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Potential for carbon offsets from anaerobic digesters in livestock production

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ABSTRACT

Methane from livestock manure accounts for ~6.6% of total greenhouse gas (GHG) emissions in the United States, and 1.1% of total emissions in Canada. Methane is 25 times more potent than CO_2 as a GHG and is emitted into the atmosphere from enteric emissions and manure. Livestock operators can reduce CH_4 emissions and may qualify for credits for its capture by utilizing manure management practices such as anaerobic digesters. Thus, livestock producers can play a role in reducing GHG emissions while also earning C offset credits. This paper has two related objectives. First, using data from Canada, we explore the economics of adoption of anaerobic digesters for Canadian dairy and hog producers. Second, using this example, we explore the institutional framework in place for livestock based GHG emissions and the sources of uncertainties facing both producers and consumers with regard to C offsets. From these two objectives we hope to better understand the potential gains for livestock producers, and consumers of CH_4 based offsets, and identify potential institutional innovations needed to allow the offset market to function efficiently.

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1. Introduction

Concern over climate change has spurred a great deal of attention to available methods to reduce greenhouse gas (GHG) emissions. While most existing climate change policies and proposals exempt agriculture from direct regulation and overall emission caps, farmers may have the opportunity to benefit from providing C offsets to other industrial emitters. These opportunities have the potential to mitigate effects of their higher input costs that may arise as a result of the regulation of emissions.

While much attention has been paid to the potential for offsets from changes in agricultural land management, livestock is a source of CH_4, which is a potent GHG with a global warming potential over 25 times that of CO_2 (Environment Canada, 2009; US EPA, 2010). In Canada, enteric fermentation and manure management are estimated to contribute ~36.8 and 13.0%,

Abbreviations: AD, anaerobic digester; CCS, census consolidated subdivision; CCX, Chicago Climate Exchange; CDM, clean development mechanism; CO_2-eqv, a measure of global warming potential of emissions equal to one tonne of CO_2; EPA, United States Environmental Protection Agency; EQIP, Environmental Quality Incentives Program implemented by the United States Department of Agriculture; ETS, emissions trading system operational in Europe; GHG, greenhouse gas; RGGI, regional GHG initiative of various northeastern and mid-Atlantic States in the United States.

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respectively to non-CO_2 GHG emissions (Environment Canada, 2009). Excluding emissions from fuel use or land use change, GHG emissions from the Canadian Agricultural Sector were estimated to be ~60 million tonnes CO_2-eqv in 2007, up from 48 tonnes CO_2-eqv in 1990. This increase was estimated to largely result from an expansion of beef and hog production, making livestock production a target for potential emissions reduction (Environment Canada, 2009). In Canada, ~87% of CH_4 emissions from animal waste management systems originate from liquid manure storage, accounting for 71% of CH_4 emissions from animal waste in Alberta and 95% in Québec (Methane to Markets, 2006).

Livestock producers face a variety of options to reduce CH_4 emissions (UNFCCC, 2008). Enhancing feed quality, improved pasture and grazing management, as well as other practices can reduce enteric CH_4 emissions (Beauchemin and McGinn, 2005; Johnson and Johnson, 1995; Jordan et al., 2006; Lovett et al., 2003, 2006; Machmüller et al., 2000; Alcock and Hegarty, 2006). Other approaches include improving animal genetics and herd health to increase feed efficiency. How much abatement can be achieved at what cost by using specific mitigation technologies is the subject of ongoing research (Beach et al., 2008; Monteny et al., 2006; Smith et al., 2007).

One proven technological option for hog and dairy producers to reduce CH_4 emissions is its capture via anaerobic digesters (AD), which convert CH_4 produced by liquid waste storage to biogas, which can be used to generate heat and electricity. This process reduces GHG emissions directly as well as offsetting emissions that would have been produced when fossil fuel based systems were used to generate the electricity. Natural Resources Canada helped fund several AD to demonstrate this technology in Canada. A review of 5 of these projects included 2 hog and 2 beef cattle operations and one municipal waste operation (Monreal et al., 2007). The projects illustrated the technical feasibility of AD in Northern climates for beef and smaller (*i.e.*, 1200 hog) swine operations.

In the United States, the EPA has touted AD as having potential to reduce GHG emissions from dairy and hog manure. Using the assumption that AD are technically feasible for dairy operations with over 500 cows and hog operations with over 2000 head with lagoon storage and over 5000 head with pit storage, the EPA estimated that 62% of CH_4 emissions from dairy and 70% of CH_4 emissions from hogs could potentially be eliminated by use of AD. However, the EPA estimates do not formally model farmer costs and benefits of AD to determine when AD are a profitable component of a livestock production system.

In a careful study of the economic feasibility of AD for US dairy farms, Gloy (2010) concluded that even at relatively modest C prices (*i.e.*, \$15/tonne CO_2-eqv) could result in almost half of possible manure CH_4 emissions from dairy farms being captured using AD. Using farm level data, Gloy (2010) noted that larger dairy operations are more likely to utilize lagoons than drylot storage for manure, resulting in higher CH_4 emissions/cow from the manure (Krich et al., 2005). This effect is compounded in that many of these large operations are located in warmer parts of the USA, which promotes growth of the bacteria responsible for producing CH_4 thereby increasing GHG emissions from manure (US EPA, 2010). However, these larger operations can better afford the substantial capital investment for AD, and stand to have steeper GHG emissions reductions than smaller operations. Because larger US dairy operations emit more GHG/unit milk than smaller farms, even if only the largest 4.5% of dairy farms comprising 32% of the national dairy herd adopted AD, about half of the national emissions associated with dairy manure would be offset.

