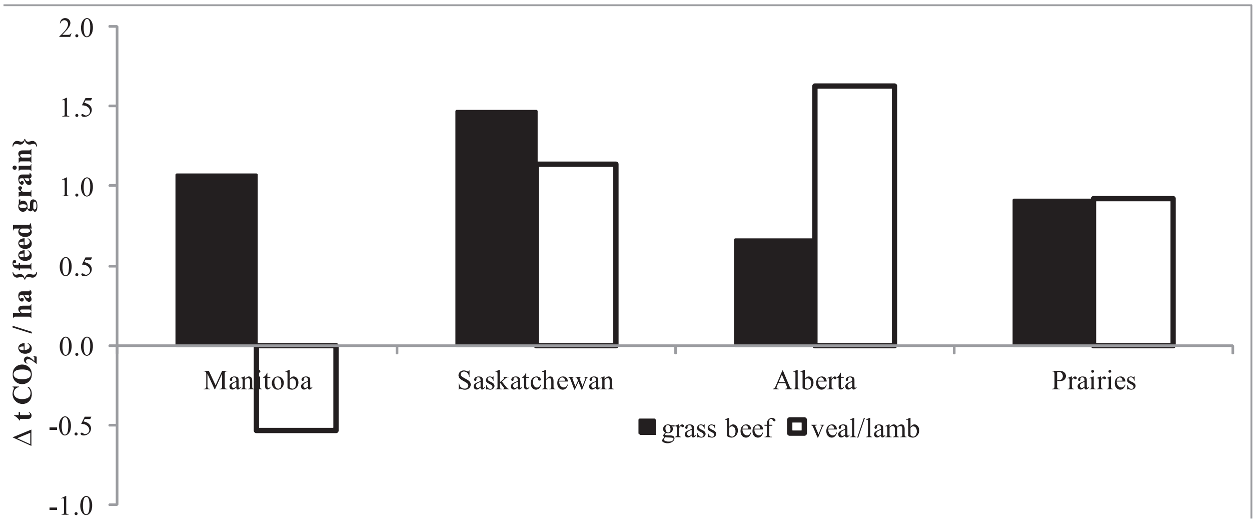

Figure 4. GHG emission intensity estimates for the two livestock based scenarios (including GHG emissions from the canola expansion and the CO_2 sequestration under forage) normalized to the area of feed grains in the diet of the baseline beef cattle populations in the Prairie Provinces during 2006.

3.6. Carbon footprints of the expansion scenarios

To calculate the GHG emissions budget for each scenario, the emission coefficients shown in Columns 4, 5, 7 and 8 from Table 5 were each integrated separately with the difference between the canola and feed grain emission coefficients, and the sequestration of CO_2 (Columns 1, 2 and 6 of Table 5). Table 6 shows the GHG emission rates from the four secondary impact scenarios for expanding canola in the three Prairie Provinces. Scenarios 2, 3 and 4 assume that canola meal can compensate for part of the displaced feed grain in the ruminant diet.

The GHG emissions intensities (EI_{1-2}) of the two scenarios based on crop differences (#1 and #2) were the result of straight forward addition of emission terms from feed grain (barley and oats combined) and perennial forages to the CF of canola. The inclusion of the CO_2 sequestration rates (SR) from Table 5 in Equation 1 reduced these GHG emissions intensity estimates. These terms were summarized as follows.

$$EI_{1-2,canola,net} = EI_{canola} - EI_{feed\ grain} + EI_{forage} - SR_{forage} \tag{1}$$

The crop-specific EI values in Equation 1 for each province and the region were taken from Columns 1 and 2, and either 4 or 5 of Table 5, depending on whether canola meal was assumed to be a feed supplement.

