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CARBON-CREDIT SYSTEMS IN AGRICULTURE: A REVIEW OF LITERATURE

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SUMMARY

As the province with the most beef cattle, the second-largest number of farms and farmed area in the country, and as one of Canada's biggest producers of crops, Alberta is a huge part of the national agriculture sector. It has also been responsible for the highest level of agricultural greenhouse-gas emissions in the country. However, there has been little exploration to date of the effectiveness of using carbon credits to encourage Alberta farmers to practise farming techniques that lower emissions, while earning extra revenue without jeopardizing their agricultural output.

In trying to achieve their carbon-reduction targets under the Paris agreement, governments should be considering their agricultural sectors. Participating in a carbon-credit system allows farmers to generate credits for reducing emissions; they can then sell those credits for cash on a credit market to emitters who need to purchase carbon-offset allowances for exceeding their mandated emission limits. Despite there being an active carbon-offset market in Alberta, however, farmers in the province hardly participate. This appears partly due to a history of regulatory risk: the agriculture sector has seen the revocation of carbon-credit eligibility for certain practices, and invalidated credits can lead to significant financial losses for farmers. Farmers are also reluctant to participate due to the inadequacy of offset-credit revenues in covering the foregone costs of implementing emission-reduction practices given current carbon-offset prices and the emissions level per farm.

Some lower-emission farming protocols have proved profitable for farmers by improving efficiency, even without carbon-offset incentives. While farmers may adopt these practices for their own reasons, they are reluctant to participate in Alberta's carbon-offset market unless they are sufficiently rewarded. Market conditions thus far have not encouraged them to do so. Alberta farmers may continue to largely sit out the carbon-credit market until returns for earning credits become more stable and more rewarding. Alberta policy-makers should emphasize the intrinsic efficiency benefits to farmers of implementing these protocols for their own sake. Convincing farmers in the province to invest in emission-reducing technologies for the purpose of making money in the current Alberta carbon market will, for the time being, remain a difficult sell.

ABSTRACT

Carbon-credit systems allow agricultural producers to earn an extra revenue through selling their surplus of carbon credits to producers who emit higher amounts of greenhouse gases (GHGs). However, agricultural carbon-credit systems are still at early stage; hence, these benefits cannot be guaranteed due to their uncertain nature and the paucity of scientific evidence about agricultural carbon credits. The objective of this study is to provide a comprehensive literature review to highlight the gaps in existing knowledge related to agricultural carbon credits/ offsets. Our particular interest is on Alberta because the province indicates the highest agricultural GHG emissions from 1990 to 2019 and, therefore, developing strategies to reduce the sector's carbon intensity without compromising its economic contribution to the provincial economy poses a challenge.

Literature is evident for promising GHG-mitigation strategies such as adoption of 4R practices (the right source at the right rate, right time and right place) as a package and improved efficiency in cattle farm management. Reduced tillage has been found to be less efficient. Researchers favour the concept of regenerative agriculture, which is more likely to return better outcomes compared to tillage practices. Moreover, ranchers are willing to upgrade their farms with efficient cattle breeds to take advantage of decreased feed costs. Conversely, farmers are reluctant to participate in the Alberta Emission Offset System unless rewarded with incentives.

However, carbon-credit markets are still growing; consequently, farmers may have more opportunities in the future. If the Alberta credit price continues to grow with no expected increase in transaction costs, agricultural producers would be more attracted to participate in the Alberta Emission Offset System. Moreover, endorsing farmers for carbon-crediting mechanisms by emphasizing the co-benefits and associated economic incentives is recommended, instead of prioritizing its potential financial gains.

Nevertheless, due to the scarcity of published studies, it is too early to project the economic and climate-mitigative potential of carbon-offset–credit markets for Canadian farmers. Literature suggests farmers wait until the carbon market becomes more stable before making a decision. Future research and scientific evidence will be crucial to filling these gaps and to guaranteeing future protocols.