The potential for C offset income also rests on the assumption of a functioning market for C credits. Examples of these markets already exist in North America, Europe and Australia, but with relatively low and historically volatile prices. For such markets to work effectively and align emissions reductions targets, offsets need to be additional in that they need to provide GHG savings that would not have occurred otherwise, must be verifiable and, ideally, should be permanent. From the perspective of the livestock producer, the offset market itself needs to be transparent, accessible and not prohibitively risky. Further, before fronting a large investment, the livestock producer needs to be assured of property rights over the emissions reductions they create.

We examine the potential for adoption of AD by Canadian dairy and hog producers, by approaching the issue from an economist's perspective by outlining a model of the adoption decision. Results of the model and its key parameters are discussed, with a focus on identifying issues that require continued research, and that could benefit from multidisciplinary collaboration among economists and other scientists. We then move on to explore some of the issues surrounding C trading as it applies to agriculture. A brief discussion of existing markets for GHG emissions is provided, along with a brief review of research on impacts of climate change policy on livestock producers. Finally, we outline some of the policy issues associated with establishing emissions regulations and barriers to entry into the C market for producers.

2. Methods

The choice of adoption of an AD can be based on the profit equation developed by Gloy (2010) as:

$$\pi = \left\{ p_e q_e + p_{CO_2} p_{CO_2} - \frac{\alpha\beta}{[(1/\delta) - (1/(\delta(1+\delta)))^n]} - \gamma g \right\} H$$

where π is profit, p_e and q_e are the price and quantity/head of energy produced, H is the number of head of livestock (either dairy cows or hogs in our example), α and β are capital cost parameters reflecting initial investment, γ is the operating cost kw/h produced and δ is the discount rate. From this equation, one can estimate the operation size (H) at which a livestock producer will receive sufficient financial incentive to adopt an AD, conditional on values for the other parameters. The

Table 1A
Parameter values used in dairy cost simulation.

Parameters	Dairy operations	
	Base scenario	Fixed costs
α Capital cost (US$/head)	10,000	560
β Capital cost	0.7	1
Fixed cost (US$)	0	678,000
S Electrical production (kWh/head/year)	1100	1100
δ Discount rate	5%	5%
n Life of digester (year)	20	20
γ Operating cost (US$/kWh)	0.035	0.035
Price for electrical sales to grid (US$/kWh)	0.1	0.1
qCO$_2$-eqv (tonnes CO$_2$-eqv/head)	2.859	2.859
pCO$_2$-eqv ($/tonne CO$_2$-eqv)	15	15

Sources: Gloy (2010), Lazarus (2009) and US EPA (2004).

parameter values in our baseline analysis for dairy operations are in Table 1A and based on Gloy (2010), Lazarus (2009), and the EPA. These estimates are based on studies from the United States, which we extend to a Canadian example for illustrative purposes.

Using data from the 2006 Canadian Census of Agriculture at the CCS level, we estimate a distribution for dairy and hog farm sizes across Canada (Statistics Canada, 2008). Taking into account the limited amount of data on manure management by province, we can estimate those operations that would be most likely to adopt AD. In some respects, digesters may be slower to be adopted in Canada than in the United States as Canadian dairy farms have smaller herd sizes and often do not use liquid manure storage, which increases GHG emissions and encourages digester adoption. Based on CCS averages, ~200 dairy farms, out of the more than 17,000 in Canada, were larger than 200 head (Fig. 1).

As shown in Fig. 2, larger dairy operations tend to be located in Alberta, the Fraser Valley and Vancouver Island in British Columbia, and Eastern Quebec and Ontario. Only ~42% of all Canadian dairy operations use liquid manure storage (Marinier et al., 2004). While there is no breakdown of manure storage types by province and farm type, the overall distribution of manure storage types suggests that dairy operations in Atlantic Canada, Quebec and British Columbia may be more likely to have liquid manure storage, and therefore are more likely to adopt AD technology.

Even less research has evaluated AD for North American hog operations. The EPA suggests that operations must have a minimum size of 2000 hogs to justify installation and use of an AD, but smaller operations have adopted digesters (Monreal et al., 2007). Using estimates from the EPA, a market hog has the potential to produce enough manure to produce between

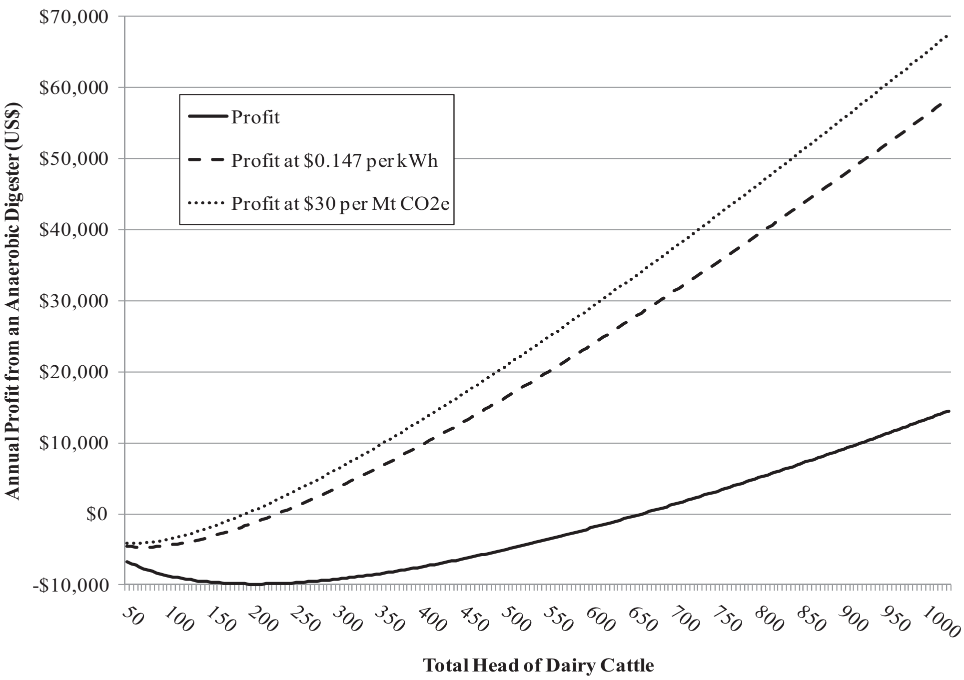

Fig. 1. Profit from an aerobic digester for varying sizes of dairy operations.

