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The Fossil Energy and CO₂ Emissions Budget for the Barnyard Operations of Livestock Farms in Canada

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Abstract

This paper describes fossil fuel energy use for on-farm transportation, heating of farm buildings, electricity generation, machinery supply and the spreading of manure. These four terms describe the barnyard energy budget. Calculations for this energy budget were driven by population data for beef and dairy cattle, hogs and poultry in Canada. Prior to comparing this energy budget for 2001 and 2011, the year-to-year trends from 1990 to 2014 were analysed. The declines in all livestock populations, except poultry, between 2001 and 2011 reduced the size of the Canadian barnyard energy budget from 25 PJ to 22 PJ. The resulting change in the fossil CO₂ emissions between 2001 and 2011 was from 1.62 MtCO₂ to 1.36 MtCO₂. A sensitivity analysis based on future elimination of coal for generating electricity, introduction of electric pickup trucks (e-pickups) and increased use of electric heat, reduced fossil CO₂ emissions during 2011 from dairy farms by 29%, beef farms by 24%, hog farms by 19% and poultry by 13%. The most affected provinces by this test were Alberta and Saskatchewan because of the heavy dependence on coal in electricity generation in these two provinces. This scenario test suggests a Canada-wide potential reduction of 0.30 MtCO₂. A second sensitivity test based on a Canada-wide 20% reallocation of protein production from beef to pork revealed a very modest potential to actually reduce barnyard fossil CO₂ emissions by 0.09 MtCO₂ for Canada.

Keywords: barnyard energy budget, fossil CO₂, livestock, farm electricity, heating fuels, farm transport

1. Introduction

This paper describes the farm energy terms that are exclusively associated with livestock-based fossil-fuel energy use. The terms of the farm energy budget described by Dyer and Desjardins (2009a) include field operations, on-farm transport, electricity, heating fuel, machinery supply and chemical inputs. Of these terms only on-farm transportation, heating of farm buildings and electricity have quantities unique to livestock production. Farm field operations, the most direct form of fossil energy consumption (Dyer et al., 2003; 2014), were excluded from this analysis because they are only directly linked to crop production and the link with livestock farming is indirect, particularly on farms where significant portions of the livestock diets are purchased off-farm. The supply of farm machinery and farm chemicals are driven by, and associated with, field crop production and are, therefore, also indirect with respect to livestock operations.

When field crop production is excluded from the scope of farm operations, management can focus on the barns, storage facilities for manure and salable products, farm machinery maintenance, equipment sheds and livestock feeding systems. Because the data to quantify the energy budget of each of these remaining energy users were not available individually, they were defined here collectively as the barnyard. While Dyer et al (2014) showed that the terms selected for this paper are relatively small, they may offer the most convenient options for many livestock producers to reduce both their farm energy use and their carbon footprints. As livestock farms increase in size and specialization, this consideration becomes more important.

Several major changes in the mix of energy sources in Canada's energy sector will strongly affect these four barnyard energy terms. As well, recent government policy initiatives by Canada aimed at meeting this country's commitment under the Paris Accord will further change this energy mix (McCarthy, 2016). To assess the impact

of these changes on the barnyard energy budget and carbon footprint of livestock farms, this paper will, first, compare the energy budgets from 2001 and 2011. Second, it will project the likely future mix of Canadian energy sources onto the 2011 livestock production energy budget. Third, the impact of a shift from ruminant to non-ruminant livestock, as suggested by Dyer et al (2010), on the barnyard energy budget will also be assessed in this paper.

2. Methodology

A wide range of fuel types and energy sources contribute both directly and indirectly to the farm energy budget. The fuel types, their roles in barnyard operations and the conversions between energy consumption and fossil CO₂ emissions (Dyer et al., 2014; Neitzert et al., 1999) are shown in Table 1. All of the barnyard fossil CO₂ emission estimates in this paper were derived from the recorded livestock farm energy quantities using the CO₂ energy ratios shown in Table 1. Although heating oil can include a range of liquid fuels, it was represented by kerosene in Table 1. By using the coefficients in Table 1, the conversions of energy quantities to CO₂ emissions are theoretical (Neitzert et al., 1999). Hence, any industrial inefficiencies in the production of the energy sources are beyond the scope of this paper, as were new technologies such as LED lighting.

Table 1. Energy types, their conversions from fossil energy to fossil CO₂ emissions and their uses for electricity generation (G), space heating (H), farm-owned transport (T) and manure spreading (S)

Fuel type	coal	natural gas	heating oil	gasoline	diesel
tCO ₂ /TJ	86.2	49.7	67.7	67.7	70.7
Barnyard uses	G	G & H	G & H	T	S

The Greenhouse Gas (GHG) emissions resulting from the indirect farm energy terms are sensitive to external effects which can change over time. As with the previous analyses of energy use on Canadian farms (Dyer and Desjardins, 2009a,b; Dyer et al., 2013; 2014), the year-to-year changes in energy use and fossil CO₂ emissions from electricity (Table 2), transportation (Table 3) and heating (Table 4) were extrapolated from the 1996 Farm Energy Use Survey (FEUS) (Tremblay, 2000).

Table 2. National energy use totals from the 1996 Farm Energy Use Survey for electrical power generation and energy use per head (hd), for four livestock types

Energy	Units	Beef	Dairy	Hogs	Poultry
total	PJ	3.0	3.8	1.9	1.0
per hd	GJ/hd	0.583	2.645	0.166	0.009

Since the FEUS only provides one year (1996) and one national energy use value for each agricultural commodity, these extrapolations had to be made over time and partitioned among provinces. The FEUS data was adjusted for household use by using the farm to farm and household energy usage ratio provided by Tremblay (2000). Confidentiality limitations of the FEUS required that only one measure of household energy use for each energy type had to be applied to all farm types.

Table 3. National energy use totals from the 1996 Farm Energy Use Survey for gasoline for farm use and energy use per head (hd), for four livestock types

Energy	Units	Beef	Dairy	Hogs	Poultry
total	PJ	7.8	2.9	1.3	0.5
per hd	GJ/hd	1.512	2.031	0.116	0.004

Unlike the previous farm energy assessments in Canada, this assessment does not rely on agricultural census data. Instead, yearly livestock statistics assembled under the National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS) (www.agr.gc.ca/ngcavs) were used to drive the estimates made for this paper. In order to show reliable trends, the external effects were assessed for all years in the 1990 to 2014 times series, not just the 2001 and 2011 census years.

