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Carbon offsets and agriculture: Options, obstacles, and opinions

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Abstract

While carbon offsets in agriculture can play a role in addressing climate change, they are not a perfect substitute for direct emission reductions. As shown in this paper through various arguments and case studies, climate policies in Canada have avoided the use of offsets to be sold in carbon markets, preferring instead to incentivize adoption of best management practices (BMPs) that provide environmental benefits along with climate mitigation benefits. We argue that this is a preferred policy option due to the perils and pitfalls inherent in the measurement and monitoring required to identify offset credits. While an appropriate approach might be to penalize Canadian farmers for any emissions their activities cause, this may do more harm than good. Canadian agricultural production is highly efficient and technologically advanced; therefore, reductions in Canada's contribution to the global food supply will result in less-efficient production occurring elsewhere (i.e., leakage) that increases global greenhouse gas emissions.

KEYWORDS

asymmetric information, best management practices, carbon markets, climate change policy, fertilizer use, livestock

JEL CLASSIFICATION

Q15, Q18, Q54

RÉSUMÉ

Même si les compensations de carbone dans l'agriculture peuvent jouer un rôle dans la lutte contre le changement climatique, elles ne constituent pas un substitut parfait aux réductions directes des émissions. Comme le montre cet article à travers divers arguments et études de cas, les politiques climatiques au Canada ont évité le recours aux compensations destinées à être vendues sur les marchés du carbone, préférant plutôt encourager l'adoption de meilleures pratiques de gestion (BPG) qui procurent des avantages environnementaux ainsi que des avantages en matière d'atténuation du climat. Nous soutenons qu'il s'agit d'une option politique privilégiée en raison des périls et des pièges inhérents à la mesure et au suivi requis pour identifier les crédits compensatoires. Bien qu'une approche appropriée pourrait consister à pénaliser les agriculteurs canadiens pour les émissions causées par leurs activités, cela pourrait faire plus de mal que de bien. La production agricole canadienne est très efficace et technologiquement avancée. Par conséquent, la réduction de la contribution du Canada à l'approvisionnement alimentaire mondial entraînera une production moins efficace ailleurs (c'est-à-dire des fuites), ce qui augmentera les émissions mondiales de gaz à effet de serre.

1 | INTRODUCTION

Along with many developed countries, Canada committed to achieve Net Zero greenhouse gas (GHG) emissions by 2050—this implies there are to be no emissions from fossil fuel burning. Yet, some emissions of GHGs will be unavoidable, in which case countries will need to offset remaining emissions to comply—they will need to purchase or create carbon offsets. The term 'carbon offset' implies that measurement is in units of carbon (C) but it generally refers to carbon dioxide (CO_2) with other GHGs converted to a CO_2-equivalent (CO_{2e}) to facilitate comparison of their differing warming potentials; further, prices are generally provided per unit of CO_2.[1]

In the strict world of Net Zero, a carbon offset only refers to the removal of CO_2 from the atmosphere that compensates for an equivalent emission of CO_2, usually from fossil fuel burning. In practice, however, carbon offsets can be created through a much broader array of activities than only those that remove CO_2 from the atmosphere (as discussed in the next section). These include activities that mitigate direct emissions. In this paper, we question whether all such activities create legitimate carbon offsets. The reason relates to the primary goal of carbon offsets, which is to mitigate the effects of climate change by balancing out or neutralizing the overall emissions of a particular country, individual, organization, or product.

Carbon offsets are already a major consideration in the drive to reduce CO_2 emissions, particularly in the forestry and agricultural sectors. Although the focus in this review is on the agricultural sector, the two primary sectors often compete for the same land. In essence the opportunity cost of creating carbon offsets in the agricultural sector is the ability of forestland to create carbon offsets, and vice versa. Our purpose is to examine the potential for agricultural producers to create and sell legitimate carbon offset credits. Since the creation of carbon credits is tied to farm operations and agricultural practices, we raise issues related to climate policy as well as agricultural policy. Ours is a broad-brush approach; we aim to avoid specifics because one could get mired down by technical details that are beyond the purview of the economist.

We begin in the next section by expanding on the concept of carbon offsets and their pitfalls. In Section 3, we consider agriculture's contribution to global warming and potential policy initiatives for reducing this impact. Then, in Section 4 we discuss Canadian and international case studies surrounding potential snags in carbon offset implementation. In Section 5, we review current agricultural climate policy in Canada as well as best management practices, followed by a concluding discussion in Section 6.

2 | CARBON OFFSETS IN CONTEXT

A carbon offset broadly defined is a reduction in CO_2 emissions, or an equivalent removal of CO_2 from the atmosphere—referred to as carbon dioxide removal, or CDR—that is realized outside of an 'emissions compliant market' and can be used to counterbalance greenhouse gas emissions from a capped entity. The concept can be explained using the back-to-back diagram in Figure 1. The emissions compliant market is presented on the left-hand side of the figure, while the carbon

[1] We will use CO_2 rather than CO_{2e} when referring to GHGs more generally. The reader will recognize the context in which we use CO_2 to refer to the specific gas or more broadly to all GHGs. Based on their molecular weights, carbon in biomass is converted to CO_2 as follows: 1 tonne carbon (tC) = 44/12 tCO_2.

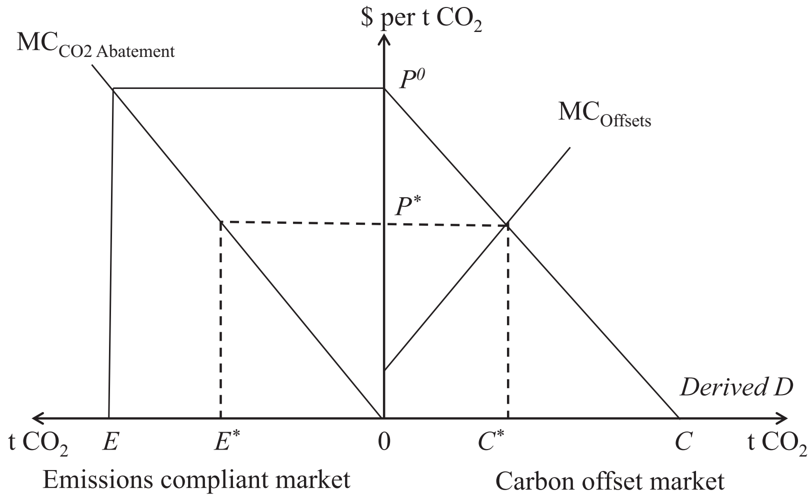

FIGURE 1 Market for carbon offsets as a function of mandatory emissions reduction.

offset market is on the right side. The carbon market represented here is recognized by the authority as creating legitimate or recognized offsets, so that Figure 1 represents a 'mandatory compliance market'. For example, the European Union's Emissions Trading System (ETS) is the best known compliance market; it permits carbon offset allowances only certified by an accredited regulator, but allows offsets to be created by emissions mitigation or carbon sink activities. Companies legally required by their country to reduce emissions must purchase carbon offsets through ETS or another recognized carbon market.