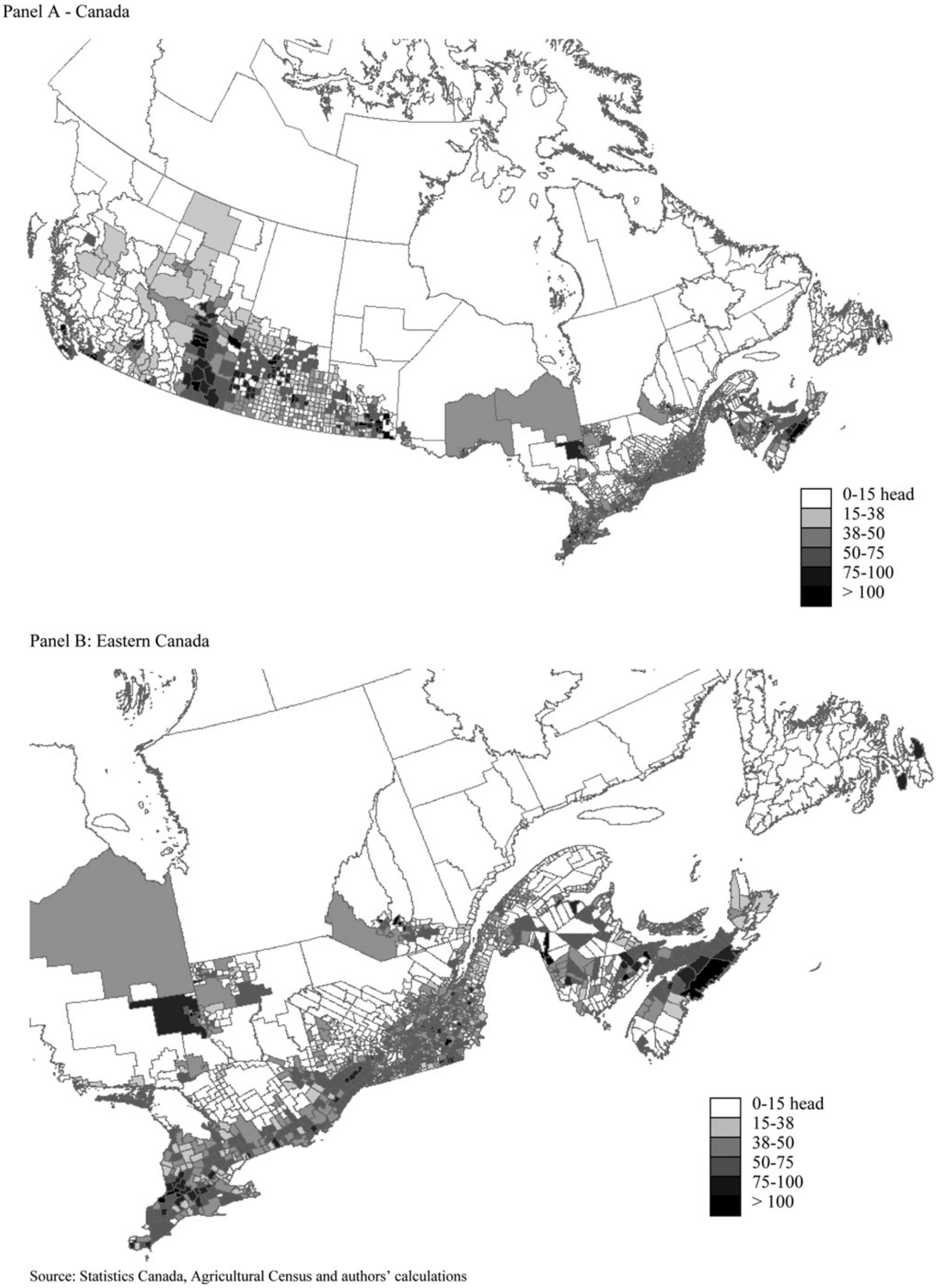

Fig. 2. Average Number of dairy cows farm^{-1} by census subdivision, 2006.
Source: Statistics Canada, Agricultural Census and authors' calculations.

80 and 93 kWh/year when processed through an AD. Using EPA estimates for Illinois, a market hog will produce ~0.365 tonnes of CO_2-eqv and generate 88 kWh of electricity annually.

To obtain cost parameter values for AD for hog operations, we compiled 11 cost estimates from case studies in Canada, Europe and the United States (Ernst et al., 1999; Yang and Gan, 1998; Moser and Mattocks, 2000; Escobar and Heikkilä, 1999; CAEEDAC, 1999). We updated these costs to reflect 2010 US$ and use the case studies to fit a linear-logarithmic model that relates total capital cost to operation size as:

$$c = \alpha + \beta \ln(H)$$

Table 1B
Parameter values used in hog cost simulation.