Table 4. National energy use from the 1996 Farm Energy Use Survey for heating fuels (heating oil, natural gas and propane) and energy use per head (hd), for four livestock types.

Energy	Units	Beef	Dairy	Hogs	Poultry
total	PJ	4.4	1.6	2.1	2.7
per hd	GJ/hd	0.864	1.125	0.182	0.024

2.1 Direct Livestock Energy Use Estimates

For the energy terms in this paper, the partitioning from national farm energy uses from Tables 2, 3 and 4 to provinces was based solely on the livestock populations. This process used the ratio of the population of each respective livestock type from the province to the national population. The Canada-wide per-head energy use rates for electricity, heating fuel and gasoline from each of the four livestock types are also shown in Tables 2 to 4. The per-head energy use rates appear much smaller for poultry and hogs compared to beef and dairy rates because of the smaller body size and large numbers of poultry and hogs.

Because the energy use factor for each energy term and livestock type was simply a dimensionless index, it was not always necessary to include the entire population of the respective livestock types, nor was accounting for the different sizes and lifespans of the different age-gender categories required. Hence for beef and dairy, only the cows, the most stable age-gender category, were used. For hogs and poultry, the entire populations were used because their breeding herds were significantly smaller relative to the whole populations compared to the beef and dairy industries.

While the decision to not index the energy use to all of the animals in two of the four livestock types (as in Tables 2 to 4) may appear to inflate these two indicators, that discrepancy is compensated for when these national rates were reintegrated over the same age-gender categories from those provincial livestock populations. Not including any of the offspring categories in either of the bovine livestock types meant a more stable response of these indicators given the flux of animals among the beef lifecycle stages and between the beef and dairy industries, particularly the disposal of culled dairy cows and unwanted dairy calves as beef animals (Vergé et al., 2007; 2008). Also, because breeding cows make up a relatively large share of both the beef and dairy populations, relative to the two non-ruminants, they are a more stable indicator of their respective populations.

Because of the very small size of the sheep population in Canada, ewes and rams were included with the beef industry, along with the beef cows. The ewe and ram populations (combined in the source data as one statistic) were factored down by 0.2 because of the weight difference between sheep and cattle. A beef cow is generally defined as one animal unit (AU), while a ewe is considered to be 0.2 AUs (Dyer et al., 2015). Bulls were not included because beef bulls could not be separated from dairy bulls in the available data, as well as being a very small part of the breeding cattle populations.

The livestock population data from 2001 and 2011 data are shown in Table 5 to help interpret the changes in barnyard energy use presented in this paper. Only the breeding females were included in Table 5 for beef, dairy and pork because these animals are the most representative age-gender categories of their respective populations. The entire population was given for poultry because the breeding stock for poultry are much smaller compared to the numbers of production animals than for the other three livestock types. The poultry populations also represent two different commodities (broilers and eggs).

Table 5. Selected population data for representing four livestock types in Eastern and Western Canada for two census years

	Beef cows	Dairy cows	Sows	Birds	Beef cows	Dairy cows	Sows	Birds
	M,hd							
	2001				2011			
East	0.65	0.85	0.79	85	0.53	0.74	0.63	93
West	4.05	0.24	0.63	46	3.47	0.23	0.55	47

For two of the four livestock types, one additional time-dependent variable was added at the provincial level. For milk production the ratio of milk yields (annual weight of milk per cow) for each year to the milk yields from 1996 (the FEUS reference year) was used to factor the 1996 dairy cow baseline populations. Similarly, the ratio of slaughtered cow carcass weights from each year to the same carcass weights from 1996 was used to factor the beef cow populations. These two indexes allowed the energy and CO₂ emission estimates to reflect increased

productivity in these two commodities. Hogs and poultry were not indexed in this way because the required annual carcass weights were not available.

2.1.1 Farm Electricity

The 1990-2014 time series of fossil CO₂ emissions from farm electricity over the 25 year period was strongly affected by the energy sources used to generate electrical power in Canada. Furthermore, the mix of power generation systems varies dramatically among provinces and there have been significant changes in some provinces, particularly in the last decade. Since hydro and nuclear power generation produce no CO₂ emissions (Dyer and Desjardins, 2006), their share of on-farm electrical energy used must be subtracted from the total on-farm electrical energy term. The different fossil fuels used in power generation emit fossil CO₂ at different rates.

Natural Resources Canada (NRCan) and Environment Canada published two national energy handbooks which provide a complete time series of power generation and all-sector usage of electrical energy, along with their fossil CO₂ emissions. This national time series had to be spliced together from three different reports (Environment Canada, 2005; NRCan, 2005; 2014) which contained a few overlapping years, yet still left some gaps. The breakout of power generation processes and energy sources in these reports changed over the 25 year period. Although the natural gas and coal usages were consistent, it was necessary to group the liquid fossil fuels into one generic group referred to as heating oil, which includes diesel oil, light fuel oil, kerosene, petroleum coke, still gas, and coke oven gas.

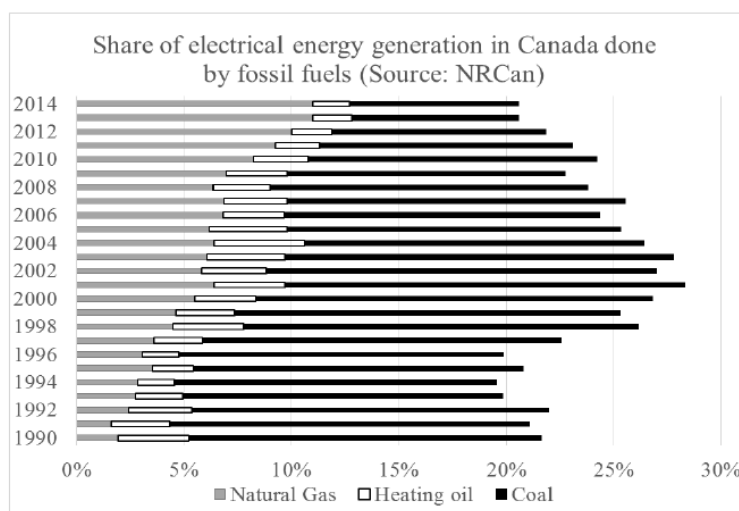


Figure 1. The shares of electricity generation by three different fossil fuel types in Canada over 25 years (Heating oil includes Diesel Fuel Oil, Light Fuel Oil, Kerosene, Petroleum Coke, Still Gas and Coke Oven Gas)