Suppose a jurisdiction or entity faces a CO_2 emissions-reduction target of $0E$ as shown in the left panel, with the marginal cost (MC) of abating CO_2 emissions as indicated. Given that the marginal cost of reducing $0E$ amount of CO_2 emissions is P^0, there exists an opportunity for the entity to buy a carbon offset at prices lower than the marginal cost of reducing its own emissions. Thus, there exists a derived demand for carbon offsets as shown in the panel on the right. Suppose that the marginal cost of creating carbon offsets is given by $MC_{Offsets}$. In equilibrium, the entity will then reduce its own emissions by amount $0E^*$ while purchasing $0C^*$ carbon offsets, which are traded at a price P^* equal to the entity's MC of abatement. This leaves $E^*E = 0C^*$ emissions that are not eliminated, but covered by carbon offsets, thereby satisfying the targeted mandate.

The mandatory compliance carbon market contrasts with the "voluntary" carbon market, where the saying "buyer beware" applies. A voluntary carbon market enables companies to purchase carbon credits on a voluntary basis (CO_2RE Markets, 2023). However, the question is whether offsets sold in any carbon market truly reduce atmospheric CO_2.

Carbon offsets (i) reduce emitters' costs of complying with emission reduction targets, (ii) buy time to develop and adopt emission-reducing technologies, but (iii) reduce incentives to invest in such technologies while (iv) increasing uncertainty and corruption (van Kooten & de Vries, 2013; van Kooten et al., 2015). Problems with carbon offsets are well known, including the following.

1. *Additionality*: This criterion dictates that an emission source can only obtain carbon offsets for emission reductions above and beyond what would occur in the absence of carbon offset incentives.
2. *Leakage*: Climate mitigation activity in one location cannot result in an increase in CO_{2e} emissions in other locations. For example, a farmer might receive a payment for implementing zero tillage on one field but use the saved machinery operating time to cultivate a permanent grassland.
3. *Double dipping*: One cannot sell carbon offsets and then claim the activity that created them against one's own required emissions reduction.
4. *Duration*: Activities such as zero tillage and conversion of land to grasslands or forest sequester carbon over time—sequestration is not instantaneous or within a period of one or two years. How does one measure carbon offsets that are realized over many years and compare them to an emissions reduction? And how does one consider the inevitable release of CO_2 when the land reverts to its original pre-zero tillage or grassland state at some future time? For CO_2

TABLE 1 Evaluation of 50 carbon offset projects.

Item	Number	Likely junk	Potentially junk	Lack information
Overall	50	39	8	3
Carbon offsets (Mt CO_2)	(343)	(267)	(61)	(15)
Forestry & land use	23	20	2	1
Renewable energy	16	15	1	0
Chemical processes/industrial manufacturing	4	1	3	0
Household devices	3	2	0	1
Waste disposal	2	0	1	1
Other	2	1	1	0

Source: Lakhani (2023).

removal projects, duration refers to the time between CO_2 uptake and its eventual release.[2] Do we sum a project's future stream of CDRs and attribute them as a carbon offset occurring today?

5. *Transacting costs*: There are costs of measuring, monitoring, enforcing, and contracting. Individual landowners will have more information about their agronomic practices, land use capabilities, and the cost of reducing GHGs than either the government or a potential aggregator of carbon offsets from various projects. As noted by van Kooten (2017), this is a classic principal-agent problem with asymmetric information—the agent (government, aggregator, or registered certifier of carbon offsets) lacks knowledge regarding the principal's (farmer) behavior. Will the farmer adhere to a long-term plan to create carbon offsets or take action that might thwart the anticipated outcome? Furthermore, biological carbon sequestration rates are heterogenous and uncertain, which leads to measurement and monitoring problems. Areas with low initial carbon stocks may sequester carbon faster than those with high initial concentrations, and uptake rates can vary widely based on climatic conditions (moisture, temperature, etc.).
6. *Corruption*: One of the more insidious problems of carbon offsets is the proclivity towards corruption (Helm, 2010, 2012). Because offsets have value, the only agents wishing to mitigate corruption are the potential purchasers and they may even tolerate corruption if they purchased carbon offset credits in a voluntary market to assuage their consciences—no one wishes to know they had been duped. Even a legitimate certifier of carbon offsets for the voluntary market has an incentive to be quite lax in what they certify, because future work is often tied to past performance as measured by previous success in certifying projects. They may prefer not to know that the creator/seller of offsets (aggregator, landowner and/or farmer) changed their mind about retaining a field as permanent grassland two years into a project because grain prices had doubled (see van Kooten, 2017).

In most cases that involve carbon offsets 'rent seeking' is a major problem. Economic agents lobby governments (and the media) to be given the right to create and sell carbon offset credits because, if they succeed, they benefit financially. Such agents usually lobby on behalf of financial institutions and 'certifiers' of carbon offsets; certifiers are companies that receive their legitimacy from environmental NGOs, such as the World Wildlife Fund, and/or the government. In turn, the certifiers give carbon offset credits their legitimacy, but there is no guarantee that the certifiers have any expertise in this task—the opposite is often true, for example, when certifiers lacking expertise in forest mensuration (wrongly) calculate the offsets created when cropland is converted to forest (see van Kooten, 2017).

It is not surprising that many questionable offsets have been created and sold in carbon markets. For example, a study conducted by the Guardian newspaper and researchers from Corporate Accountability (a non-profit) analyzed the top 50 emission offset projects (representing nearly 350 Mt CO_2) found at the AlliedOffsets CDR database (see Table 1).[3] According to their classification system, 78% of the emission offset projects were categorized as likely junk (i.e., worthless) due to some failing that undermined its promised offsets—failings related to the six reasons noted above. The analysis also indicated that nearly half of the large offset projects were in the forestry and land use sector, where 97% of projects were likely or potentially junk.

[2] This is a problem when biomass substitutes for coal or natural gas in generating electricity. Burning biomass initially increases CO_2 emissions. Although growing trees eventually remove the CO_2 from the atmosphere, it could take 50–100 years to do so. If there is some urgency to address climate change, early emissions are to be avoided, not encouraged (see van Kooten et al., 2021; van Kooten, 2023).

[3] Available at https://alliedoffsets.com/cdr-data/ (accessed October 11, 2023).