Parameters	Hog operations	
	Base scenario	High operation cost
α – intercept for capital cost ($'000)	−824.3	−824.3
β Capital cost ($'000/ln(head)[a])	144.6	144.6
S Electrical production (kWh/head/year)	88	88
δ Discount rate	5%	5%
n Life of digester (year)	20	20
γ Operating cost ($/kWh)	0.035	0.12
Price for electrical sales to grid ($/kWh)	0.1	0.1
qCO_2-eqv (tonnes CO_2-eqv/hd)	0.365	0.365
pCO_2-eqv ($/tonne CO_2-eqv)	15	15

Sources: Ernst et al., 1999; Yang and Gan, 1998; Moser and Mattocks, 2000; Escobar and Heikkilä, 1999, CAEEDAC, 1999, EPA (2004), and author's calculations.
[a] ln(head) is the natural logarithm of the number of hogs per farm.

where c is total AD investment cost, ln(H) is the operation size in the natural logarithm of the head of hogs per farm, α and β are estimated coefficients. We also obtained a range of estimates for AD operating costs, ranging from $0.015/kWh (Moser and Mattocks, 2000) to $0.12/kWh (Yang and Gan, 1998). The parameter values used in our baseline analysis for hog operations are in Table 1B.

3. Results

Fig. 1 illustrates profitability of adopting an AD across a range of dairy herd sizes under 3 price scenarios. Using Gloy's model and parameters, with a slightly higher electricity price of 10 US cents/kWh and C offset price of $15/tonne of CO_2-eqv, only farms with more than 675 dairy cows would break even with an AD in Canada. However, as this approach does not explicitly separate fixed investment cost from cow investment cost, this may underestimate up front investments for smaller producers. Using the data of Lazarus (2009), as reported in Outlaw et al. (2009), herd sizes would need to be close to 785 cows for the producer to break even on investment in an AD. From the perspective of the price of C, a 200 dairy cow Canadian operation would need a price of $33/tonne CO_2-eqv to justify investment in an AD. That value would have to increase to $86/tonne CO_2-eqv using the costing numbers of Lazarus (2009), illustrating the difficulty for a smaller farmer to reach the economies of scale needed to afford the capital investment needed for an AD.

For an AD to be economically viable for more than a handful of dairy producers in Canada, dairy farms will require subsidization for their initial investment, or they will have to develop some way of pooling the fixed cost among several producers. However, given that one dairy operation listed on the former Chicago Climate Exchange has adopted an AD on an operation with only 400 cows indicates that these cost estimates may be too restrictive.

Fig. 3 illustrates the profitability of adopting AD across a range of hog operation sizes under 3 price scenarios. Using the electricity, C and other prices from Gloy (2010) and an operating cost of US$0.035 generated/kWh, a hog operation would have to produce almost 2000 hogs/year to financially justify purchasing an AD. Interestingly, this estimate is very close to that provided by the EPA (US EPA, 2004). Our model implies that, for an average Canadian hog operation of 1700 head (Statistics Canada, 2010), C prices/tonne of CO_2-eqv would only need to be a few dollars higher than our baseline of $17/tonne CO_2-eqv) to justify AD investment. Virtually all hog operations in Canada use liquid manure storage (Marinier et al., 2004), implying that any government support for digester systems in the Canadian hog sector could substantially reduce their CH_4 emissions (Fig. 4).

It should be noted, however, that these results are highly sensitive to using the relatively high price of electricity of 10 US cents/kWh, and relatively low operational cost. If the higher operation costs suggested by Yang and Gan (1998) are used, then a 1700 hog operation would need a CO_2-eqv offset price of US$38 before AD is profitable. Similarly, at a lower cost of electricity and lower operation cost, the average Canadian hog farm would need a CO_2-eqv price of over US$47 to make an AD profitable. This latter simulation demonstrates the sensitivity of the model to electricity prices.

A current policy alternative to direct subsidization of livestock producers may be provided by mandating electric utilities to pay additional fees for purchase of energy from small scale renewable sources. For example, Ontario hydro's feed-in-tariff program offers 14.7 Cdn cents/kWh produced by small scale AD. Using the same base scenario parameters, and changing only the electricity price to reflect the current Ontario program, AD would become feasible for 200 cow dairy operations and hog operations under 500. Thus, results are highly sensitive to the price of electricity and the price of C offsets. At the current price for residential electricity in the Montreal area of Cdn $0.07/kWh, and no offset, our model finds that it is never profitable for hog or dairy producers to adopt an AD. Even with the electricity price premium provided by Ontario for biogas generation, without offsets only dairy operations >550 cows and hog operations >2500 head would find it profitable to adopt AD merely for electricity generation. Thus, it is unlikely that AD would be adopted only for providing electricity without special renewable energy subsidies or much higher electricity prices.