Using Columns 1 and 2 of Table 5, and either Column 7 for the grass beef (#3) scenario or Column 8 for the veal/lamb (#4) scenario, the GHG emissions intensities (EI_{3-4}) of the two livestock based scenarios (#3 and #4) can be represented symbolically by the following equation, which includes the same SR_{forage} term as Equation 1 and the emission cost of the additional hay (EI_{forage}) in each livestock scenario.

$$EI_{3-4,canola,net} = EI_{canola} - EI_{feed\ grain} + \Delta EI_{livestock} + EI_{forage} - SR_{forage} \tag{2}$$

However, the feed grain EI values in Equation 2 were generated as part of the ULICEES simulation of the livestock-specific Scenarios 3 and 4. The emission cost of the additional hay production appears as a separate term in Equation 2 because it had to be calculated externally from ULICEES. Since EI values generated by ULICEES were expressed on the basis of the scenario feed grain areas, it was necessary to convert the EI for canola and the SR for the new forage from Table 5 back to the feed grain area basis. This was done by multiplying the canola GHG emission rates from [36] and the SR terms from Table 5 by the areas freed from feed grain and adding the difference between these two GHG emission quantities to the respective GHG emission differences.

These new GHG emissions (for canola plus livestock and additional hay, minus the sequestered CO_2) were then divided by the respective new canola areas to give the emission rates shown in Table 6 to represent the net CF for canola under the two livestock scenarios. To convert from the feed grain to the new canola area basis, the area ratios of feed grain to canola were taken for the whole Prairie region for both livestock scenarios as a way of smoothing these normalized estimates over the three provinces.

Scenarios 1 and 2 were useful for demonstrating the role of canola meal in minimizing the crop displacement by the expanded canola area. As well, Column 4 of Table 6 (for Scenario 2) showed what the inclusion of carbon sequestration without accounting for GHG emissions from livestock would mean for the CF of canola. The difference between the sequestered soil carbon shown in Column 6 of Table 5 and Column 4 of Table 6 was that in Table 5 the sequestration rates did not include the GHG emission costs of growing the new forage. It was the CO_2 sequestration rates from Table 6 that were incorporated into Scenarios 3 and 4.

	Expanded	Required forage			Livestock		Fossil CO_2
	canola	no	with	with meal	scenarios		offset by
	only	meal[1]	meal[1]	and soil C[2]	grass beef[2]	veal/lamb[2]	canola
Scenario #		1	2	2	3	4	
				t CO_2e/ha{canola}			
Manitoba	1.30	0.80	0.55	-1.17	2.41	-0.69	-1.64
Saskatchewan	1.03	0.87	0.68	-1.03	3.32	1.48	-1.63
Alberta	1.28	0.96	0.72	-0.78	1.50	2.12	-2.00
Prairies	1.16	0.88	0.67	-0.97	2.05	1.20	-1.77

[1], meal = canola meal after oil extraction which is available as substitute livestock feed.

[2], includes CO_2 sequestered by the land use change from annual feed grain to perennial forage.

Table 6. Area based GHG emission intensity estimates for canola, and four canola expansion impact scenarios normalized to the area of the expanded canola crop, and potential the fossil CO_2 emissions offset by canola oil as a biodiesel feedstock in the Prairie Provinces during 2006.

Only Scenarios 3 and 4 represent the net CF of the expanded canola because the secondary impact on ruminant livestock production was incorporated by ULICEES into these two scenarios. The measure of this impact and the net CF of the new canola was a comparison with fossil CO_2 emissions that were expected to be offset by the expanded canola. The offset fossil CO_2 emission intensities (FI) are shown in each province and for the Prairies in the last Column of Table 6. They are also shown as negative values to reflect the opposite direction from the net CF. These fossil CO_2 emission offsets vary with provinces because their calculations accounted for the variations in the provincial canola yields (Y_{canola}). Each prairie yield was the production-weighted average from the 2006 and 2011 census years (Table 4). The offset fossil CO_2 emission intensities (FI) per ha of canola were calculated as follows.

$$FI = 2.8 \times 88\% \times 0.39 \times Y_{canola} \tag{3}$$

The diesel fuel to fossil CO_2 conversion factor is 2.8 kgCO_2/kg of fuel [36]. Equation 3 also took account of the 12% difference in energy content between petrodiesel and biodiesel [37] and the 39% by weight of canola yield (kg oil/kg canola seed) that is canola oil.