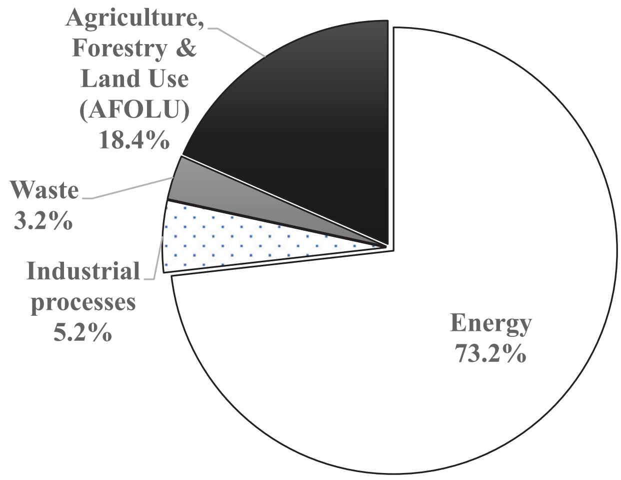

FIGURE 2 Share of global greenhouse gas emissions by sector. *Source*: Richie et al. (2020).

TABLE 2 CO_{2e} emissions from agriculture, forestry and land use, % of sector total.

Activity	Share
Grassland	0.5%
Cropland	7.6%
Crop burning	19.0%
Rice cultivation	7.1%
Agricultural soils	22.3%
Livestock & manure	31.5%
Deforestation	12.0%

Source: Richie et al. (2020).

It is little wonder, therefore, that many economists prefer straightforward carbon taxes over emissions trading—with taxes, financial institutions do not stand to make large profits in trading carbon emissions and there is a lot more transparency under a tax than under an emissions trading system. In agriculture, however, it would be politically difficult to tax CO_2 emissions from input use, say, as this would result in higher costs and greater risks (as chemical inputs are a means to reduce on-farm risk). To examine these issues further, we now consider the agricultural sector in terms of its contribution to GHG emissions and its ability to create carbon offsets.

3 | AGRICULTURAL ACTIVITIES AND CLIMATE CHANGE

From a climate change perspective, the agricultural sector plays a significant role both globally and in specific countries like Canada. In addition to CO_2 emissions, the agricultural sector is a source of methane (CH_4) and nitrous oxide (N_2O), both of which are important GHGs—one tonne of CH_4 has 20 times the warming potential of a tCO_2 and a tonne of N_2O has 300 times the climate impact. Agriculture is a source of these gases through various processes and practices. Agriculture, forestry, and other land uses combine to account for 18.4% of total global anthropogenic CO_{2e} emissions in 2020 (Figure 2)—the contribution of the sector's emissions attributable to its various components is provided in Table 2. The provision of food contributes 26% of global CO_{2e} emissions—of these emissions, livestock and fisheries are responsible for 31% (i.e., 8% of global emissions), crop production for 27% (7%), land use for 24% (6%), and supply chains for the remainder (Richie, 2019). Overall, crops grown for direct human consumption account for 21% of total food production emissions while animal consumption contributes 6%. Regarding the land-use component, use by livestock accounts for 16% of emissions compared with only 8% for humans (Richie, 2019).[4] Of course, the proportions in each of the forgoing categories will vary based on regional practices, land use, and technology.

[4] This is not unexpected as livestock graze on marginal lands that are less suited for crop production.

Based on data for 2009, Canada's agricultural sector contributed about 8% of the nation's emissions (or 56 Mt CO_{2e}), largely as CH_4 (about two-thirds) and N_2O (about one-third). If energy use by the sector is included, agriculture accounts for about 10% of Canada's GHG emissions (AAFC, 2023a).

To design climate policy related to agriculture, it is important to know how different agricultural activities contribute to emissions, and how emissions might be reduced (although in some cases simply stopping or reducing the activity is required). Some notion in this regard is provided here.

- *Enteric fermentation*: Ruminant animals (such as cattle, sheep and goats) have complex digestive systems that produce methane during their digestion process. Although livestock related CH_4 emissions account for a substantial portion of the agricultural sector's greenhouse gases, there are several ways that these can be somewhat reduced. For example, feeding cattle more grains as opposed to forage changes the fermentation process resulting in reduced CH_4 emissions (Escobar-Bahamondes et al., 2017). Reducing livestock herds is considered by some to be a better approach, but a controversial one.
- *Manure management*: Manure from livestock contains organic matter that can decompose and emit CH_4 and N_2O when stored or managed improperly. Proper manure management practices can help minimize these emissions. Biodigesters can be used to create biogas from livestock manure and crop residues, with the methane used as a fuel.
- *Crop residue burning*: Burning of agricultural residues, such as crop stalks, can release CO_2 and other pollutants into the atmosphere, although the resulting ash could also lead to improved soil moisture retention.
- *Rice production*: In rice paddies, anaerobic conditions (lack of oxygen) during the flooded cultivation of rice leads to the production of methane. This is a significant source of methane emissions in certain regions, but not in Canada as there is no significant rice production.
- *Synthetic fertilizer use*: The application of synthetic fertilizers containing nitrogen can lead to the release of nitrous oxide.
- *Land use change*: Deforestation for agricultural expansion and changes in land use can release stored CO_2 into the atmosphere, while afforestation can account for large CO_2 removals from the atmosphere. Additionally, wetlands and native pasture or tame forage for livestock grazing represent important carbon sinks that can be threatened by conversion to annual cultivation.
- *Soil management*: Disturbances to soil, such as plowing, can release carbon stored in the soil into the atmosphere as CO_2, while reduced or no-till practices can perhaps mitigate this.
- *Energy use*: On-farm energy consumption, including the use of fossil fuels for machinery operations and transportation, contributes to emissions associated with agriculture.

Efforts are underway globally to address the agricultural sector's contributions to greenhouse gas emissions. These efforts include promoting climate-friendly farming practices, improving livestock management, reducing and/or increasing the efficacy of fertilizer use, enhancing carbon sequestration in soils, and exploring innovative technologies to reduce emissions. As awareness of climate change and its impacts continue to grow, many countries are working to strike a balance between food production and environmental sustainability.

4 | ADDRESSING NET ZERO WITH CARBON OFFSETS: CASE STUDIES

Despite commitments to attain Net Zero, policymakers have identified few means for offsetting any remaining emissions. Those that have been identified include:

1. *Carbon capture and storage (CCS)*: Several initiatives have been identified under this approach, including the capture of emissions from fossil fuel burning and direct air capture of CO_2. This usually involves geological (as opposed to biological) carbon storage where CO_2 is pressurized until it becomes a liquid, and then injected into porous rock formations (see Siqueira et al., 2017). Often downplayed is the significant energy—sometimes referred to as parasitic energy—required to implement CCS, increasing the fuel needs of a conventional power plant, for example, by 25–40 per cent (British Geological Survey, 2023).
2. *Bioenergy with CCS (BECCS)*: The idea is to use residual biomass from agriculture and forestry to produce energy, whether the biomass is burned to generate electricity or converted to liquid form. In addition to wood pellets and

heavy oil from wood via pyrolysis,[5] biodiesel and ethanol would fall into this category as would methane produced by a biodigester (IPCC, 2019). Without CCS, however, this option would add to CO_2 emissions.
3. *Carbon dioxide removals (CDRs)*: This method would entail the creation of carbon offsets, mainly by planting trees where none exist today. They can also be created by projects that store carbon in post-harvest product sinks and ones that convert cropland to permanent pasture to store carbon (IPCC, 2019).