POLICY RECOMMENDATONS

- Design projects at farm level, ensuring GHG-emissions reductions follow a suitable offset standard
- Incentivize farmers via cost-share programs for expert agronomic services
- Endorse farmers for carbon offsetting by emphasizing co-benefits and associated economic incentives, instead of prioritizing potential financial gains
- Future research should consider farmers' benefit-risk evaluation of participation in the carbon-offset market

INTRODUCTION

Increasing awareness of climate change and global warming identifies the emissions of CO_2 and other greenhouse gases (GHGs) as possible causes of climate change, causing perilous impacts on humans, economies and livelihoods (Poolen and Ryszka 2021). Given that, the Paris agreement, which entered into force in 2016, aims to limit global warming to 1.5 degrees Celsius to achieve a climate-neutral world by mid-century. To accomplish the long-term goals of the Paris agreement, participating countries have pledged to come up with strategies to reduce GHG emissions (United Nations Climate Change n.d.).

However, emissions from some activities, such as agriculture, are unavoidable. The Intergovernmental Panel on Climate Change (IPCC) (2019) reports that agriculture and other land-use changes are responsible for about 23 per cent[1] of net anthropogenic global GHG emissions that comprise 13 per cent of CO_2 (carbon dioxide), 44 per cent of CH_4 (methane), and 81 per cent of N_2O (nitrous oxide) during the period of 2007–2016 (Sharma et al. 2021). CO_2, CH_4 and N_2O emissions stem from wide array of sources that differ from each other. CO_2 emitted from fertilizer manufacturing, use of machinery for farm work and feed imports are the prominent sources that are accountable for agricultural CO_2 emissions, while net soil CO_2 emissions relate to the balance between humified organic matter input and mineralization or leaching (Gingrich et al. 2007; Dyer et al. 2010; Aguilera et al. 2015). CH_4 emissions come mainly from livestock (Moss, Jouany and Newbold 2000; Vermorel et al. 2008; Springmann et al. 2018), manure management and enteric fermentation (particularly in ruminants) (Balafoutis et al. 2017). N_2O emits from the microbial transformation of nitrogen in soils and manure during inorganic

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1 This 23 per cent includes the net anthropogenic emissions due to agriculture activities within the farm gate and associated land-use dynamics, such as deforestation and peatland degradation. Emissions coming from these activities are well quantified and evidenced by an extensive body of literature. GHG emissions coming from the activities beyond the farm gate, such as manufacturing of fertilizers, food processing, transport and retail, and food consumption, contribute to five to 10 per cent of total anthropogenic emissions, however, this estimation is very uncertain due to lack of sufficient studies. When this estimate is added to the emissions coming from agriculture and other land-use changes, total emissions from food systems (i.e., within the farm gate, other land use and beyond the farm gate) may contribute to 21–37 per cent of total GHG emissions (IPCC 2019).

fertilizer and manure applications and via other organic substances (Aguilera et al. 2013; Balafoutis et al. 2017), such as urine and dung deposited by grazing animals (Balafoutis et al. 2017).

Moreover, the agricultural sector faces three challenges that are interrelated with each other: reducing GHG emissions, adapting production practices to changing climate conditions and meeting an increasing global demand for food by a growing population. Producing more food to meet rising food demand will emit more GHGs, which will exacerbate the impact of climate changes. This highlights the importance of adapting climate-smart agricultural strategies, which lead to sustainable agricultural practices, to yield food security under climate changes while mitigating or eliminating GHG emissions (Verschuuren 2018).

According to Shockley and Snell (2021), GHG emissions (especially CO_2) coming from agricultural operations are relatively low compared to industrial emissions. As a result, carbon-credit systems in the agricultural sector have gained wide attention globally (Shockley and Snell 2021) in achieving climate neutrality, where agricultural producers can earn extra revenue through selling their surplus of carbon credits to producers who emit higher amounts of GHGs.