3.7. Protein based GHG emission intensities of scenario livestock

The assessment of canola expansion must also take into account the CF of the protein production from the proposed new distributions of age-gender categories of the ruminant livestock industries. The differences in GHG emission intensities between the two scenarios were assessed on the basis of protein supply and compared to baseline simulations for this indicator from ULICEES [3]. In this context, protein is taken to include only human edible protein (excluding blood meal, pet food, edible offal and leather). This comparison did not allow for potential nutritional differences between the protein derived from beef and lamb. Figure 5 shows the protein based GHG emission intensities for both livestock scenarios. As a reference baseline for this comparison, the 2006 protein based intensities of beef and lamb [3] are also shown in Figure 5. For this indicator, the actual GHG emission intensity simulations, rather than the differences from baseline GHG emissions, were used.

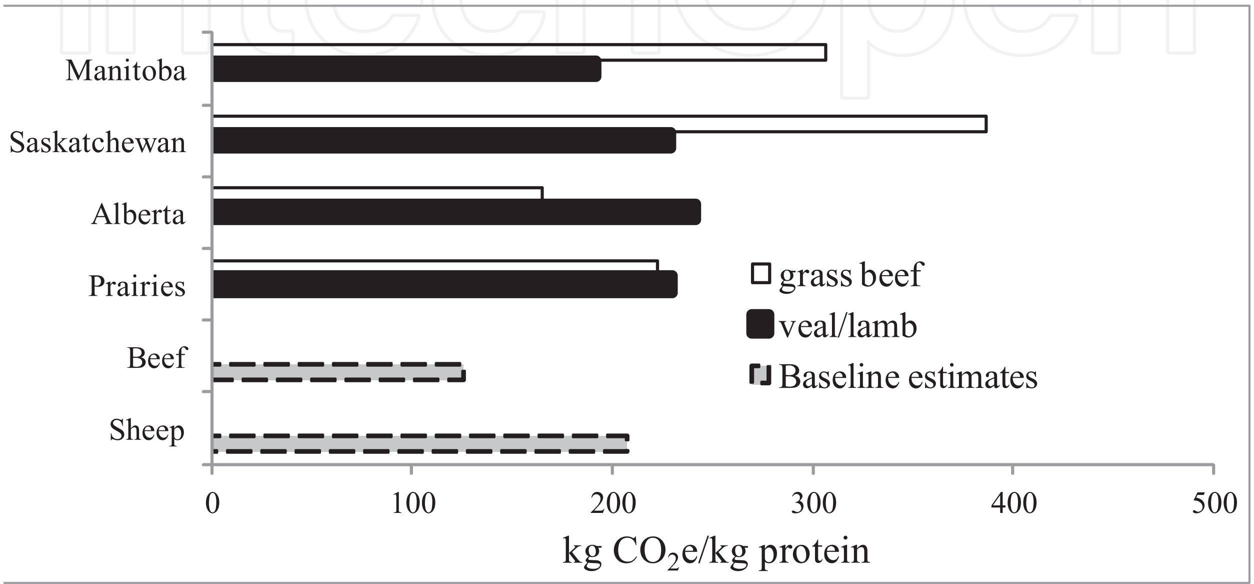

Figure 5. Protein based GHG emission intensities for the two livestock based canola expansion scenarios and for the baseline beef and sheep populations in the Prairie Provinces during 2006.

To calculate the protein based GHG emission intensities for Scenarios 3 and 4, the weight of animal Protein (P) was computed from the number of head (H) and the live weight (W) of the age-gender categories involved in simulating the two livestock scenarios that provide slaughter animals. The age-gender categories involved in the assumed population redistributions were steers and slaughter heifers (*s&sh*), replacement heifers (*rh*), culled cattle (*cc*), slaughter calves (*sc*), culled ewes (*ce*) and slaughter lambs (*sl*). The live weight conversions to protein were 6.4% for slaughter lambs [38, 39] and 8.3% for slaughter steers and heifers [10, 39]. Because breeding cows were culled every six years and ewes were culled every 4.5 years [3], reduction factors of 0.17 and 0.22 were applied to culled cow and ewe populations, respectively, in Equations 4 and 5.

$$P_{grass\ beef} = 0.083\left(H_{s\&sh} \times W_{rh} + 0.17 \times H_{cc} \times W_{cc}\right) \tag{4}$$

$$P_{veal/lamb} = 0.083\left(H_{s\&sh} \times W_{sc} + 0.17 \times H_{cc} \times W_{cc}\right) + 0.064\left(H_{sl} \times W_{sl} + 0.22 \times H_{ce} \times W_{ce}\right) \tag{5}$$

The Prairie average live weights (W) used in ULICEES were 495 for steers and slaughter heifers, 506 for replacement heifers, 616 for culled cattle, and 380 for slaughter calves, while the live weights were 57 for ewes and 48 kg and for lambs.