Although prevention of deforestation was included in the Kyoto Protocol and subsequent Paris Agreement as means for countries to meet their targeted emissions reduction, this option does nothing to reduce atmospheric CO_2—carbon is simply left in situ in an ecosystem in perpetuity, neither emitting nor sequestering additional CO_2. The original intent was to address ongoing tropical deforestation, especially in the Amazon, and thereby bring together the United Nations' conventions on climate change and biodiversity (both signed in 1992 at Rio de Janeiro); it was not intended to apply to deforestation in developed countries. It appears strange to consider prevention of deforestation as an activity that creates carbon offsets when no CO_2 is removed from the atmosphere. Rather, emissions from deforestation should be treated like emissions from fossil fuel use—to be prevented but requiring any remaining emissions to be offset under Net Zero.

Not all approaches to create carbon offsets apply to agriculture. The main ones were briefly outlined in Section 3. Here we consider several cases in the light of the discussion in the preceding sections. We study the creation of carbon offsets from mandated reductions in fertilizer use, livestock management, soil management, and forestry. In each case, we identify one or more of the six problems identified in Section 2 as ones most likely to be encountered.

4.1 | Mandated reductions in fertilizer application: Transacting

Because fertilizer applications lead to an increase in emissions of nitrous oxide (N_2O), governments seek to reduce fertilizer use through regulation. A tax on fertilizer may be just as effective, but there is little political appetite to tax farm inputs.

Mandates requiring farmers to use less fertilizer have been proposed in Canada and the Netherlands, for example, but only implemented in Sri Lanka to disastrous effect. The government of Sri Lanka mandated farmers to go organic and forgo use of fertilizer, partly because they sought to reduce imports of fertilizer to reduce pressure on the rupee. The consequences of implementing a zero-fertilizer policy were a reduction in yields leading to inadequate food production; starvation due to high food prices and the need to import food; and social unrest resulting in the overthrow of the government with the President fleeing for his life on July 13, 2022 (Logan, 2022).

At one point (December 2020), the Canadian government intended to reduce nitrogen emissions from agriculture by 30% between 2020 and 2030 by mandating reductions in fertilizer use. After discussions with stakeholders, the government backed away from implementing a targeted limit on fertilizer use, proposing instead that farmers voluntarily reduce fertilizer use while maintaining crop yields (see AAFC, 2023b; Bexte, 2022). In any event, monitoring and enforcement of any restriction on input use would be expensive. More importantly, perhaps, provinces such as Alberta and Saskatchewan would challenge such mandates on constitutional grounds since agriculture, particularly when it comes to input use, is a provincial rather than a federal jurisdiction (van Kooten & Scott, 1995, p. 239). An alternative is to use economic incentives, such as subsidies or taxes, although measurement of changes in GHG emissions and monitoring would still be expensive. In addition to concerns about policing and jurisdictional powers, a restriction on fertilizer use leads to economic inefficiency.[6]

The identification and measurement of leakages associated with reduced fertilizer use would also be difficult to calculate (see next example), although Boyland (2006) argues that at least 25% of the carbon offsets that projects create are lost due to leakages. Given that Canadian crop production is highly efficient compared to many other regions, increases in fertilizer use elsewhere (either due to lower fertilizer prices or higher grain prices) would result in greater release of N_2O per unit of grain production. Further, as an example, evidence indicates that canola producers in Saskatchewan (and presumably in other provinces as well) are not over applying N fertilizer (Ross, 2023). The focus in Canada should be on the identification

[5] With pyrolysis, the heavy oil might be produced on site where harvest occurs, but it would then need to be shipped to a refinery before eventually being available as a fuel. This makes it a very costly option (see Stennes & McBeath, 2006).

[6] A fertilizer restriction prevents attainment of a first-best optimal in the sector as adjustments to the use of other inputs are required to remain on the expansion path. That is, $\frac{VMP_j}{r_j} = \frac{VMP_k}{r_k} \neq 1$, $\forall j, k\ j \neq k$, where VMP_i refers to the value of the marginal product ($P \times MP_i$) of input i in production of wheat, say, and k and j are inputs. A first-best solution requires that the inequality be an equality.

TABLE 3 Annual change in net farm returns from adopting best management practices.

Best Management Practice	Location[a]	Average Change in Net Revenue Mean (Low, High) ($/ha per year)[b]
4Rs		
Right Timing (Split N Application)	ROC	**−3.63** (−55.24, 49.25)
	Prairies	2.85 (−30.52, 39.78)
Right Source (Enhanced Fertilizer)	ROC	**−19.35** (−162.49, 139.31)
	Prairies	**−33.41** (−125.24, 80.30)
Right Rate (Recommended Rate)	ROC	7.01 (−10.39, 24.40)
	Prairies	13.48 (0.90, 22.18)
Right Place (Variable Rate Application)	ROC	27.11 (−45.29, 95.54)
	Prairies	17.51 (−45.29, 27.11)
Rotational Grazing	Canada	22.24 (3.54, 47.95)
Increased Legumes in Pasture	ROC	**−29.73** (−96.40, 21.89)
	Prairies	**−34.65** (−101.32, 16.97)
Maintain Pasture	ROC	113.97 (−90.82, 557.83)
	Prairies	257.64 (229.35, 331.90)
Maintain Wetlands	ROC	**−205.32** (−265.80, −114.84)
	Prairies	3.28 (−29.65, 36.20)
Maintain Shelterbelts	ROC	**−257.79** (−271.36, −244.22)
	Prairies	2.00 (−9.69, 3.06)

[a] ROC refers to rest of Canada.
[b] Negative changes in average net revenue are bolded. The high and low estimates of net returns are provided in parentheses.
Source: DeLaporte et al. (2021).

and adoption of beneficial management practices (BMPs), such as nutrient stewardship, the 4Rs (see Table 3), as means for reducing emissions from fertilizer (Ross, 2023). Extension effort and policy development are needed to identify BMPs and incentivize their adoption.

4.2 | Livestock management: Leakage

Although changing the diet of ruminant animals, such as cows, sheep, and goats, may help reduce methane emissions (Haque, 2018), more effective means are simply to shrink or even eliminate cow herds (less milk) and beef production, thereby reducing emissions of CH_4—a powerful GHG.

In the Netherlands, the government's climate policy aims to reduce the agricultural sector's GHG emissions by some 40%. Despite its small size, the Netherlands is the second largest exporter of food and agricultural commodities in the world, after the United States, so a reduction in output will impact global food markets. The unrest resulting from climate policies targeting the agricultural sector led to a new party, the Boer Burgerbeweging, or Farmer Citizen Movement, that quickly became a major player in Dutch politics. In Ireland, the government is seeking to cull 200,000 cows to reduce methane emissions, as some 40% of its entire GHG emissions come from agriculture; the plan would cost an estimated €600 million to be spent over a period of three years (O'Neill, 2023). Together the Netherlands and Ireland account for a significant proportion of dairy production and exports in the EU. In addition to the reductions in dairy herds, those employed in the dairy sector (roughly 54,000 in Ireland and 45,000 in the Netherlands) could face large scale layoffs. The impact of these actions will have a global impact on dairy markets—they will affect the prices of dairy products.