The trends shown by the electricity generation energy sources differ among the provinces. Energy type breakouts of provincial electrical power generation, however, were not available for all 25 years. Several on-line sources provided provincial distributions of these power generating sources for three years (CAEEDAC, 1998; CEA, 2006; Environment Canada, 2005; Statistics Canada, 2014). These three provincial distributions of energy sources in 1995, 2003 and 2013, facilitated the creation of complete 1990-2014 time series for each province by interpolation. This linear interpolation (based on differences in years) provided reasonable provincial estimates for 2001 and 2011. The grouping of fossil fuel types into coal, natural gas and heating oil gave a workable generalization for the provincial differences, as well as the national time series. This difference is most acute for beef farms. The shares of electricity generation from different fossil energy sources is shown at a national scale in Figure 1. This figure demonstrates both the changing shares of electricity generation that was based on fossil fuels and the changing distributions among fossil fuel types. The shares that were generated by fossil fuels peaked at about 2001 and has been declining steadily since then. The share from natural gas has been increasing since 1990.

2.1.2 On-farm Transportation

The use of fuel for farm-owned transport from Table 3 has been included in all of the Canadian farm energy budgets associated with the farm field work (Dyer and Desjardins, 2009a,b; Dyer et al., 2013; 2014). In this

report, as in all of the previous farm energy budget assessments referenced here, light pick-up trucks powered by gasoline purchased by farmers were assumed to be the most common means by which farmers move materials on and off the farm, and the basic energy user in this term. Trucking of livestock or livestock products to market or processing plants not done directly by farmers is not included in this fuel consumption estimate.

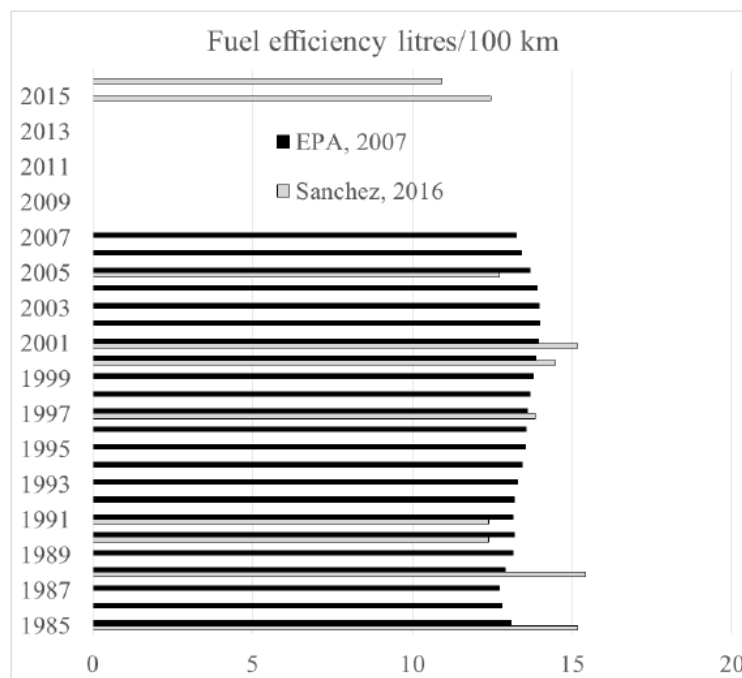


Figure 2. Historical fuel consumption data from two studies in the USA that contributed to a proxy 25 year gasoline time series for pickup trucks on Canadian farms

The main consideration in assessing the trends over years was the external (off-farm) changes that would affect how much gasoline farmers burned in doing farm transport. The changes in gasoline fuel consumption rates over the 25 year period due to the improvements in fuel efficiency of the pick-up trucks were considered in this assessment. Two reports on light vehicles were relied upon for this time series. The United States Environmental Protection Agency (EPA) provided annual rates of fuel consumption between 1975 and 2007. Sanchez (2016) published on-line an analysis of five popular pickup truck models. These data involved three years for each model starting in 1985 and as late as 2016. The Sanchez data used different years for each truck model, with the year for the old trucks in each model ranging from 1985 to 1990. The later years of these models were all from either 2015 or 2016.

A time series of gasoline consumption efficiency covering the 25 year period was constructed by splicing these pickup truck fuel efficiency data from these two reports (Figure 2). The EPA report timeline was smoothed by a running average as follows. For each year, that data point times 2 was added to the data points from the year before and the following year, and the sum was divided by 4. To fill the gap between 2007 and 2015, a linear change in the Sanchez data (2016) between 2005 and 2015 was assumed. The annual increments between 2007 and 2015 were added to the 2007 year value from the EPA series for the gap years from 2008 to 2014. This time series was then converted to a dimensionless index by taking the ratio of each year's fuel efficiency value to the fuel efficiency value from 1996, the FEUS reference year. For 2001 and 2011, the fuel efficiencies were 14.0 l/100km and 12.7 l/100km, respectively.

It was assumed that there would be no differentiation of farm pickup fuel efficiencies among provinces since the farmers in all regions would have access to the same pickup manufacturers. During the period of interest (2001-2011) the change in pickup fuel efficiency was disappointingly small. The biggest fuel efficiency change was prior to the period of interest in this analysis. The peak year was 1998 and fuel consumption rates increased into the early- to mid-2000's before slowly declining again to 2007. Then the Sanchez (2016) data suggested that this mild decline continued to 2016.

2.1.3 Heating fuels for Livestock

Livestock farms in Canada consume fossil fuels in order to maintain barns at an adequate temperature during the coldest months. The 1996 FEUS attributed quantities of natural gas, propane and heating oil (referred to collectively as heating fuel) to each of the four major livestock industries. It did not, however (for reasons of confidentiality), disclose the quantities of each fuel type to the individual livestock types that were specifically used for heating buildings (mainly livestock barns). Therefore, to determine what the fossil CO₂ emissions from the heating energy usages for livestock were in Table 4, the mix of fuels used for this purpose had to be approximated. How the mix of fuels might have changed over the 25 year period also had to be determined because the price and supply of these fuels affects the mix of their use on livestock farms.