However, despite the growing popularity of carbon-credit systems in agriculture, there is a paucity of research on GHG-emission reduction linked to agricultural carbon credits. Instead, a large body of literature has explored GHG-mitigation practices that basically fall into three broad categories: reducing emissions, enhancing removals, and avoiding (or displacing) emissions (Smith et al. 2008). Emission-reduction strategies emphasize improved efficiencies and best farming practices (Richards, Wollenberg and van Vuuren 2018). These include: efficient use of nitrogen fertilizers (Bouwman, Boumans and Batjes 2002; Gerber et al. 2016), improved nutrition and health management of ruminant livestock (Gerber et al. 2013), and adoption of new technologies to breed ruminants for lower emissions (Pickering et al. 2015). Carbon sequestration methods (Lal 2004) and conversion of agricultural biomass into biofuel (Cannell 2003; Schneider and McCarl 2003) fall under enhancing removals and avoiding emissions, respectively. Some studies go beyond the production side and examine possible GHG-mitigation strategies across the entire food system. Yue et al. (2017), with respect to China, suggest that not only improved farm-management practices, but also sustainable consumption habits and balanced diets have the potential to contribute to GHG mitigations. Niles et al. (2018) examine the topic via a food-systems approach that includes pre-production, production, processing, transport, consumption, and loss and waste, and suggest that GHG-mitigation strategies should follow a food-systems research approach and be dependent on country-specific economic and food systems.

In spite of the international attention that the agricultural sector has received lately, concrete policy-driven mechanisms that are capable of reducing GHG emissions, such as carbon pricing, have received uneven attention to date. The World Bank

(2021c) identifies different types of carbon pricing, such as carbon taxes,[2] cap-and-trade systems,[3] baseline-and-credit systems,[4] offset mechanisms,[5] etc., as cost-effective policy tools for governments and companies to follow in mitigating GHG emissions; however, carbon-credit systems linked to the agricultural sector have received very little attention to date. Most studies found in the literature on carbon-pricing policies have exclusively focused on carbon taxes. Goulder and Schein (2013) state that decision-makers favour carbon taxes as part of broader tax reform or as a source of new revenue to reduce budget deficits, while Richards et al. (2018) proclaim that, compared to other sectors, agriculture and land-use sectors lack finance for GHG mitigation. GHG-mitigation policies should go beyond carbon taxes to carbon-credit and carbon-offset systems that may prove of particular use to the agriculture sector, but have yet to receive much attention and analysis.

Therefore, the objective of this study is to provide a comprehensive literature review to highlight the gaps in existing knowledge related to agricultural carbon credits/offsets. We specifically focus on understanding the carbon-credit policies in/on Canadian agriculture, providing a state of knowledge and making recommendations, with particular interest in agriculture systems in Alberta. The study is organized as follows: The following section (1) provides background regarding the current state of carbon-credit systems in the agricultural sector of selected regions (the U.S., EU and Australia) followed by (2) a review of carbon-credit systems in Canadian agriculture, with specific focus on the Alberta Emission Offset System. Section (3) will summarize the results of a comprehensive review of both academic and non-academic (e.g., NGO, policy) literatures on carbon-credit systems that are relevant to the development of carbon-credit systems that fulfill the needs of agricultural-sector stakeholders in Alberta. Section (4) concludes with a discussion of policy implications and recommendations.

BACKGROUND

Global crediting demonstrates two distinct phases in its activity levels: until 2012 and post 2012 (Figure 1). Until 2012, Kyoto crediting mechanisms dominated the market and there was a rapid growth in crediting activities. Then, in 2013, the credit market crashed as a result of the lack of demand by the EU emissions-trading system, the biggest buyer of Kyoto credits at the time, due to the financial

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2 Carbon tax: Directly sets a price on carbon by defining an explicit tax rate on GHG emissions, i.e., a price expressed as a value per tonne of carbon dioxide equivalent (tCO_2e).