The economic impact of the combined withdrawal of dairy products by the Netherlands and Ireland can be determined with the aid of Figure 3. A significant reduction in the cow herds of the Netherlands and Ireland will shift the EU's dairy products supply function inwards, from S to S' (left panel). As a result, less dairy products from the EU are provided on the international market, as shown by the shift in the excess supply curve from ES to ES' in the middle panel. Assuming the demand for milk remains unchanged, the international dairy price increases from p_0 to p_1. This triggers an increase in supply by producers in the rest of world from q_0^R to q_1^R (right panel).

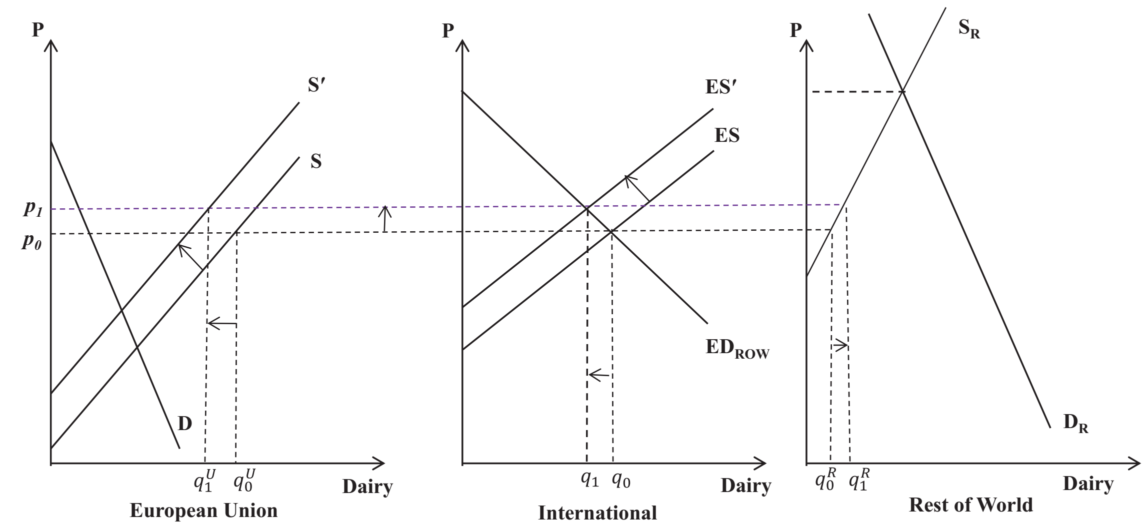

FIGURE 3 Impact of livestock policies to reduce methane emissions in the European Union.

Notice that global dairy prices have increased, but not by as much had there been no supply response by the rest of the world. Indeed, the leakage is measured by the methane emissions associated with the increased rest-of-world production response to the reduced output by the EU. It is given by $q_1^R - q_0^R$ in the right panel of Figure 3. Depending on where production is located and the nature of the cow herd and production technology, emissions of GHG may be lower or even higher than they might have been if the milk was produced in Ireland or the Netherlands.

There is also a leakage associated with potential reductions in beef herds. Since deer, bison, and elk are also ruminants, a reduction in grazing by cattle on marginal lands could lead to a growth in the populations of deer, bison, and elk that could compete with domestic livestock for range forage (van Kooten et al., 2001). Emissions from wildlife ruminants would offset emission reductions from reduced domestic ruminants.

4.3 | Soil management: Additionality and transacting

The potential for agricultural soils to remove CO_2 from the atmosphere and store it as soil organic carbon (SOC) could represent a significant opportunity for GHG mitigation and thereby create carbon offset credits (Page et al., 2020). Zero tillage agriculture has often been cited as a potential source of carbon sequestration (Smith et al., 2007) and has been widely encouraged (and adopted) throughout Canada. However, conservation tillage methods were originally implemented as a management tool to limit soil erosion and were incentivized by reduced costs of herbicides and the seeds of herbicide-resistant crops. Therefore, a producer who adopted zero tillage methods in the absence of a carbon market or subsidy did so because the costs of adopting zero tillage equaled or exceeded the associated benefits, not only the benefits of soil conservation but also the benefits of fewer machine operations and other cost savings. Because conservation tillage proved economically attractive prior to any carbon payments, the carbon sequestration benefits are additional to the other benefits captured by the producer. Carbon offsets cannot be credited as a result.

Despite the presumed carbon benefits from conservation tillage, there is no definitive answer as to how much more carbon is sequestered in soils under zero tillage compared to conventional tillage. A meta-regression analysis of 51 studies by Manley et al. (2005) found that zero tillage agriculture in the Prairies and other regions outside of the Southern U.S. was less effective at sequestering carbon in wheat fields than conventional tillage. In many studies, the carbon benefits of no-tillage decreased as measurement depths increased, as indicated in Figure 4.

In regions where many farmers find reduced or zero tillage practices to be profitable without carbon payments, the creation of carbon offsets would have only a small impact on further adoption of conservation tillage. In many areas (especially the Prairies), creating carbon offsets by changing tillage practices is inefficient due to the low mass of additional carbon stored by changing tillage practices—if farmers are paid for carbon sequestered, the payment would be small (Manley et al., 2005). Because of these barriers, creating offsets in these areas would be additional and expensive. In contrast, there are areas (like the Southern Corn Belt) where significant carbon credits can be created as zero tillage stores

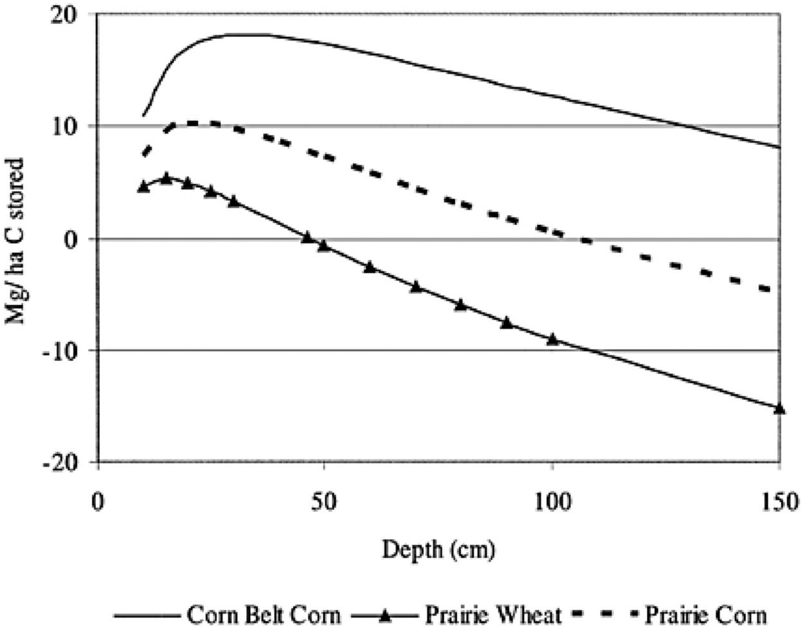

FIGURE 4 Carbon Stored by no tillage (Compared to Intensive Tillage) over a range of soil depths. Assuming 30 years of no tillage. *Source*: Manley et al. (2005).

large amounts of biomass in soil, but offsets can only be earned if carbon payments are required to make the switch to zero tillage cost effective. Although the Manley et al. (2005) study might not be considered definitive, it does point to the challenge of measuring the carbon credits, if any, that might accompany a switch from conventional to reduced or zero tillage.