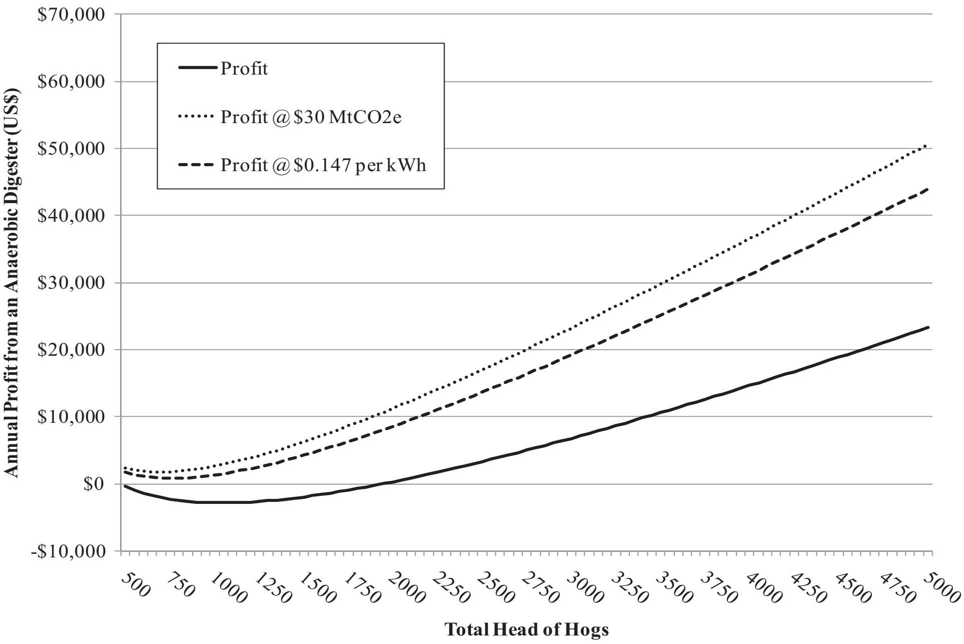

Fig. 3. Profit from an aerobic digester for varying sizes of hog operations.

3.1. Limitations

A number of limitations of this analysis should be highlighted. First, our capital and operational cost data should be treated with caution since they are based on individual case studies which, in the case of hogs, are all more than 10 years old. Further, we aggregate over all types of hogs and hog operations. Thus, these numbers most closely represent a farrow-to-finish operation, as opposed to a farrow-wean or finish only. Third, as noted above, estimates of operational costs vary by an order of magnitude, in some cases implying that current market electricity prices would not be sufficient to cover the expense of operating and maintaining an AD. Fourth, we use single parameter estimates to generate a representative farm for all of Canada. We recognize the potential hazards associated with this, since feeding regimes and weather differ with geographical location. For dairy operations, most importantly, manure storage methods differ. All of these factors can be incorporated into the simple model above by changing parameter values to suit regional specific requirements.

3.2. Policy options and ancillary benefits

If governments set socially appropriate limits for GHG emissions, then the price for offsets will reflect their true social costs. Thus, if a functioning C policy were adopted with cap-and-trade in CO_2-eqv credits, it would not be socially optimal to further increase permit prices to induce adoption of specific technologies such as AD purely for GHG reasons. If, with an efficient market and binding emissions caps, C prices are not high enough to justify adoption, it implies there are cheaper and more efficient methods to reduce GHG emissions.

Even before a comprehensive global price on C has been adopted, some jurisdictions have implemented specific policies that subsidize adoption of AD. For example, by providing initial capital subsidies and providing incentives for electricity produced, California's Dairy Power Production Program funded 10 AD prior to 2006, and 9 afterwards (California Energy Commission, 2011). Other incentives are available in the USA through renewable portfolio standards which require US states to generate a certain proportion of their electricity from renewable sources. Along with subsidies from the US EPA's Energy Star program, the United States now has 135 agricultural digesters in place (Pew Center on Global Climate Change, 2010). Other countries, such as Germany, have similar policies to Ontario and give preferential purchase prices to electricity generated from renewable sources such as biogas. These policies are referred to as feed-in-tariffs. In Germany, feed-in-tariffs have generated substantial incentives for adoption of AD, leading to over 4000 AD becoming operational by 2008, with an additional 800 slated for construction (Pew Center on Global Climate Change, 2010).

AD reduce GHG emissions and can generate ancillary environmental benefits by reducing odor and promoting sound nutrient management (Gloy, 2010; Monreal et al., 2007). These effects could be substantial and, if not valued, will result in under adoption of AD. Thus, one could envision further sources of funding for AD from potential federal or provincial water quality programs that funded farm level nutrient management. Similar approaches are already employed in the form of the existing nutrient agri-environmental schemes in Europe or the Environmental Quality Incentives Program (EQIP) in the United States. While it is beyond our scope to estimate the value of such ancillary benefits, the existence of these other