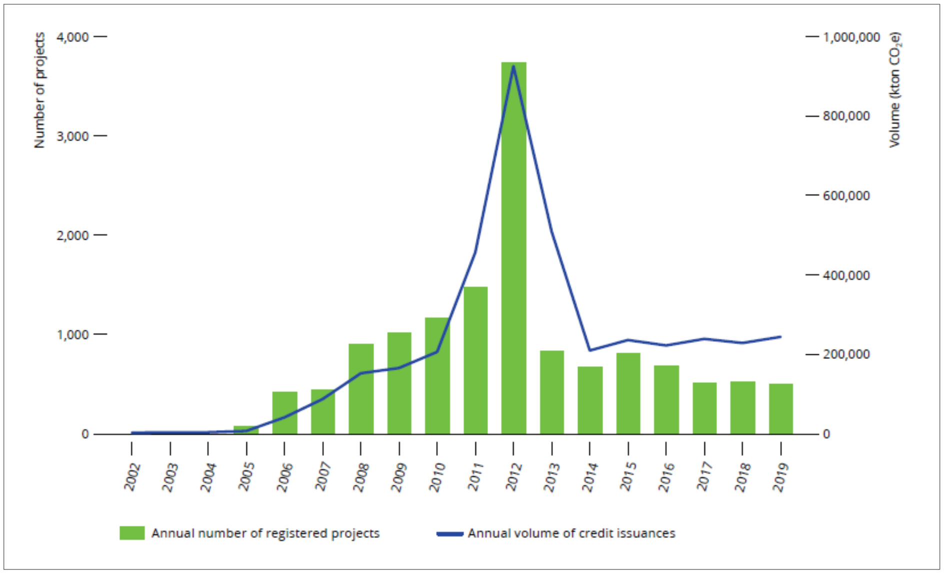
3 Cap and trade systems: Apply a cap or absolute limit on the emissions within the emission-trading system and emissions allowances are distributed, usually for free or through auctions, for the amount of emissions equivalent to the cap.

4 Baseline-and-credit: systems: Baseline emissions levels are defined for individual regulated entities and credits are issued to entities that have reduced their emissions below this level. These credits can be sold to other entities exceeding their baseline emission levels.

5 Offset mechanisms: Designates the GHG-emission reductions from project- or program-based activities, which can be sold either domestically or in other countries (World Bank 2021a).

crisis and oversupply of EU allowances. However, with the adoption of the Paris agreement, crediting activities have stabilized since 2015 and the voluntary carbon-credit market has grown significantly in recent years (World Bank 2020). The World Bank (2021c) mentions that carbon-credit markets show remarkable growth in the past year, despite the COVID-19 pandemic and the related economic downturn. Both the number of registered projects and the number of credits issued have increased by 11 per cent and 10 per cent, respectively. This growth brings the total number of credits issued since 2002 to around 4.3 billion tonnes of carbon-dioxide equivalent (tCO_2e) (World Bank 2021c).

Figure 1. Annual number of projects and issuances of covered crediting mechanisms for 2002–2019