4. Results and discussion

Alberta had the highest rangelands ESSR by virtue of being the only province with the Foothills Fescue (FF) Ecoregion, which had the highest ESSR value (Table 1). Because it had the largest share of the Dry Mixed Grass (DMG) Ecoregion, with the lowest ESSR of the four ecoregions, Saskatchewan had the lowest provincial ESSR value. The Mixed Grass (MG) and the Parkland-Northern Fescue (PNF) ecoregions, with similar ESSR values, are more or less evenly divided between Saskatchewan and Alberta. Table 2 shows that Manitoba has only 7% of the prairie rangeland while Alberta has 50%. The yields of forage from Prairie rangelands (Table 2) were roughly one tenth of those of tame hay (Table 4). However, in both cases these forage yields were general approximations since these yield statistics are not regularly surveyed in the prairie region.

All of the statistics for annual crops (Table 3) showed considerable variability over the three provinces and the two census years, which helps to explain some of variability in the results of this assessment. The area in canola in the Prairies grew between 2006 and 2011 while the area in feed grains (barley and oats) shrank by a similar proportion (Table 3). The dry matter yield of two feed grains was 62% higher than the yield of canola. Even though the proposed expansion area for canola is only a little over 10% of the total canola crop land in the Prairies, Table 4 shows that the proposed expansion could lead to the conversion of roughly 80% of the rangeland to full time grazing by domestic ruminants in order to make up for the feed lost to the canola expansion.

Figure 3 demonstrated the importance of the province of Alberta to the CF of the beef industry in the Prairie Provinces. Alberta beef generated as much of the total GHG emissions as did Saskatchewan and Manitoba combined. Methane was the dominant type of GHG in the western Canadian beef industry. Not only was CH_4 the type of GHG with the highest quantity, it is the GHG that will increase the most if cattle are fed a more roughage based diet. This is because most of this gas is enteric methane which is the direct result of the ruminant digestion of roughage, the dominant component of the diet when cattle are displaced from a feed grain diet. This trend is partly counteracted, however, by the decreases in both N_2O and fossil CO_2 emissions when cattle are less intensively managed (as in Scenario 3), or when sheep are substituted for the feedlot finished cattle (Scenario 4). This feedback effect is accounted for in ULICEES.

Because the emission rates for Scenarios 3 and 4 in Table 5 were estimated from differences between the scenario simulations and the baseline, they were, not surprisingly, rather unstable. This instability carried over into Table 6. The wider spread among provinces for Scenario 4 in Table 5 indicates that they were a bit less stable than Scenario 3. For the Prairies, Scenario 3 was closer to the baseline ULICEES simulations (the baseline being zero in this regard) than

Scenario 4. Even with Manitoba having a negative difference, the Scenario 4 emissions rate for the Prairies was more than double the Scenario 3 emissions rate for the Prairies.

Being normalized to the same area basis, the prairie-wide GHG emission rates were almost equal for the two scenarios. In Figure 4 both scenarios show lower values for the prairie region than the respective rates in Table 5 because the rates in Figure 4 included the differences between GHG emission rates from the expanded canola and the respective CO_2 sequestration rates, which were negative quantities. For both Figure 4 and Table 5 (Columns 7 and 8), Scenario 3 in Manitoba was the only negative emission rate difference. In Figure 4, the only province where Scenario 4 was greater than Scenario 3 was Alberta.