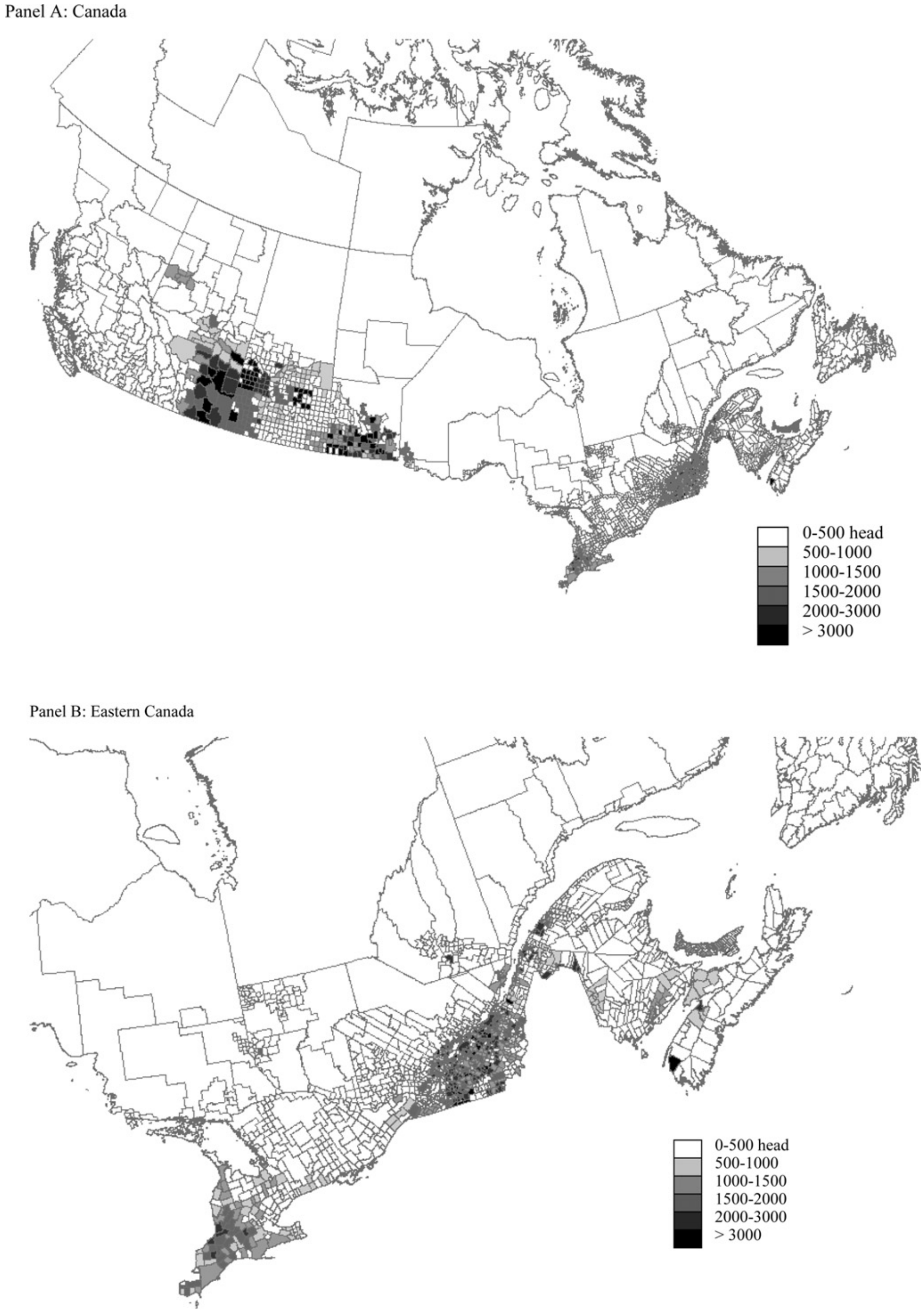

Fig. 4. Average number of hogs/farm in 2006.

positive outcomes associated with AD may justify further government support to provide the necessary economic incentives for their adoption.

4. Discussion

As noted above, adoption rates for a technology such as AD will be highly sensitive to C and electricity prices, as well as costs of the investment. Creation of a formal C market would establish a value for CO_2-eqv emissions, in addition to affecting prices of energy commodities, electricity and other agricultural inputs. Cap-and-trade systems are just one possible form of such a market, but with consideration for existing markets and proposed legislation, they seem to be the most popular.

The concept of a cap-and-trade emissions trading system is both deceptively simple and profound. The process begins with a government establishing a cap on the overall amount of emissions and allocating emissions permits. Each recipient can emit relative to the number of permits held. Recipients are allowed to buy and sell permits, and those who cannot reduce emissions, except at a prohibitively high cost, can purchase permits from others who can more easily reduce theirs. While the overall quantity of emissions is no different than would occur by merely imposing a total limit on emissions, introduction of tradable permits allows emitters to sort themselves by the cost of reducing emissions and generates emissions reductions at least cost. As the total emissions cap shrinks, these permits grow in value, creating a financial incentive to invest in emissions reducing technology, and allowing them to profit from this investment by selling their emissions reduction efforts to the highest bidder.

Cap-and-trade emissions trading schemes have been very successful in reducing SO_2 emissions from coal fired electricity generators in the mid-west and north-eastern US under the Acid Rain title of the 1990 Clean Air Act, and are being used to curtail N_2O and SO_2 emissions in the Los Angeles basin through the Regional Emissions Clean Air Market, or RECLAIM (JEC, 1997).

A number of general GHG emissions markets have been either adopted or proposed at international, national and regional levels. The European Union has established an ETS which allows industrial emitters to trade C permits to help Europe comply with its commitment to reduce total GHG emissions. The RGGI represents a regional regulatory approach where 10 states in the northeastern and mid-Atlantic US are cooperating to reduce GHG emissions from electric power plants. This program allows for offset projects, including capture of CH_4 via AD on livestock operations. A national cap-and-trade program for GHG in the US has been proposed in the Waxman–Markey bill that passed the US House of Representatives in 2009 (H.R. 2454). The CDM under the Kyoto Accord also established a market for C offset projects in developing countries. A comparison of these markets is in Kollmuss et al. (2008).

In Canada, a number of provinces have adopted GHG emissions reduction legislation, creating markets for emissions trading. Alberta was the first province to develop legislation to regulate GHG emissions, which includes an offset credit system. Five Canadian provinces are involved with the Western Climate Initiative (WCI), which is a multinational GHG emissions reduction effort along with 6 states in the Western US. The WCI includes a comprehensive cap-and-trade program with provisions for offsets provided by unregulated sectors such as agriculture. The Canadian and Australian governments are also developing national offset programs (Kollmuss et al., 2008; Environment Canada, 2009).

Relative to the regulation of specific GHG, general GHG trading poses a problem in that there are a very large number of emitters, and emissions are not always easily measured. In response, the caps set under the current European system, the earlier Canadian Kyoto proposals and the proposed cap-and-trade market in the US House Bill are typically targeted at select industries, such as electric utilities, oil and gas producers and other large industrial emitters. Smaller entities, including farms and individual households, are largely excluded from direct regulation.