Several other studies support the conclusion that it is not straightforward to determine the carbon benefits of conservation or zero tillage. For example, Deen and Kataki (2003) found no significant differences in carbon sequestration between various tillage treatments. Liang et al. (2020) found that carbon storage under zero tillage was highly dependent on climate and soil texture. In cool and humid areas of eastern Canada, zero tillage had lower soil organic carbon than conventional tillage, but the opposite was the case in areas with a semi-arid climate. Therefore, one must be vigilant when determining whether to incentivize conservation and zero tillage practices for their carbon sequestration benefits.

4.4 | Grassland conversion: Additionality and corruption

The retention of SOC in native prairies varies widely with the characteristics of grasslands—differing by soil textures, landscape features, or plant communities (Bork et al., 2019). Scientists agree that the tillage of native prairie or tame grasslands into cropland causes a reduction in SOC (Baker et al., 2020). Therefore, programs have been developed to promote the retention of grasslands, such as the Conservation Reserve Program (CRP) in the United States (Schmitz et al., 2022, pp. 151–152). The CRP allows producers to receive government payments for retaining grasslands or converting croplands to pasture grazing or haying, with over four million acres enrolled as of 2023.[7] Such programs are susceptible to "nonadditional market participation", which occurs when a producer enters a program and receives compensation for actions they would have undertaken anyway (Baker et al., 2020). That is, native grassland would not have been converted to cropland even in the absence of retention incentives. With regards to cropland enrollment the same "rules" apply—producers may not have chosen to plant on the marginal acres and would have converted them to grasslands in the absence of the conversion incentives. Program designs can combat additionality by identifying native grasslands (and thus program participants) most likely to be converted to cropland under baseline conditions. Researchers have found that limiting "nonadditional program participation" is key to the economic success and overall effectiveness of a conservation policy.[8]

[7] See https://www.fsa.usda.gov/news-room/news-releases/2023/grassland-crp-accepted-acres-in-2023-signup (accessed September 02, 2023).

[8] To exclude areas of low risk of conversion, Baker et al. (2020) limited eligible acres based on economic and environmental factors. Economic rent difference thresholds (RDT) were the deciding factor—the potential returns to cropping on eligible acres had to exceed the returns to pasture or grassland by *x*%, where *x* represented the chosen RDT. The authors then ran a series of simulations with varying prices of carbon ($/t$CO_2$) to demonstrate that additionality thresholds could be set optimally to minimize total abatement costs and maximize program size.

Cultivating native grassland or converting wetlands to produce crops are similar to the conversion of native forests to agriculture (deforestation)—carbon is primarily stored in grassland soils and in living wood biomass in forests.[9] As discussed above, in neither situation can one argue that carbon offset credits are created because emissions of CO_2 are not reduced, nor is CO_2 removed from the atmosphere. The additionality and leakage arguments basically rule out avoidance of deforestation or conversion of native grasslands to cropland for creation of carbon offset credits. Recognizing this, some environmentalists have made the case for including carbon credits regardless because their sale helps to protect wildlife habitat and other environmental amenities. While it may be important to protect grasslands and native forests, or wilderness areas, on those grounds, it is disingenuous to use payments for such a purpose to make people believe that the purchase of carbon credits makes their or the government's activities carbon neutral; it is also an inefficient way of protecting habitat. Contentiously, the GHG emissions from converting native grassland or forest to another use need to be offset through the purchase of carbon credits, not the other way around. As Baker et al. (2020) and others recognize, the creation of carbon credits in these cases would lead to corruption as landowners will threaten to convert their land and emit substantial CO_2 unless they receive carbon offset credits—payments for not changing land use. The appropriate policy is to require purchase of carbon offsets before land can be converted.

It is unlikely, however, that there exists the political will to require landowners to pay a penalty for converting their land. Currently, only two such programs have been implemented, with minor costs to producers for breaking native prairie or infilling wetlands. As a provision of the 2008 U.S. Farm Bill, "SodSaver" (formerly "SodBuster") in the United States is intended to reduce the conversion of native prairie to cropland.[10] This is done by restricting federally funded program payments to producers cropping on converted native prairie acres (Janssen & Hamda, 2009). Producers who choose to till native sod receive reduced crop insurance premium subsidies and have limits on the guaranteed insurance payout available during the first four years of crop production. The complementary program SwampBuster (a provision of the 1985 farm bill) states that producers who receive Farm Bill benefits (subsidized crop insurance, or commodity payments) must agree not to drain wetlands on their property (Hovorka, 2018). These reductions and limitations are by no means extreme but do serve as a deterrent to land-use change. Subsidies might also be appropriate to prevent land conversion, but the avoided emissions cannot properly be considered carbon offsets that can be set against actual emissions. Permitting this on a large scale would do nothing to achieve Net Zero.

4.5 | Forest carbon offsets: Duration, transacting and corruption

In 2013, British Columbia's Auditor General (AG) was looking into the operations of Pacific Carbon Trust (PCT), a provincial government agency that buys carbon offset credits and sells them to government departments, hospitals, schools, universities, and others, so that the entire operation of government can be declared "carbon neutral". The government mandates that government agencies are responsible for any emissions of carbon dioxide and must purchase carbon offsets from PCT at the going carbon tax rate.[11] Given critiques levelled at carbon offset trading (Helm, 2010, 2012; Woodward, 2011; van Kooten & de Vries, 2013), the AG wanted to know if the offset credits that PCT purchased and then sold to the various government agencies was indeed meeting the stated objective of reducing CO_2—that is, whether the scheme was truly making the government's operations carbon neutral.

The AG (2013) examined two projects that, in 2010, accounted for 70% of PCT's purchases of carbon offsets in 2010—the Darkwoods Forest Carbon Project (450,000 tCO_2 offsets) and Encana's Underbalanced Drilling Project (85,000 tCO_2). The Darkwoods Project was justified by comparing the carbon sequestered under conservation of the site versus the carbon that would be sequestered under a counterfactual management scenario (van Kooten et al., 2015). The difference between the two scenarios would constitute a measure of the carbon offsets. The counterfactual was an assumption that a private logging company would clear cut the site in a period of a few years. However, a private owner would surely not be able to do so because whoever purchased the site would need to certify their operations before they would be capable of selling timber. That is, they would not be able to market timber unless the site was managed in a sustainable fashion. Thus, the original premise of the counterfactual against which to compare the carbon fluxes (conservation vs private owner) was flawed.