It was assumed that the energy mix for residential space heating would be close to the energy mix that livestock producers would use for the space heating of barns. Price and supply, and the fact that livestock producers would also own and maintain their own residences, would suggest that the mix of heating fuels for farm residences would be more or less the same as any other residence (or at least follow the same trend). The same economic forces would drive the fuel mix used in farm buildings. Some degree of confirmation for this assumption was provided by the FEUS which showed that 13% of the heating was done with heating oil across all farm types in Canada, with the remaining heating fuel split as 80% natural gas and 20% propane. Although the NRCan data only provided natural gas use, the 20% propane only increased the CO₂ to energy ratio by less than 4%. Hence, natural gas was assumed for the 2001-2011 comparison and the sensitivity analysis.

The same two sources (NRCan, 2005; 2014) that allowed a time series to be constructed for changing energy use for farm electricity provided residential space heating data for Canada for 1990 to 2011. Splicing and interpolating, as was done for the electricity generation time series, was needed for the residential space heating data, including the same missing and overlapping years. Since this time series ends at 2011, the remaining three years of the 25 year time series (2012-2014) were approximated by linear interpolation from 2011 to 2015, for which residential space heating energy records were provided by NRCan (2015) on the assumptions that space heating continued to decline after 2011 and that the share of heating oil and natural gas remained at the same percentages of total space heating energy use. Figure 3 shows the Canada-wide barnyard use of fossil fuels actually burned in livestock barns as a % of the 1996 fossil energy use (Table 4).

The space heating data were adjusted to account for the provincial distribution on the livestock barn heating energy use. Although the FEUS provided provincial breakdown of these fuel type percentages, confidentiality limited the provincial percentages to all agriculture, rather than to specific farm types, and included farm household use. Hence the provincial distributions from the FEUS were considered too general to use in this analysis. It was assumed that the colder agricultural regions of Canada would require more heating energy to maintain barns at an adequate temperature during the winter. Spatial extraction from a map of Annual Total Heating Degree-Days from the Climate Atlas of Canada 1951-1980 (source: Environment Canada - available on-line, publication date unknown) gave the cumulative annual degree-days below 18 °C for the seven provincial agricultural regions of Canada. Even though out of date climate normals were used to draw this map, it would still reflect the same general spatial differences in winter temperatures as today.

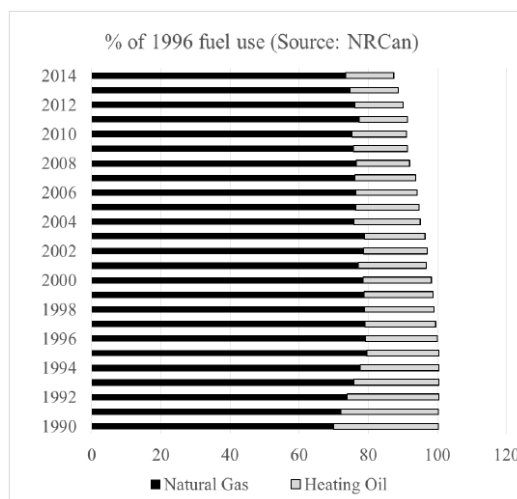


Figure 3. The time series of heating fuels burned in Canadian barns for space heating from 1990 to 2014 expressed as a percent of 1996 energy survey data.

For each province and livestock type the heating energy from Table 4 (disaggregated to provinces using the respective 1996 livestock populations) was factored by the ratio of heating units from each province to the average heating units from all seven provinces. The averages were weighted by the 1996 distribution across provinces of each of the four livestock types. These averages were then multiplied by the share of national populations of each livestock type in each province. Thus, the weighting was slightly different for each livestock type, depending on the distribution of each type across provinces. Also, the share of heating energy that is fossil across Canada starts to drop after 1997, so that by 2011 that share fell 9% compared to the baseline 1996 year. The time series in Figure 3 took this decline into account by indexing the share of all space heating energy use that was fossil from each year to that same share for 1996.

2.1.4 Spreading Manure

The last barnyard energy term that is driven by livestock populations is the diesel fuel to spread manure. This term had previously been treated as one of the operations in Farm Fieldwork and Fossil Fuel Energy and Emissions (F4E2) model (Dyer and Desjardins, 2003) because it was a field operation. In the initial version of F4E2 (Dyer and Desjardins, 2005; 2009a) the area in annual crops to receive manure fertilizer drove the fuel use calculation (Dyer and Desjardins, 2005). In this application to livestock the inputs that drive this energy term were changed to solely the source livestock populations.

No time trend adjustment was made for the fuel use efficiency for spreading manure. Manure can be applied as either a solid or a liquid. Since liquid manure is typically twice the weight of solid manure (Landry et al., 2002), a simple doubling of the fuel use for spreading solid manure would suffice for estimating the fuel required to apply liquid manure. Some direct incorporation is required during the application of liquid manure, which was ignored in this paper because such tillage would have been accounted for in the applications of the F4E2 model to livestock feed crops. For this paper liquid manure storage was assumed for dairy and hog barns and solid manure was assumed for beef and poultry barns.

The mechanism of the spreader requires roughly 0.2 kWh/t{manure} (ASAE, 2000). Because this work rate is for tonnage of manure, it is applicable to either solid or liquid manure. Because the as-voided volume of manure depends on the livestock type, the fuel used for spreading manure is also livestock dependent. The weights of manure to be applied were based on the livestock type manure excretion rates proposed by ASAE (2003). These manure weights are shown in Figure 3 for both livestock types and the most important age-gender categories.