The difference between Columns 4 and 5 in Table 5 (Scenarios 1 and 2) shows that the potential contribution by canola meal to ruminant diets could decrease the requirement for replacement perennial forage by over a third in the Prairie region. The inter-provincial variations in GHG emission intensities from the differences between the assumed livestock systems in Scenarios 3 and 4 were several times higher than the inter-provincial variations in just the direct emission intensities of the expanded canola crop (Column 1 in Tables 5 and 6). All of the GHG emission intensities from Table 5 showed considerable inter-provincial variations with Saskatchewan having the lowest GHG emission intensities for the crops of the three provinces, but the highest intensity differences from the baseline simulations for the two livestock scenarios. This inter-provincial variation was evident even before the livestock GHG emission rates were normalized to the canola areas.

The areas in feed grain production in the BCC that were freed to expand canola production were 1.75 Mha in Scenario 4 and 1.01 Mha in Scenario 3. The regional total feed grain area was 2.28 Mha.

Hence, the expanded canola areas were smaller than the feed grain areas in Scenario 3 but greater in Scenario 4. Thus, normalizing from feed grain to canola areas (for Table 6) would inflate the rates in Column 7 of Table 5 and deflate the rates in Column 8. The greater area changes associated with Scenario 4 helps to explain why Scenario 4 was more sensitive to the inclusion of GHG emission from the new canola and the sequestered CO_2 under the new forage area.

Without considering the livestock in Table 6, Scenarios 1 and 2 would actually appear to reduce the net CF of the expanded canola. Additionally, when CO_2 sequestration is considered, Scenario 2 suggests that just the growing of canola reduces GHG emissions without having to consider the fossil CO_2 emission offset potential. The ranking of the two livestock scenarios reversed in Table 6 compared to Table 5, with Scenario 3 having the greater net CF for expanded canola. Manitoba showed the biggest difference between the two livestock scenarios, whereas Alberta (with the largest beef industry) showed the least difference. The offset fossil CO_2 emission intensities (Table 6) were highest in Alberta because of the higher canola yields in that province. The net CF of the expanded canola in Table 6 was below the offset fossil CO_2 emission intensities (Column 7) for Scenario 3 in Alberta and for Scenario 4 in Saskatchewan. At the prairie region scale, however, the potential fossil CO_2 emissions offset by canola oil was less than the net CF of the expanded canola for Scenario 3. The potential fossil CO_2 emissions offset for the prairie region exceeded net CF of the expanded canola for Scenario 4, but not by a high enough to meet the EC directives [1].

To understand the role of CO_2 sequestration in the net CF of the expanded canola, a sensitivity test was run on the soil carbon storage rate [35] with a plus or minus 20% range. For Scenario 3 the range on the net CF was from 1.7 to 2.4 tCO_2e/ha, for a range about 2.1 tCO_2e/ha of ±16%. For Scenario 4 the range was from 0.9 to 1.5 tCO_2e/ha, for a range about 1.2 tCO_2e/ha of ±27%. Whereas a 20% increase in soil CO_2 sequestration rate would change Scenario 4 to 51% below the fossil CO_2 emission offset by canola, the result for Scenario 3 would only be 3% below that offset level. If the expanded canola described in this chapter were considered to be a continuation of the current operation of Canadian canola production, rather than a new installation, Scenario 4 might be deemed to just barely qualify for export to the EU [1] with soil carbon sequestration made 20% higher than reported by [35]. The increased sensitivity of Scenario 4 compared to Scenario 3 was due to the greater area of feed grain that was freed from the BCC for expanded canola in Scenario 4.

The protein based emission intensities in Figure 5 were close to equal for the two livestock scenarios in the Prairie region. Saskatchewan had the highest protein based GHG emission intensities in Scenario 3, while Alberta had the highest intensity for Scenario 4, but only slightly higher than Saskatchewan for Scenario 4. Scenario 3 exceeded Scenario 4 in Manitoba and Saskatchewan, while Scenario 4 was higher in Alberta. For the region, both scenario protein based emission intensities were higher than the baseline intensities for both beef and sheep, although only slightly higher than for sheep.