Most existing or proposed climate legislation allows emitters outside the formal regulated sector to participate in the emissions trading scheme through provision of C offsets. In general, offsets are created by an unregulated firm which reduces its emissions below some baseline, and then sells those emissions credits in the market. To conform to the overall emissions limit, these offsets must be additional to usual reduction practices in that they would not have happened without the financial incentive provided by the emissions market. In this way, these offsets balance the permits provided in the market.

4.1. Additionality

One substantive policy challenge lies in the need to define the baseline against which ‘additional’ emissions reductions are measured. A question of equity arises around those parties who have invested in emissions reducing technologies for non-monetary reasons. Adoption of technologies too early can result in these emission reduction efforts being subsumed by the ‘baseline’ relative to those individuals who adopt reduction practices after the baseline level is set. Past proposals in Canada suggested establishing a baseline based on ‘business as usual’ practices. Essentially, the provincial and federal governments were proposing to capture reductions by early adopters (Allan and Baylis, 2005).

A related issue arises because agricultural emissions are not capped, leading to the question of whether the baseline includes the potential increase in emissions which may be associated with adoption of new technology. For example, current convention would not allow a farmer who had been practicing no-till to plow up the field, thereby releasing stored C, and then sell offsets as they re-adopt reduced conservation, or no-till, practices to store C in soil.

In the case of livestock production and manure management, AD work best with liquid manure storage, which itself emits much higher levels of GHG than manure in dry storage or deposited on pasture. If a livestock producer increases emissions by moving to liquid manure storage, but then adopts an AD, the question arises with regard to whether the baseline level of emissions should be established before or after adoption of the liquid manure storage system. Since liquid manure storage is associated with better manure handling practices and nutrient management, the move to liquid manure management is generally seen as a change to be encouraged, and producers are not penalized for the potential increase in emissions.

Chicago Climate Exchange (CCX) guidelines require that the baseline for a CH_4 offset be pre-existing to manure management by liquid slurry, pit storage below animal confinement or an anaerobic lagoon (Chicago Climate Exchange, 2009). Under Alberta Offset System rules, projects can claim credits back to 2002 if they meet the requirements of the system and protocols. There is no deadline to access credits for these past accumulated offsets, providing they can be verified. If a project developer wanted to wait to see how the market evolves, they could get involved later and gain credit back to 2002 if all requirements were met. However, whether liquid or solid manure handling is treated as the baseline is unclear, since it appears to depend on which manure handling practice was in place before establishment of AD. The biomass supplier must also verify that the agricultural material would otherwise have been managed in a manner that would increase emissions without the AD.

4.2. Market participation issues

Once a C offset market has been created, potential offset providers, such as livestock producers considering installation of an AD, face the question of whether to participate. From 2004 through August 2009, over 1.4 million tonnes of CO_2-eqv in offsets from agricultural CH_4, projects were registered on the CCX. While these represent only 2% of total offset projects, livestock offsets have been increasing. Methane emission offsets were issued by CCX on the basis of all CH_4 collected and combusted. Eligible agricultural CH_4, collection/combustion systems include covered AD, and complete mix and plug flow digesters. Further, noting that 135 livestock based AD were in operation in the US in 2009 (Pew Center on Global Climate Change, 2010) it appears that only a handful of potential agricultural CH_4 projects already underway are making use of potential offset revenue. As of September 2010, 53 agricultural CH_4, projects were registered, all but one of which are based in the USA. Of these, almost 90% were associated with dairy operations.

By contrast, in Canada, only 6 agricultural offset projects were registered, 4 of which were for soil sequestration with the remaining 2 based on CH_4 capture from landfills. While we do not know the number of AD in use in Canada, the EPA identified 100 systems on US dairies as early as 2005. This implies that economic incentives to encourage use of AD exist, but raises the question as to why more of these existing operations are not participating and receiving C offset revenue. While the currently low C price acts as a deterrent, at US\$3/tonne CO_2-eqv for Dec 2011 contracts on the voluntary Montreal exchange, US\$2.90/tonne CO_2-eqv on the voluntary and now defunct CCX compared to European Union ETS prices of 11 Euros/tonne CO_2-eqv, price risk may deter livestock producers from participating (Chicago Climate Exchange, 2009).

Historical prices for CO_2-eqv on the ETS have experienced high levels of volatility. As of September 30, 2010, prices hovered around 15.33 Euros/tonne CO_2-eqv, which is about half their value just 2 years prior. Livestock producers who install digesters as part of an offset project are making a long term investment in uncertainty surrounding the future value of the offsets they generate. Moreover, for projects registered with the CCX, a time lag exists between registration and the actual time of sale or retirement of those offsets. The existence of such a time lag reduces the informational value embedded in current price levels, which livestock producers and other potential offset providers may use to make investment decisions.

While a futures market exists to help manage such price risk, it is unclear how this risk is shared among aggregators and individual offset participants. Compared to the well established futures and options markets for agricultural and energy commodities, the futures markets for C administered by the Chicago, European, Montreal and Tianjin Climate Exchanges trade at relatively low volumes and provide limited opportunities for price risk management at the farm or project level. For example, from March 2008 to November 2010, the volume traded on the European climate exchange was less than 0.2% of traded oil futures and slightly more than 2% of the value of trade in corn. Within that small average volume, however, there are large among day price variations. While firms offering registration, verification and offset aggregation services may be positioned to use these tools, costs of risk management are passed along to individual projects in fees.