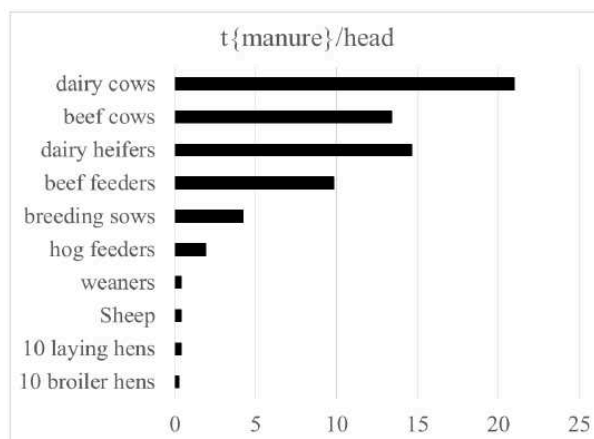


Figure 4. Manure excretion weights (as voided) per head for a range of livestock types and representative age-gender categories (after ASAE, 2003)

Unlike the other three livestock types, the manure calculations for poultry were not based on the first principles of per-head excretion rates and manure spreader fuel usage. This was because the very small body weights and the less than one year life spans made these calculations unreliable for poultry. Instead, poultry manure spreading was indexed to the hog manure calculations using the respective heating fuel and gasoline consumption by the two industries. But like the other three livestock types, these calculations were driven by, and sensitive to, livestock populations.

2.2 Sensitivity to Policy Scenarios

Only the fossil CO₂ emissions were compared in the following sensitivity analysis, mainly because the only

changes in energy quantities used in the barnyard are the result of changes in livestock populations. In any case, changes in the fossil CO₂ emissions capture (are sensitive to) any changes in energy requirements. Impacts were assessed from the total fossil CO₂ emission differences among the four livestock types. Two sets of tests were undertaken: sensitivity to shifts in energy types and up-stream sources of energy (Section 2.2.1), and sensitivity to recommended changes in livestock populations (Section 2.2.2). The baseline year for all of the following sensitivity tests was 2011.

2.2.1 The Impact of Changing Barnyard Energy Mixes

The first set of sensitivity tests was to project the 2011 fossil CO₂ emissions from the barnyard to 2030 using three scenarios for barnyard fossil CO₂ emissions from livestock farms. The choice of 2030 was based on being the year by which the Federal Government of Canada has committed to removing all coal generating stations in this country (McCarthy, 2016). These projected scenarios showed the impact of upstream energy use on the fossil CO₂ emissions from each of the three main barnyard energy terms. Given its small magnitude, no scenario was included for manure spreading.

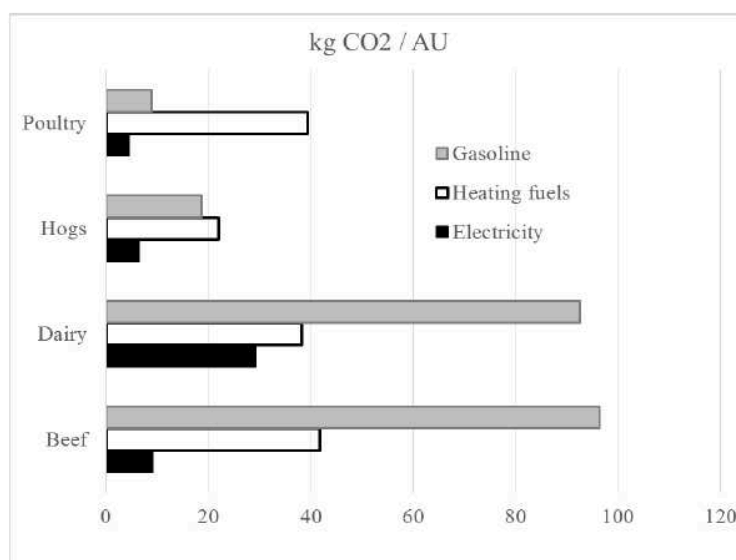


Figure 5. Distribution of fossil CO₂ emission rates over energy sources and livestock types expressed as CO₂ per Animal Unit (AU) for 2011

Figure 5 shows the fossil CO₂ emission rates for the three direct barnyard energy terms and the four livestock types. These emission rates were expressed on the basis of AUs (UIE, 2016), rather than on a live weight basis in order to normalize the comparison among the energy sources. The AU were for the breeding animals of each population, and are not necessarily representative of all age-gender categories of each population. For beef cows, dairy cows, sows and brood hens, the AUs were 1.0, 1.4, 0.4 and 0.03, respectively.

For the first 2030 scenario, coal was totally eliminated from the mix of energy sources used to generate the 2011 electrical energy. It was assumed that all of the electric power from coal would be replaced by non-fossil energy sources (hydro, nuclear or renewables). But the current share of the energy mix for electricity generation that was by natural gas would be unchanged in 2030. Since the reliance on different fossil fuels for electricity generation varies appreciably among provinces, the 2030 energy mix projected for Canada was redistributed over the provinces, as was done in section 2.1.1.

For the second scenario it was assumed that electric pickup trucks (e-pickups) could replace gasoline-powered pickups. The market penetration by electric vehicles into the private transportation sector is projected to reach 35% by 2040 and to reach approximately 20% by 2030 (MacDonald, 2016). Hence for the farm-owned transport scenario, the 2011 farm transport estimates from above (Section 2.1.2.) for 2011 were reduced by 20%, so that this transport work would be done by e-pickups. This simple scenario was used for transport because only one fuel type (gasoline) was used and no appreciable trends in pickup fuel efficiency were found for the 1990-2014 period. As above (Section 2.1.2.), no partitioning of the national estimate over provinces was assumed to be needed.

The third scenario involved heating fuels. Since Figure 3 showed a steady decline in fossil fuels for barnyard heating between 1996 and 2014, that trend was assumed to continue for this scenario until 2030. To simulate this scenario it was assumed that heating oil would cease to be used in space heating by 2030, but that the other fuel types (mainly natural gas) would continue to be used at the same rates as in 2011. The eliminated heating oil would be replaced by electric heat generated by non-fossil energy sources in order that the 2011 heating requirements would still be met in 2030. The distribution of the projected natural gas for space heating was partitioned over the provinces using provincial heating unit climate normal as above (Section 2.1.3).

2.2.2 The Impact of Livestock Types

The potential changes from ruminant to non-ruminant livestock was assessed by a sensitivity test based on maintaining a constant supply of animal protein from Canadian farms, as suggested by Dyer et al (2010). In order to maintain a constant animal protein supply to the market, the loss in protein from the reduction of one type of livestock would need to be equal to the increase in protein from the livestock population being increased. The test was based on a transition from beef to pork for Western and Eastern Canada. This test assumed that there would be no shifts in the distribution of age-gender categories within either population.