[9] Because native grassland might store as much as 700 tCO_2/ha, programs designed to prevent conversion of grasslands are important. To avoid the problems identified below, programs should target conservation of grasslands specifically, without the need to measure carbon offsets and the problems associated with their creation.

[10] For information on U.S. legislation and various farm bills, see Schmitz et al. (2022, pp. 131–135).

[11] The current carbon tax rate in Canada (and BC) is \$50 per metric ton of carbon dioxide (\$50/tCO_2).

Van Kooten et al. (2015) developed a GIS model of the Darkwoods site that included the standing forest inventory (species and volume of timber), existing roads, elevations, slopes, et cetera, duplicating what existed on the stand. Then, using the Provincial Government's TIPSY model, it was possible to determine how much carbon was located on the site, and how the site would change over time under various management options. For each management option, the researchers tracked the commercial yields of timber, CO_2 released because of harvesting operations, and changes in forest biomass and carbon on the site over time. A forest management model was used to determine how a private company was most likely to manage the site in a way that would maximize its net returns subject to minimal sustainability constraints.

The authors found that the conservation management regime that was used to justify the carbon offset credits sold to PCT led to less carbon offsets than would be available by sustainably managing the site for its commercial timber benefits. Indeed, the carbon credits available under such a management regime could be significantly larger if the wood was used in construction, replacing concrete as construction material. By changing the counterfactual used to 'create' carbon offsets for sale, it was unlikely that the carbon offset credits claimed and sold to PCT would materialize. In essence, while government agencies spent taxpayer money to become carbon neutral, it was all for naught as there would not be any benefit for the climate.

5 | AGRICULTURAL CLIMATE POLICY IN CANADA

5.1 | Carbon policies

Canada has thus far avoided the assignment of carbon offset credits for actions taken by agricultural producers. Yet, governments have implemented various programs to address agricultural emissions and promote sustainable practices. These activities can include:

- *Renewable energy projects*: Adoption of renewable energy sources for on-farm energy needs has been supported in part by the Agriculture Clean Technology program, which cost shares up to 40%, to a limit of $2 million dollars, for the adoption of green energy (fuel switching, heat pumps, solar or geo-thermal systems panels), precision agriculture, or bioeconomy solutions that utilize agricultural wastes to generate energy or bio-products (AAFC, 2023c). At the same time, governments incentivize development of wind, solar, hydroelectric, or other renewable energy projects that generate clean energy and displace the need for fossil fuels.
- *Carbon cropping*: Programs encourage adoption of agricultural practices that enhance soil carbon storage, such as no-till farming, cover cropping, and conversion of marginal croplands to permanent pasture. Also included here are programs that encourage the planting of trees on less productive agricultural lands (afforestation), as trees absorb carbon dioxide during photosynthesis, acting as natural carbon sinks.
- *Nutrient management*: Improved nutrient management practices reduce fertilizer use and minimize N_2O emissions, including promotion of the '4Rs' (Table 3) and cover cropping.
- *Livestock management*: Strategies to reduce methane emissions from livestock, such as improved feed quality, digestive aids, proper manure management systems, and increased animal fertility. Additional efforts have been taken to promote strategies that increase the ability of pasture-based livestock to increase SOC storage. These include the promotion of rotational grazing, and the addition of legumes in pasture. This was supported by the On-Farm Climate Action fund that provided financial support to provincial agricultural organizations to adopt BMPs (AAFC, 2023d). Incentives to develop biodigesters for animal waste and crop residues are also ongoing.
- *Research and innovation*: Ongoing investments in research and technology help develop more efficient farming practices and reduce emissions. Currently, AAFC has committed funding to various research projects related to carbon and Net Zero in several areas including: individually targeted animal feeding on pasture to support Net Zero beef targets, grazing management on soil microbiomes and carbon sequestration, wetland carbon sequestration abilities from on farm management practices, and perennial grass productivity and carbon sequestration (AAFC, 2023e). In terms of direct funding for crop production studies, there is research that focuses on carbon inputs from high disturbance cropping systems, soil health and carbon management in wheat cropping, legume use in varying ecoregions, and cover cropping between soybeans and corn (AAFC, 2023e).

5.2 | Best management practices (BMPs)

The agricultural sector's contribution to greenhouse gas emissions is a complex issue, and ongoing efforts are needed to balance food production with environmental sustainability. Besides the strategies considered above, identifying best management practices and incentivizing farmers to adopt them are considered a desirable means of achieving climate targets while also benefiting the environment. BMPs related to cover cropping, zero tillage, regenerative agriculture, rotational grazing, wetland conservation, planting of shelter belts, and managing nitrogen are considered the gold standard of agricultural practice. They are not a one-size-fits-all solution, however; adoption of every possible BMP by every producer may not lead to an efficient outcome. If they are not doing so already, or if financial or production benefits from a practice are not immediately obvious, producers will need incentives to adopt BMPs.

Reiter et al. (2020) found that producers appreciated local program delivery (as opposed to programs delivered federally, or in another province). Producers also desired opportunities for further education and greater incentives to participate in a program if the plan includes regional level outcomes. The researchers also found that, when producers see larger-scale collective benefits, their willingness to adopt BMPs rose. Producers were also more willing to undertake new practices if these involved only subtle changes to their existing operations, while participation was less likely if the required changes were significant. Again, the financial compensation needed to be large enough to invoke participation in BMP programs (Reiter et al., 2020).

A study by De Laporte et al. (2021) noted that not all BMPs improved farm income.

This is shown in Table 3, which provides a summary (and range) of estimated net returns to farmers of adopting various BMPs in different parts of Canada. Many management practices—the 4Rs, increasing pasture legumes, maintain wetlands, and shelterbelts—resulted in negative average returns implying a need for subsidies to incentivize their adoption. Of course, this is not true for all producers who adopt a particular BMP as indicated by the high range of the change in net revenue from adoption; results varied between farmers depending on soil zone, operation size, and local weather patterns. Nonetheless, if the environmental benefits (not only those limited to reducing atmospheric CO_2) exceeded the loss to an individual farmer, it would still be worthwhile to provide a subsidy for adopting the BMP.

It is not clear whether the climate benefit is the largest component of the environmental benefit to be gained in these cases. For example, cover-cropping reduces wind and water erosion of soil and nitrate leaching and can rapidly build soil organic matter (Snapp et al., 2005). However, there are potentially negative environmental consequences if cover crops are mismanaged—the presence of a cash crop or alternate cover crop is important to establishing a N sink; that is, if adequate plant populations are not grown following a cover crop, there can be high levels of nitrate leaching. Further, choosing a deep-rooted cover crop like alfalfa can enhance macropores in soil, leading to increased water filtration and higher leaching in some areas. Additionally, the cost of implementing cover crops can be very high with little returns, and N levels in the soil before and after cover cropping can be difficult to estimate without proper measurement (Snapp et al., 2005).