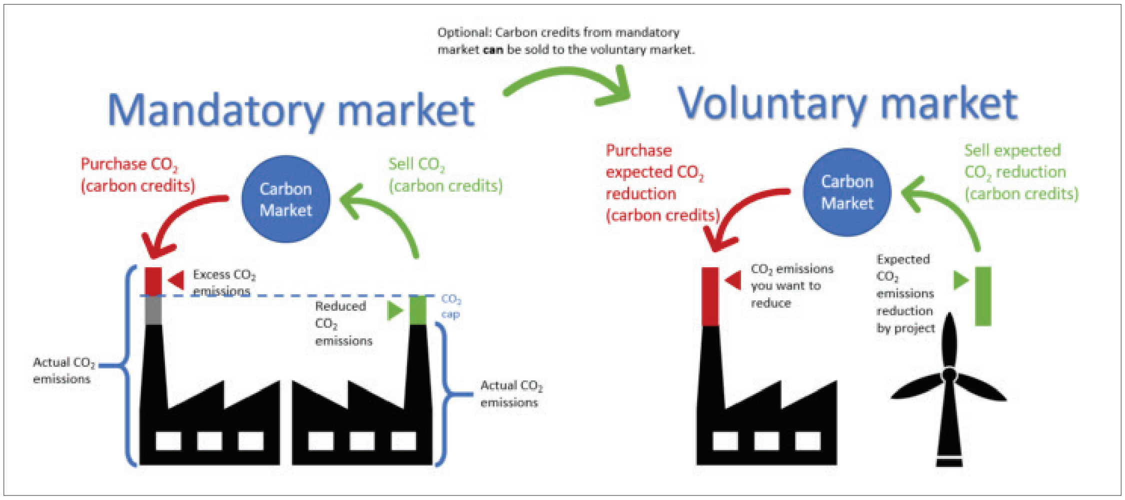


Source: World Bank (2020).

A carbon-credit market functions the same way as other markets, where carbon-credit transactions involve a buyer who purchases emission rights from a seller who has the technical ability and economic feasibility to reduce GHG emissions or sequester additional carbon. Those who can reduce GHG emissions below current levels or sequester additional carbon are eligible to receive a carbon credit for each tonne of carbon reduced or sequestered. Based on the global-warming potential of different GHGs, such as methane and nitrous oxide, emission reductions of each GHG can be converted to a common carbon-equivalent reduction for trading. The market price per carbon credit is determined when carbon credits are traded between buyers and sellers. If buying a carbon credit is cheaper than controlling additional emissions, a GHG emitter would buy credits, while a seller would sell credits if the cost of reducing GHG emissions or sequestering additional carbon is less than the price of the carbon credit (Williams, Peterson and Mooney 2005).

Carbon-crediting mechanisms can be either international,[6] independent[7] or domestic[8] (World Bank 2020, 2021c), while crediting can take place in two types of carbon markets: either compliance (mandatory) or voluntary carbon markets (Figure 2). A compliance market serves regulated entities (e.g., firms) who are legally required to reduce their GHG emissions (e.g., California's Cap-and-Trade Program) while voluntary carbon markets serve businesses and individuals who intend to offset some or all of their GHG emissions but are not legally required to do so (e.g., corporate sustainability reporting) (Aiken 2021).

Figure 2. Types of carbon markets



Source: De Jong, Elkerbout and Geleijnse (2020).

Most of the present carbon markets are voluntary incentive-based markets where countries and companies have lately been showing greater interest in using voluntary agricultural carbon markets to offset their emissions (Castagné et al. 2020). According to Shockley and Snell (2021), when agricultural carbon credits are considered, farmers often contribute to the supply of carbon credits. Farmers can earn revenue by selling carbon credits, which can be generated through best-management practices, such as no-till/reduced-till, cover crops, crop rotation and buffer strips that sequester carbon, and other changes in operating practices. Farmers are typically paid for the carbon credits they generate based on the amount of carbon sequestered, either on a per-acre basis or per tonne of carbon sequestered. Once the carbon credit is generated, it enters a market that facilitates the transaction of carbon credits. Today, these transactions are mostly facilitated by a third-party entity (aggregator) that links sellers (farmers) to buyers (corporations)