Poultry were not used in the test because this industry involves two distinctly different commodities (broilers and eggs) for which the available production data to allocate protein across these two commodities were inadequate. The dairy industry was also ignored because the dairy quota system would make any downsizing scenario unrealistic. Total GHG emissions for 2001 were estimated by Vergé et al (2012). Dyer et al (2010) provided the GHG/protein ratios for 2001. The total protein was calculated by dividing the total GHG emissions from 2001 by the GHG-per-protein ratios. This calculation can be seen in the first six columns of Table 6 for Eastern and Western Canada. The next step was to equate the protein quantities to the respective populations for beef and hogs using the beef to pork ratios of Column 5 to Column 6 in Table 6 (0.23 for the east and 1.70 for the west).

Table 6. GHG emissions and protein production for beef and pork used to calculate the pork population increase for a 20% reduction in beef cattle to maintain constant protein supply and the resulting changes GHG emission rates in Canada in 2001

	GHG/protein		Total GHG		Total protein		% +	% +	% -
	kg/kg		Tg		Gg		in head	in GHG	in GHG
	beef	pork	beef	pork	beef	pork	pork	beef	pork
East	138	25	5.3	4.2	39	166	4.7	1.1	0.2
West	116	25	25.8	3.3	223	131	34.0	5.2	1.1

For the test quantities of 20% reduction in beef populations, the hog population would have to increase by 4.7% and 34%, respectively, for Eastern and Western Canada. For 2001, this meant that breeding beef cows would be reduced by 130 thousand and 810 thousand head, and the breeding sows would be increased by 40 thousand and 210 thousand head, respectively, for Eastern and Western Canada, to maintain the same protein production. To apply this test to 2011, these percentages were simply applied to the 2011 population data used above (Section 2.1.). As can be derived from Dyer et al (2010), this population shift resulted in overall GHG reductions of 0.9 TgCO₂e and 4.1 TgCO₂e (Column 8 – Column 9) in the combined over-arching carbon footprints of these two industries, respectively, in Eastern and Western Canada for 2001.

3. Results

At 108 MtCO₂/TJ for 2001 and 92 MtCO₂/TJ for 2011, farm electricity was found to have the highest Canada-wide CO₂ emission cost of the four barnyard energy terms. Heating fuel, farm transport and spreading manure had CO₂ emission costs of 51, 68 and 71 MtCO₂/TJ, respectively in 2011. The only change from 2001 was that heating fuel had dropped from the 52 MtCO₂/TJ in 2011. Electricity generation was the only barnyard energy term with any variation among provinces for this indicator. Hence, Figure 6 shows the provincial CO₂ emission costs of the energy sources for electricity generation (MtCO₂/TJ) for 2001 and 2011. The other CO₂-per-energy ratios were not shown in any figure or table.

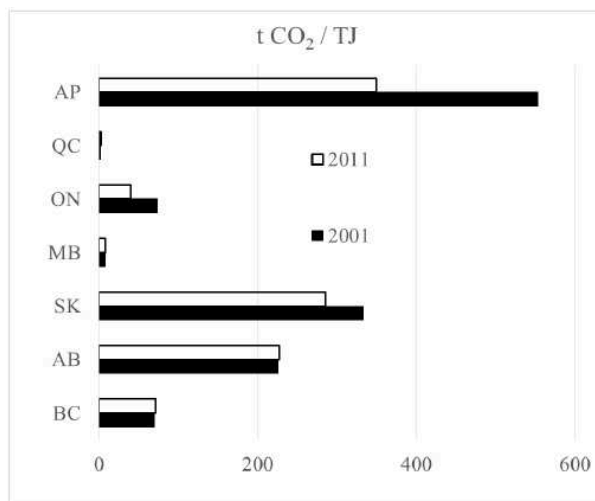


Figure 6. Provincial Ratios of fossil CO₂ emissions to electrical energy on Canadian livestock for 2001 and 2011

Figure 6 shows that the highest CO₂ emission cost per unit of energy in 2011 was in the Atlantic Provinces (AP), whereas the lowest costs in both years were in Quebec (QC), followed closely by Manitoba (MB). Saskatchewan (SK) was the next highest, followed by Alberta (AB). This emission cost dropped or stayed the same in all provinces between 2001 and 2011, except for very slight increases in Alberta and British Columbia (BC). The biggest drops were in Ontario (ON) and the Atlantic Provinces, followed by Saskatchewan. These drops were consistent with Figure 1.

The livestock energy use estimates (Section 2.1) are shown in Table 7 for 2001 and 2011. The four livestock types were combined as one livestock commodity group and summarized for Eastern and Western Canada. Farm transport was the largest energy user of the four terms, while heating fuel was the second largest energy user of the four terms. Spreading manure was by far the smallest. Both CO₂ emissions and energy use for all four energy terms decreased by 10% to 15% between 2001 and 2011, which is consistent with the declines in beef and hog populations in Table 5. In both 2001 and 2011, the barnyard energy use in Western Canada was from 30% to 80% higher than in the East. Hence, the effect of larger dairy, hog and poultry populations in the east on energy use was less than the effect of a much larger beef population in the west.

Canada-wide, the highest barnyard energy term in 2001 was farm transport, but in 2011 heating fuel was the largest energy term. But these differences were less than 10% in both years. Manure spreading was by far the smallest term in the barnyard energy budget. Electricity was less than a quarter of the energy used for farm transport and heating. The decline in fossil CO₂ emissions was the same as the decline in energy use for transport and heating between 2001 and 2011. But the decline in CO₂ emissions from electricity use (about 30%) was significantly greater than for transport and heating, and in relative terms, much greater than the decline in electrical energy use. The biggest decline in CO₂ emissions from electricity use between 2001 and 2011 was in the east. Although western livestock production used about 40% less electrical energy than the east in both years, this term had three times as much CO₂ emissions as the east in 2001 and 5 times as much in 2011.