5. Conclusions

There are appreciable margins of error associated with a theoretical assessment such as described in this chapter that should be viewed with caution. Given the number of assumptions and approximations that this assessment relied on, the hope is that this chapter would set the scope for studying the potential canola-beef industry interactions more intensely and with more empirical data. Instead of being able to use individual simulations of GHG emission budgets from ULICEES, this assessment had to rely on incremental changes between scenario and baseline simulations. This meant that the incremental results from ULICEES were very sensitive to the random noise from the inputs to ULICEES. This noise means that the results are more meaningful on the basis of the prairie region than on the provincial scale. The need for terms external to ULICEES to be integrated with ULICEES output to account for the additional hay, as well as for the expanded canola, was the result of ULICEES not having the capacity to generate additional hay area in the LCC. The need for these external terms made Scenarios 1 and 2 important steps in this assessment.

On the other hand, the strength of this analysis stems from the use of the ULICEES model which has undergone both peer review in the scientific literature and a wide range of successful applications, also described in scientific form. It was reassuring also that, at least regionally, the two livestock scenarios provided comparable quantities of protein. Scenario 4 embodied

http://dx.doi.org/10.5772/60047

an additional challenge. To use the feed resources freed by the early slaughter of so many cattle an increase in the Prairie sheep population by a factor of about 50 was called for, given the very small size of the current prairie sheep industry relative beef in the region. It was not surprising that such an exchange between two livestock types would result in the greater differences among the provinces seen in Table 6 for Scenario 4 compared to Scenario 3. It was also not surprising that 73% more land was made available for the expanded canola crop by Scenario 4 than Scenario 3.

Two issues regarding the methodology need clarification. First, in the CF stage of the assessment, grazing land, either tame pasture or rangeland, was mostly left out of the GHG emission budget calculations. This omission was mainly because ULICEES does not attribute any GHG emissions directly to these lands, electing instead to treat all enteric methane emissions as direct emissions from each animal, regardless of where that animal is located, and also because almost no inputs can be directly attributed to pasture. Manure voided directly onto pasture was also considered to have no methane emission cost in ULICEES.

The second issue was the ethical implications for the choices for scenarios. These scenario choices were made strictly for their value as boundary conditions in reallocating cattle to other categories in the assessment and forcing ULICEES to redistribute the resulting GHG emissions. Raising and slaughtering young calves for veal, is considered by many to be inhumane and, therefore, ethically unsustainable, regardless of the outcome of the CF assessment. Although this chapter does not advocate or condemn veal as a meat source, this assumption facilitated the expansion of sheep in Scenario 4. Also by assuming an all-roughage diet for the inflated sheep population for Scenario 4 the problem that the actual diet for Canadian sheep contained too much feed grain for this assessment was bypassed. However, removing all feed grain from the diet of the expanded sheep ignored the need to have a small share of grain in the diet of breeding ewes.

The third issue was the use of GHG emission intensities based on land areas in this assessment, rather than on measures of productivity. Land based emission intensities are generally not practical in describing the CF of ruminant livestock because these farming systems involve three different land uses, including annual crops, hay and pasture (both improved and unimproved), which are difficult and rather arbitrary to equate to a single indicator of land value. Land based emission intensities were the only way that terms external to ULICEES could be integrated with ULICEES output. The land basis for emission intensity was applicable in this assessment only because it was the incremental changes in these intensities, rather than the integral values, that were used. Otherwise, the land based GHG emission intensities in Tables 5 and 6, particularly for the two livestock scenarios, are not likely to be applicable outside of the context of this assessment.

This chapter explored three parameters of sustainability. The first was land use change in which it was revealed that the needed increase in forage production cannot be acquired from the use of rangeland. Given the very low yields of livestock feed that can be achieved within the limits set by the ESSR, small increases in canola area require too large portions of the remaining natural grasslands in Western Canada to be grazed. This deprives wild native ungulates of their feed sources in these areas and it could threaten the natural plant diversity in these lands as well, even with the co-grazing of cattle with sheep. In contrast to the greater net CF for canola, a shift to tame hay or improved pasture as a way of increasing forage, would protect both biodiversity and reduce soil erosion, because the soil surface is never bare.