Rotational grazing is also considered to be a best practice for pasture-based livestock production. Rotational grazing is often paired with other grazing management practices (moderate stocking rates, or seasonal grazing) and has been shown to increase carbon sequestration in soils, enhance vegetation, and boost nutrient cycling (Alemu et al., 2016). Rotational grazing systems with heavy stocking rates have been shown to reduce individual animal efficiency as measured by average daily gains (kg/head/day) but increase overall system efficiency (higher kg beef/ha) (Derner et al., 2008). Higher stocking rates decrease plant biomass in a pasture but increases the nutritive value of the forages as they remain in a vegetative state due to defoliation (Vargas et al., 2022). Cattle grazing on forages in a vegetative state lowers CH_4 emissions (g CH_4 per unit dry matter) but could increase total CH_4 production (g CH_4/animal/day) (Vargas et al., 2022). Further, both CH_4 intensity and yield of enteric methane could increase with higher stocking rates if forage availability is low and is not of high enough quality to meet the nutritional needs. Overall, Vargas et al. (2022) found no consistent difference between rotational and continuous stocking of pastures, indicating that there are no clear methane-reducing benefits from adopting rotational grazing.

From a CO_2 emissions standpoint, adaptive multi-paddock (AMP) grazing (a subset of rotational grazing) also had mixed results. AMP grazing occurs when livestock are on pasture for a short duration at high intensities in many paddocks followed by long rest periods to promote regrowth (Shrestha et al., 2020). At 5°C AMP grazing emitted 17% more CO_2 than continuous grazing, but at 25°C AMP grazing emitted 18% less. Under warm and moist soil conditions, AMP grazing had lower emissions of CO_2 and a better uptake of CH_4 in soils than was the true of conventional grazing, although this was not true for cool dry soils. Despite increased uptake of CH_4, the change was not enough to offset CO_2 emissions in any soil type (Shrestha et al., 2020). Furthermore, compared to soil moisture and microclimate conditions, grazing patterns had little effect on total GHG emissions. Overall, if done properly rotational grazing has the potential to provide environmental benefits in some scenarios, but benefits were sometimes marginal at best, and detrimental at worst.

Recent behavioral economics research has focused on the use of 'nudges' to facilitate efforts by agricultural producers to reduce GHG emissions or remove CO_2 from the atmosphere. A nudge works only if the targeted behavior results in a very small loss to the farmer (Carlsson et al., 2021). In a relevant application that investigated ways to encourage farmers to reduce fertilizer use, Chai et al. (2023) employed nudges that included strategies for correcting biases in perceptions about the relationship between N fertilizer applications and yield/profit increases or risk reductions. Perhaps nudges can be employed to facilitate adoption of BMPs, although by their nature their effect in reducing CO_{2e} emissions or removing CO_2 from the atmosphere is likely small.

Adoption of best management practices is not without its challenges, but we suggest that they are a preferred alternative to climate policies that rely on the creation of offset credits to be sold in carbon markets.

6 DISCUSSION AND CONCLUSIONS

When an entity offsets its greenhouse gas emissions, it must invest in projects or activities that lead to equivalent CO_2 removals from the atmosphere. The idea is to balance emissions reduction and removals of CO_2 from the atmosphere to achieve Net Zero; this distinction is important in combatting global climate change because the latter are packaged differently than the former. This is evident if one looks to the agricultural sector for potential carbon offsets. Clearly, there remain climate change mitigation strategies in the agricultural sector that need to be exploited, but these strategies may not necessarily lead to the creation of offsets that farmers can sell in carbon markets. As indicated in this paper, there are critical pitfalls associated with the creation of carbon offsets in the agricultural sector.

Let's be clear: while carbon offsets in agriculture can play a role in addressing climate change, they are not perfect substitutes for direct emissions reductions. The primary strategy is to reduce emissions at the source, with offsets used as a complement to address emissions that are challenging to eliminate. The effectiveness of carbon offset programs can vary based on the quality of projects, monitoring, and verification mechanisms in place. In this regard, grassland and forest preservation projects constitute a stumbling block. Indeed, many activities that are considered eligible for carbon offsets, such as conserving shelterbelts, refraining from land use conversion, reduced tillage and maintaining wetlands, are associated with non-action—they provide producers with carbon credits for not undertaking anything. It is strange to grant carbon credits that offset emissions when absolutely nothing occurs. Indeed, by awarding offset credits, one opens an avenue to corruption. A landowner could simply say that they intended to cultivate grasslands or harvest a forest and, to prevent this, require carbon offset credits.

The same problem arises when the focus is on fossil fuel substitution. Suppose a biofuel replaces gasoline in the transport sector. Can one really attribute the emissions reduced in the transport sector to agriculture? Certainly, the transport sector will claim emissions reductions—that emissions have gone down. Can the agricultural sector still claim the same as a carbon offset?

Other actions such as planting shelterbelts, implementing conservation tillage, providing climate-friendly feed to livestock, and so on are considered legitimate means for creating carbon offsets. However, without perfect information, there is no way to tell if a landowner is acting honestly, or if they are taking advantage of the ability to sell credits—a classical principal-agent problem fraught with moral hazard (van Kooten, 2017). The costs of contracting, measuring, and monitoring the creation of offsets is prohibitive in many of these cases.

To mitigate such problems, it may be better to identify best management practices for the various activities that agricultural producers undertake. BMPs would be based on their overall environmental benefits and not simply because of their GHG-emissions reduction or ability to remove CO_2 from the atmosphere. Producers would be incentivized to adopt the BMP most appropriate for their activity and location. The authority would then need only ensure that the producer implemented the practice. But even in these cases, there is no way to tell if a farmer is acting honestly in the adoption of the BMPs as the authority cannot possibly know what the producer knows—it is impossible to avoid moral hazard. Yet, moral hazard is likely less of a problem when BMPs are subsidized or nudged than when a variety of different activities are permitted to create carbon offsets; further, many problems related to the creation of carbon offsets are avoided by focusing on BMPs. Overall, we suspect that transaction costs would be lower.

Climate policies in Canada have thus far avoided implementation of a carbon credit market in agriculture, and this should continue for reasons indicated in this paper. On the other hand, penalizing Canadian farmers for emissions or requiring direct reductions in any agricultural practise often does more harm than good (e.g., efficiency declines as on-farm costs rise and farmers' risks potentially increase). Canadian agricultural production is highly efficient and technologically advanced. Implementation of harsh regulations may do little more than virtue signal; agricultural production will simply occur elsewhere (likely in a less efficient fashion) and/or harm the poorest in global society (depending on the extent of leakage).

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