Table 7. Comparisons of eastern and western fossil CO₂ emissions and energy use quantities in four farm energy uses for livestock production in 2001 and 2011

	Elec- tricity	Heat- ing	Trans- port	Spread manure	Total	Elec- tricity	Heat- ing	Trans- port	Spread manure	Total
	2001					2011				
	Mt CO ₂									
East	0.06	0.24	0.29	0.01	0.60	0.03	0.22	0.23	0.01	0.49
West	0.19	0.31	0.51	0.01	1.02	0.16	0.28	0.42	0.01	0.87
	PJ									
East	1.42	4.66	4.27	0.10	10.45	1.26	4.36	3.43	0.09	9.14
West	0.90	6.07	7.50	0.15	14.62	0.79	5.50	6.20	0.14	12.63

The impact of the three 2030 scenarios for changing the barnyard energy mixes is shown in Table 8. The change impacts are represented as percentages of the 2011 baseline estimates (Section 2.1) for each province and for Canada. The lowest percentages in Table 8 identify the scenarios with the greatest impact (biggest drop from 100%). Also included in Table 8 are the national CO₂ emissions for each livestock type.

Generally, the lowest percentages of the four livestock types belonged to the dairy industry. Poultry had the highest percentages. The provinces with the lowest percentages were Saskatchewan (SK), Alberta (AB) and the Atlantic Provinces (AP). The provinces with the highest percentages were Quebec (QC) and Manitoba (MB) (as stated above for Figure 6). The highest actual barnyard CO₂ emissions (last column of Table 8) were from beef farms, at close to three times any of the other three livestock types in Canada. Canada-wide, over all four livestock types, this scenario suggests a potential reduction of 0.30 MtCO₂.

Table 8. Provincial fossil CO₂ ratios of the 2030 barnyard energy use scenarios to the 2011 Canadian baseline estimates of barnyard energy use by livestock farms in Canada

	AP	QC	ON	MB	SK	AB	BC	Canada	2011 baseline
	% of 2011 Canadian baseline								Mt CO ₂
Beef	79	83	81	83	75	73	81	76	0.68
Dairy	68	77	72	76	63	59	74	71	0.21
Hogs	79	87	82	88	72	69	84	81	0.24
Poultry	86	92	88	92	81	78	89	87	0.22

Figure 7 shows the provincial impact of the 2030 energy scenarios on the barnyard energy use summarized over all four Canadian livestock industries. The biggest differences between 2011 and the 2030 scenarios were in Alberta, Saskatchewan and the Atlantic Provinces. The smallest differences were in Quebec, British Columbia (BC) and Manitoba. The dropping fossil CO₂ emissions from 2011 to 2030 are consistent with Figure 6 and Table 8. The highest CO₂ emissions in both 2011 and 2030 were from Alberta, followed by Saskatchewan, Ontario (ON) and Quebec.

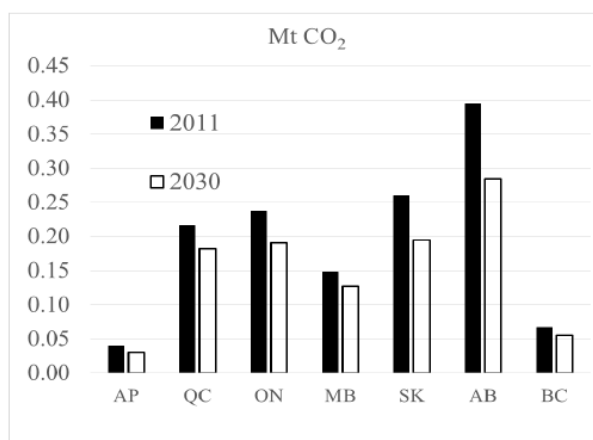


Figure 7. The fossil CO₂ emissions from the 2030 upstream energy scenarios on the barnyard energy use and the 2011 baseline barnyard energy use by the combined Canadian livestock industries

The impact of the transition of 20% of the beef production into hogs is shown in Table 9. The relative increase in the hog population, as indicated in Table 6, is much greater than the decrease for beef. The savings were 0.011 MtCO₂ for the East, 0.079 MtCO₂ for the West and 0.090 Mt CO₂ for Canada. Manitoba (MB) was the only province where the barnyard fossil CO₂ emissions increased with this scenario. This was likely the result of Manitoba having a relatively small beef population compared to the other western provinces and that only one inflation factor for pork protein was applied to all of Western Canada.

Table 9. Sensitivity of barnyard fossil CO₂ emissions to shifting 20% of Canada's protein production from beef cattle to expanded hog farms compared to 2011 baseline estimates

	AP	QC	ON	MB	SK	AB	BC	Canada
	Mt CO ₂							
	2011 baseline							
Beef	0.007	0.031	0.045	0.072	0.209	0.294	0.026	0.683
Hogs	0.002	0.067	0.052	0.052	0.028	0.040	0.001	0.242
Beef & Hogs	0.009	0.098	0.097	0.124	0.237	0.334	0.027	0.925
	Beef to pork protein transfer							
Beef	0.006	0.024	0.036	0.057	0.167	0.235	0.021	0.546
Hogs	0.002	0.070	0.054	0.070	0.037	0.054	0.002	0.289
Beef & Hogs	0.008	0.095	0.090	0.127	0.204	0.289	0.022	0.835

4. Discussion

With the largest change in barnyard fossil CO₂ emissions between 2001 and 2011 being in electrical energy supply (Table 7), it is apparent that a big shift in the barnyard energy use has already occurred in electricity generation. The small change in the heating fuel CO₂ per energy ratio between 2001 and 2011 was the result of the very small change in the fuel mix (Figure 3). Most of that change was in the small decrease in heating fuel, giving way to non-fossil (electric) heating after 1996 (Figure 3). No attempt was made to model the CO₂ emission cost of the increased electric heating energy because it was assumed that this electricity would have been accounted for by the barnyard electricity term. The higher CO₂ per energy ratio for heating oil (68 tCO₂/TJ) compared to the CO₂ per energy ratio for natural gas (50 tCO₂/TJ) accounted for the change in CO₂ emissions from the heating fuel mix. The reason there was no change in the CO₂ per energy ratio for farm transport and manure spreading was that only one type of fuel is used in each of these two operations (gasoline and diesel, respectively).