The degree to which rangelands are already grazed by cattle is not known. Even if all of the rangeland shown in Table 2 were available for expanded livestock grazing, the 0.71, 1.60 and 2.14 million head of breeding cattle in Manitoba, Saskatchewan and Alberta, respectively (from Figure 2), in 2006 greatly exceeded the 0.10, 0.54 and 0.85 million AU that can be supported for six months on Prairie rangeland (Table 2). For the Prairies, the breeding cow population (the basis for defining the AU) was three times larger than the carrying capacity of rangeland defined on this basis. Also modern beef cattle are appreciably larger than the breeding cows at the time the AU indicator was devised.

The second sustainability parameter, and the main target of this assessment, was the extended scope of the CF of the new canola areas. The net CF of the expanded canola exceeded the fossil CO_2 emission offsets associated with petrodiesel by 16% in Scenario 3 and was exceeded by the fossil CO_2 emission offsets by 32% in Scenario 4, leaving little hope of this expansion option ever complying with the EC directives on biofuel feedstock production. In spite of the limitations of the modeling approach used for this assessment, the findings from both livestock scenarios send a message that expansion of canola for biodiesel feedstock is unlikely to be sustainable if ruminant livestock are displaced into a more forage dependant production system by the expansion.

Without CO_2 sequestration under the new hay area, the margin between the net CF of canola and the fossil CO_2 emission offsets would have been much greater. Because CO_2 sequestration declines to almost zero by about 40 years as the soil carbon sink is recharged [27] (a consideration in all GHG mitigation strategies), this term is not perpetual. The magnitude by which the fossil fuel GHG emissions to be offset were too low in relation to the change in scenario GHG emissions was further demonstrated by the sensitivity to the yearly soil carbon storage rate. The need for a 20% increase in the CO_2 sequestration to bring just Scenario 4 into complying with EC directives indicates that allowing canola to displace feed grains from the BCC is unsustainable. This suggests that a shift from ruminant to non-ruminant livestock farming [9] would be a better strategy for expanded canola feedstock to interact positively with Canadian livestock industries with respect to GHG emissions.

The failure of Scenarios 3 and 4 was in spite of not including several factors that would have made the net CF of the expanded canola even higher. The main factor was that no allowance was made for the processing side of the canola oil, or the fuel that was required to collect and transport the canola seed to processing plants. While the canola expansion described in this chapter called for more perennial forage to replace feed grain in the ruminant diet, it was not known if sufficient new land would be available to grow the required forage. Both of the livestock scenarios assumed that canola meal could be incorporated into the livestock diet. While this is possible in principle, the poor palatability of canola meal to livestock is a limitation. In order to minimize this limitation, that meal would have to be spread throughout the prairie beef population so that it appeared in smaller portions in individual diets.

The third sustainability parameter was the protein based GHG emission intensity. This protein based indicator for the livestock described in both Scenarios 3 and 4 was higher than the protein

http://dx.doi.org/10.5772/60047

based GHG emission intensities for the current beef and sheep industries. So in addition to more GHG emissions, this canola expansion option contributed less protein to the human diet for the same level of GHG emissions. This provides yet more argument for not allowing canola expansion into the beef industry to make that industry more dependent on a high roughage diet.

This assessment does not condemn all options for expanding canola production. Canola is a valuable cash crop for Canadian farmers and, in the right circumstances, can be a viable GHG mitigation option as a biodiesel feedstock. However, as the conversion of land that was in summerfallow to other crops in western Canada nears completion, continued displacement by canola of any other land use in the Prairie Provinces of Canada needs close assessment, including attention to secondary land use changes.

From a policy perspective, this assessment has one more limitation, because it may not always be clear exactly what land is being displaced. For example, canola expansion was more the beneficiary than the cause of shrinking areas in summerfallow in the Prairie Provinces. Similarly, feed grains may be displaced by food quality crops that were displaced as the direct result of canola expansion. In this case the causative role of canola expansion in livestock displacement may not be recognized, even though it would be the main driver of this land use change in this situation. In spite of these potential policy implementation hurdles, the general lesson from this assessment may still give some valuable guidance for international pasture and rangeland managers, particularly given the close similarity between canola and rapeseed. This chapter may also provide insight into the CF of more extensive, forage based, beef production, regardless of whether or not biofuel feedstock is what is driving the shift away from intensive, feed grain dependant beef production.

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