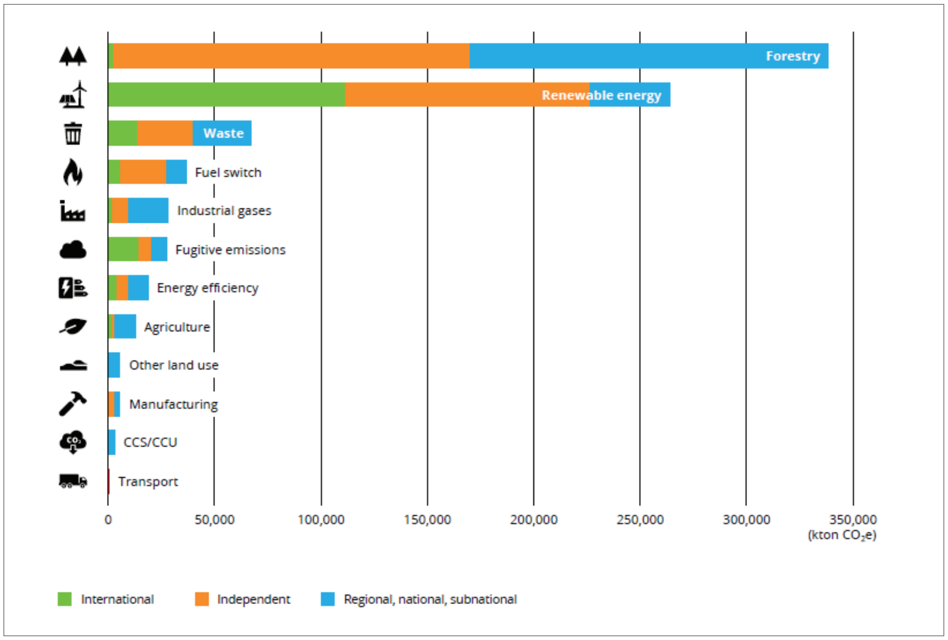
6 International credit mechanisms are governed by international climate treaties and are usually administered by international institutions.

7 Independent credit mechanisms are administered by private and independent third-party organizations, which are often nongovernmental organizations.

8 Domestic crediting mechanisms (regional, national and subnational) are governed by their respective jurisdictional legislature and are usually administered by regional, national or subnational governments (World Bank 2020; World Bank 2021c).

(Shockley and Snell 2021). However, the volume of credits issued in the agriculture sector is remarkably low compared to other sectors, such as forestry and renewable energy (Figure 3) (World Bank 2020). Manure-methane-digester projects, which are accountable for 0.94 per cent of agricultural carbon credits, signify the highest contribution to agricultural carbon credits (Appendix Table A1) (Ellis 2021).

Figure 3. Issuance volumes in kiloton of carbon-dioxide equivalent (ktonCO$_2$e) by sector and type of mechanism for 2015–2019



Source: World Bank (2020).

Nevertheless, many developed countries, such as the U.S., Australia and EU countries, have recently been paying more attention to agricultural carbon markets as ways to mitigate GHG emissions to achieve the long-term goals of the Paris agreement. Aiken (2021) and Shockley and Snell (2021) emphasize the prioritization of carbon markets in the Biden administration's U.S. agricultural policy agenda as a way to help achieve net carbon neutrality by 2050. Through improved agricultural land-management practices, foresters, ranchers and farmers can increase carbon transfer from the air into the soil; hence, agricultural carbon credits from additional carbon sequestration are expected to serve as a significant component in achieving carbon-neutrality goals (Aiken 2021; Shockley and Snell 2021).

Australia is also prioritizing its agriculture and forestry sectors in its emission-reduction policy. Australia's Emission Reduction Fund (ERF), formerly the Carbon Farming Initiative (CFI), permits farmers and land managers to earn carbon credits by storing carbon or reducing GHG emissions on the land (Murray n.d.).

International consulting group COWI, the Ecologic Institute and the Institute for European Environmental Policy (2021) have all indicated that achieving climate neutrality by 2050 will be impossible for the EU if policies do not focus on land management, including agriculture and forestry. Therefore, the EU planned to launch a carbon–farming framework, which will require action-based[9] or results-based farming practices,[10] or a hybrid of both, as required, by the end of 2021 (COWI et al. 2021).

In Canada, the new Federal GHG Offset System is intended to create new economic opportunities in the forestry, agriculture and waste sectors by supporting the domestic carbon-trading market, which facilitates projects that reduce or eliminate GHG emissions to generate credits and sell them to industries that exceed emissions limits imposed by Canada's carbon tax (Williams 2021).