The high percentages for poultry, and to a lesser extent for hogs, in Table 8 were a result of the heating fuel needed for intensive confined housing for poultry and hogs. The greater dependence of the two non-ruminant industries on heating fuel was confirmed by Figure 5, whereas the two ruminant industries were most dependent on gasoline. The low percentages in Table 8 for Saskatchewan, Alberta and the Atlantic Provinces were a result of the heavy use of coal for electricity generation in those provinces. The high percentages (minimal decrease) for Quebec and Manitoba in Table 8 were a result of being well endowed with hydro-electric generation capacity. This result also reflects that a large part of the Canadian dairy industry, with its high dependence on electricity (Figure 5), is in Quebec.

In Figure 7, the biggest differences between 2011 and the 2030 scenarios were in the provinces with the largest shares of their electricity generated by coal, including Alberta, Saskatchewan and the Atlantic Provinces. The smallest differences were in Quebec, British Columbia and Manitoba, the three provinces with the highest shares of hydro-electric power generation.

The results of this analysis demonstrate that the greatest source of provincial variance in barnyard energy was from coal powered electricity generation. These differences, along with the total CO₂ emissions, should be largely reduced by the commitment to eliminate coal in Canada (McCarthy, 2016). The effect of coal was more strongly felt in Western Canada, mainly because of Saskatchewan and Alberta. The results in Table 7 also reflect the overall declines in livestock populations between 2001 and 2011, with only the western dairy and poultry populations staying the same.

Because energy use was not reported in the 2030 sensitivity test, no CO₂ per energy ratios were calculated in these tests. Nonetheless, there would have been a small change in the CO₂ per energy ratio for heating fuel in the 2030 sensitivity test because heating oil was assumed to be removed entirely, leaving only the propane-natural gas mix (with a lower CO₂ per energy ratio) as the heating fuel. Changes in the CO₂ per energy ratio would be significant in the 2030 sensitivity test for farm electricity because of the impact on this ratio of eliminating coal from the electricity generating energy mix.

There would also be some CO₂ per energy ratio change in the 2030 sensitivity test for e-pickups if the work done by those e-pickups was counted in this energy calculation. That calculation would have to assume that the net electrical energy required for transport by e-pickups added to the fuel energy used by the remaining gasoline pickups would be unchanged from having all of the farm-owned transport powered by gasoline, while the

resulting fossil CO₂ emissions would drop. Even if the e-pickup power was assumed to be electricity generated by renewable resources, quantifying the efficiencies for generating electricity and charging batteries would be beyond the scope of this paper.

In the beef to pork scenario test (Table 9), the fossil CO₂ emissions resulting from increased pork production was less than the decreased beef production. This result is somewhat counter-intuitive because hogs generally require more intensive management and confined housing than beef cattle, and they cannot be fed cellulosic roughage. This result stemmed from pork having a much lower CO₂e per protein ratio than beef when all GHGs are taken into account (Dyer et al., 2010; Vergé et al., 2012). Hence, the proportional increase in hog production to provide the same protein was much lower than the decrease in beef production. Although this emission reduction is modest, it has implications for the over-arching carbon footprints of the two respective livestock industries in Canada. Instead of having to offset the overall carbon footprint difference by the barnyard energy uses, the difference in the two carbon footprints would actually be increased slightly.

5. Conclusions

Both directly and indirectly, changes in electricity generation with the elimination of coal will have the most impact on the future barnyard carbon footprint. The possible changes in barn lighting and heating energy requirements have implications for other agricultural commodities if coal is eliminated. For example, conversion of barn heating to electricity would result in lower indirect CO₂ emissions because electricity would then have no carbon footprint.

Farm-owned transport was the weakest term in the sensitivity analysis because there is weak evidence that significant changes have occurred in the vehicles that farmers choose for their transport requirements. Yet this term is close to the same order of magnitude as farm electricity use and heating fuels. Similarly, the future adoption of e-pickups was, arguably, the most daring assumption in the sensitivity analysis. However, coupled with the elimination of coal, so that these e-pickups are powered by zero-emissions electricity, this could be an attractive GHG reduction strategy for the livestock industries in Canada (the price of e-pickups notwithstanding).

Although not the intended goal of this paper, the sensitivity analysis demonstrates another application of the protein based GHG intensity indicator and the inefficiency of beef as a protein source compared to non-ruminants. The importance of this indicator is that it gives a common basis for comparing all livestock products. It is also implicit that such a change in animal protein sources would require some reinvestment in the infrastructure associated with the barnyard. This transition cost should be weighed against the reduction in barnyard fossil CO₂ emissions.

Splitting farm energy by whether it was needed for livestock or crops will be an important step forward to achieving the integration of energy use and CO₂ emissions from livestock over the LCC. The application of the barnyard energy budget described in this paper to the NCGAVS database opens up new levels of precision for determining the farm energy budget. The finer spatial scale of the NCGAVS database will put greater focus on knowing where those LCC areas actually are compared to previous analyses of livestock. The NCGAVS database also means that the methodology in this paper can be applied to any year of the 25-year time series, and beyond. The importance of yearly data for this analysis was that (as seen in Figures 1 to 3) the declines in these three terms between 2001 and 2011 were all continuous. In other words, there were no intervening years with values higher than 2001, which made the 2001-2011 comparison more meaningful.

Some caution is needed, given the frequent need to interpolate data gaps and to generalize a set of fuels as one energy source in the electricity and heating energy terms. Quantifying energy use as only the energy measured in the barnyard, and converting that energy to CO₂ emissions using the theoretical coefficients in Table 1, ignores the energy losses and additional CO₂ emissions associated with industrial inefficiencies in the energy sector(s). In electricity generation, for example, the upstream CO₂ emission costs could be considerably higher (NRCan, 2005; 2014), which could appreciably raise the barnyard carbon footprint. As well, the non-fossil CO₂ emission impacts of energy sources were ignored in this analysis.

Three of the four terms in the barnyard energy budget could only be quantified by making direct interpolation from the 1996 FEUS. In addition to only providing one year of data, the age of this data source casts a degree of uncertainty around the estimates in this paper. Moreover, there was no recent survey data source that could directly update the FEUS. Conversely, relative to the broad carbon footprint of Canadian agriculture, and particularly for livestock, the barnyard energy terms are small GHG emission contributors. This should not, however, negate the need to carry out another FEUS in Canada.

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