Emissions reductions programs can be voluntary (*i.e.*, the former CCX) or regulated/mandatory (*i.e.*, RGGI or European ETS). The fundamentals driving prices for C emissions and offsets differ considerably in the two markets. For example, under a voluntary system participating emitters are likely to have a relatively low cost of reducing emissions leading to comparatively low values for C permits. Under a regulated system, emitters which are faced with higher emission reductions costs will be required to participate, creating more demand for emissions offsets thereby putting increased pressure on C prices. This will also encourage more rapid development of mechanisms to help manage C price risk, and lead to more active trading in existing futures markets. More sophisticated derivative markets for C, such as options and insurance contracts tailored to specific projects could then be developed in both spot and futures contexts.

The costs, in terms of time and money, of verification are another barrier to producer participation in offset creation projects. For example, CCX projects required that biogas flow measurements, records and documentation procedures be verified by a CCX approved independent third party. Following an initial on site inspection, projects must be verified annually and are subject to inspection at any time. To date, there are only 6 approved verifiers for agricultural CH_4 projects, limiting the competition among firms offering verification services. Costs of the verification process are not publicly available, but anecdotal evidence indicates that they are substantial and price discrimination is likely used by verification firms when working with offset projects.

4.3. Other impacts of GHG regulation on agricultural producers

Regardless of whether agriculture is directly regulated, or provisions for an offset market are made available to livestock or other agricultural producers, a binding regulatory system such as a cap-and-trade program will impact livestock and other agricultural operations. Since large upstream energy producers would have to make investments to reduce emissions or purchase additional permits or offsets, these regulated firms will face higher production costs. These higher costs will be passed on to customers in the form of higher oil and gas prices, and higher electricity rates. While, in Canada, much electricity is produced by hydroelectric generators, the extra kWh used in periods of peak demand often still come from coal fired plants, implying that Canadian consumers will also face higher electricity rates.

The debate in the US House of Representatives on the climate change bill proposed by Congressmen Henry Waxman and Edward Markey (H.R. 2454) spurred much discussion and research on effects of a cap-and-trade system on US agriculture. Given the similarities between US and Canadian agricultural production, these studies are likely indicative of what might occur in Canada. Most studies show costs increasing for US agriculture, but that these increases would not be large (Golden et al., 2009; Babcock, 2009). Given that the USA is a large producer, some of these increased costs would be passed along to consumers in the form of higher prices, moderating the decrease in farm profit. Many of these studies also do not include the potential for farmers to earn income from use of offsets. When offset markets and renewable energy mandates are included, a Kansas State University study (Golden et al., 2009) argues that agriculture may benefit, but that these benefits will be larger for feed grain and wheat than other agricultural commodities, particularly livestock.

As energy prices rise, farmers will incur an increase in direct costs for fuel and electricity. These costs will also translate into increases in other input prices, such as N fertilizer and livestock feed. In response, farmers may adopt different management practices, such as no-till or precision agriculture, to use less fuel or fuel intensive inputs, as a response to some of these cost increases. One of the more comprehensive studies on the effect of HR 2454 on crop and livestock producers was done by a team at Texas A&M University (Outlaw et al., 2009). Using a simulation model, the authors estimated effects of the legislation on farm costs and revenues allowing for changes in cropping patterns and technology as a result of higher input prices. Their simulation was restricted to dairy and beef cattle operations with the only offset option being adoption of AD, arguing that pasture offsets would require a dramatic reduction in stocking rates. The AD were assumed to only be economically viable for dairy operations with over 500 cows. Overall, they found that crop producers in the US mid-west and prairies may benefit from a cap-and-trade system, gaining from offset opportunities more than they lose due to higher production costs. In contrast, they assume rice and cattle producers cannot make use of offsets and therefore face reductions in returns.

Using a wider range of potential C offset options, specifically around biofuel production, APAC (2009) finds potential net benefits to agriculture from the Waxman–Markey proposed climate change legislation. A study from the Nicholas School at Duke University incorporated more offset options from afforestation (*i.e.*, planting of trees), on farm and pasture land (Baker et al., 2009). It also considered potential reductions in enteric CH_4 emissions and manure management. They found that by far the largest potential source of offset revenue comes from afforestation and forest management. Within agricultural practices, however, they estimated that reduced enteric CH_4 emissions plus manure management could provide between US$342 and 2243 million in offset revenues/year. However, livestock producers would face increased feed and input costs.

5. Conclusions

In addition to the environmental benefits of GHG emissions reductions within the agricultural sector, C markets may hold financial potential for Canadian livestock producers by generating revenues from creation of emission offsets. Along with currently low C prices, price risk, policy risk and verification costs are additional barriers to participation of livestock producers in existing C and C offset markets. Provision of a clear and mandatory regulatory system would diminish policy risk and offset prices would be expected to increase, as well as be accompanied by other financial instruments which would allow livestock producers to better mitigate potential price risk.

Using data from the 2006 Canadian Census of Agriculture, and methods established by previous research in the area, we provided estimates of potential adoption rates for AD by Canadian hog and dairy operations, and the resulting supply of C offsets generated by adopting farms. At a modest C price of $15/tonne, which is lower than the current ETS price, AD would be profitable for the largest Canadian dairy and hog producers. Results are extremely sensitive to parameter values in the model, specifically the assumed energy price received by producers for AD generated electricity. While not surprising, this suggests that our values should be interpreted with care. Further, the equilibrium market price for C will ultimately be determined by the interaction between a number of factors, most important of which is the aggregate cap set on emissions and the parties which fall under such regulation.

The primary constraint to adoption of AD by livestock producers is the substantial initial fixed cost, which is prohibitive for smaller producers. While direct subsidization of this investment is one policy tool to encourage adoption, alternatives include tighter regulations on manure management practices as well as mandated price levels for energy generated from renewable sources such as AD. Programs such as Ontario Hydro's feed-in-tariff combined with a modest C price would make AD affordable to the larger operators within the Canadian livestock industry.

Conflict of interest statement

None.

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