Despite the increased attention of developed countries on agricultural carbon credits, the agriculture sector is still covered by only a few crediting mechanisms that are currently active. Out of the 28 crediting mechanisms that are already implemented, the agriculture sector is covered by only eight:11 The Alberta Emission Offset System (29 per cent), the California Compliance Offset Program (four per cent), the Joint Implementation Mechanism (three per cent), the Climate Action Reserve (two per cent), Australia's ERF (1.1 per cent), the American Carbon Registry (0.2 per cent), the Gold Standard program (0.2 per cent) and the Verified Carbon Standard program (0.2 per cent) (World Bank 2020). It is interesting to note that the highest agriculture sectoral coverage (29 per cent) is represented by the Alberta Emission Offset System and it is the only agricultural carbon-credit market that currently functions in Canada.

CARBON-CREDIT SYSTEMS IN CANADIAN AGRICULTURE

Carbon credits are defined as tradable certificates that allow the holder to emit, over a certain period, carbon dioxide or another GHG. One carbon credit is equivalent to one tonne of carbon dioxide or the mass of other GHG with a carbon-dioxide equivalent (tCO_2e) corresponding to one tonne of carbon dioxide (Mezzanotte 2019; Sellars et al. 2021). Consequently, one carbon credit helps to prevent the emission of one metric ton of carbon dioxide into the atmosphere (Mezzanotte 2019). A carbon tax, on the other hand, directly sets a price on carbon through an explicit tax rate on GHG emissions (i.e., a price per tCO_2e); unlike with carbon credits, the carbon price is predefined in a carbon tax (World Bank 2021a).

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9 Action-based carbon farming: Farmers comply with specific farming practices or technologies introduced by the managing authority for the assumed environmental benefits and are incentivized to improve their farming practices and protect the environment (COWI et al. 2021).

10 Results-based carbon farming: Farmers are paid with incentives based on the measured outcome of the farm in reducing emissions, regardless of the specific farming practices used (COWI et al. 2021).

11 Agricultural sector coverage is presented as percentage in parentheses. Crediting mechanisms are listed according to the descending order of sectoral coverage.

In Canada, the Ministry of Environment and Climate Change is developing the Federal Greenhouse Gas (GHG) Offset Credit System with the objective of supporting Canada's actions on reducing GHG emissions. The already-implemented carbon-pricing systems, such as the federal carbon-pricing-backstop system and Pan-Canadian Greenhouse Gas Offsets Framework, do not cover all sources of GHG emissions in Canada. By implementing a federal GHG-offset credit system, the government expects to incentivize activities that result in GHG-emission reductions that are not required under existing regulations or covered by other measures related to carbon pricing. Consequently, the federal GHG-offset credit system initially prioritizes four project types (Table 1) that would allow participants attached to refrigeration systems, landfill sites, forestry and agricultural lands to earn credits (Government of Canada 2021b).

Because some of these provisions target agricultural activities, some agricultural organizations (e.g., the Ontario Federation of Agriculture) believe that the agriculture sector will finally be rewarded for the best practices it has been adopting over decades, and farmers will have the potential to generate large amount of credits upon the proper setup of the federal program, for which final regulations were to be established by fall 2021 (Healing 2021).

Table 1. Projects prioritized by the federal GHG-offset credit system[12]

Project type	Objective
Advanced refrigeration systems	Reduce or avoid the use of fluorinated refrigerants
Landfill methane management	Reduce methane emissions from open or closed landfill sites
Improved forest management	Maintain or enhance carbon storage by increasing rotation ages, thinning diseased trees, managing competing brush and stocking trees
Enhanced soil organic carbon (SOC)	Practise sustainable agricultural land-management activities that reduce GHG emissions and enhance soil carbon sequestration on agricultural lands

Source: Government of Canada (2021b).

The federal program would follow similar systems around the country, including those in Alberta and British Columbia. Thus, the federal GHG-offset credit system will continue to complement these provincial credit systems (Clean Energy Canada 2021). However, only the Alberta Emission Offset System covers the agriculture sector, while British Columbia's offset program covers only waste, energy efficiency, forestry and fuel switch. The Quebec government expects to expand its project types to include the agriculture sector by assessing new protocols that ensure enhanced fertilizer-application practices, even though its current coverage targets only waste (World Bank 2021c).

12 The proposed regulations for the federal GHG offset credit system were published in the Canada Gazette, Part I on March 6, 2021, and were open for comment until May 5, 2021. The draft of the proposed regulations is available on https://canadagazette.gc.ca/rp-pr/p1/2021/2021-03-06/html/reg1-eng.html and no final version of the regulations is available to date.

THE ALBERTA EMISSION OFFSET SYSTEM

Alberta's Climate Change Emissions Management Amendment Act of 2007 introduced an emission-offset system to supply the credits for use by entities with obligations under the province's Specified Gas Emitters Regulation (e.g., gas plants, power plants and chemical facilities), which was replaced by the Carbon Competitiveness Incentive Regulation in 2017 and subsequently by the Technology Innovation and Emissions Reduction System (TIER), along with the Standard for GHG Emission Offset Project Developers in January 2020 (World Bank 2020).

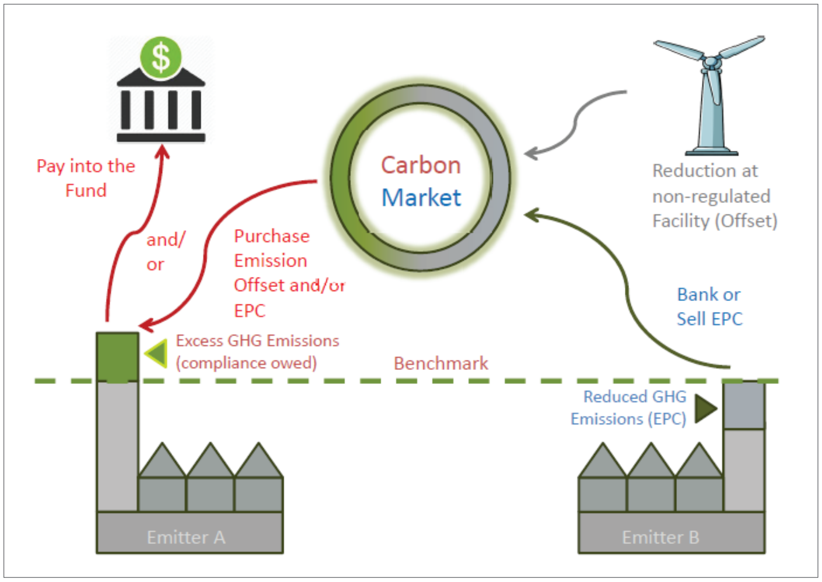
The Alberta Emission Offset System covers agriculture, carbon capture and storage/carbon capture and utilization, energy efficiency, forestry, fugitive emissions, industrial gases, manufacturing, renewable energy and waste (World Bank 2021c). All activities must take place in Alberta to be eligible for crediting. Even though Alberta's crediting system covers multiple sectors, most credits have come from projects in the renewable energy and agriculture sectors (World Bank 2020).

Projects that have voluntarily reduced their GHG emissions earn emission offsets, which are quantified using provincially approved methodologies (quantification protocols)[13] and are verified by a third party according to the Standard for Validation, Verification and Audit. Emission-offset projects must satisfy the requirements in the TIER regulation and a relevant provincially approved quantification protocol. Once verified, emission offsets are publicly listed on the Alberta Emission Offset Registry, which is currently operated by CSA Group, to facilitate purchases for Alberta's large final emitters (Government of Alberta 2021c). The TIER system sets an emissions benchmark that determines a facility's allowable emissions for the year. If a facility is unable to remain within its allowable emission limits, it can either:

1. purchase emission performance credits (EPC);
2. purchase emissions offsets from smaller entities (not covered by the regulation) who then undertake voluntary emission reductions; or
3. pay into the TIER Fund (Kennedy and Brinker 2021), as illustrated in Figure 4.

[13] See "Quantification protocols," https://www.alberta.ca/alberta-emission-offset-system.aspx#jumplinks-2.

Figure 4. Alberta's carbon-pricing system



Source: Climate Implementation and Compliance Branch (2019).

Like any other market, the carbon market in Alberta determines the price of credits[14] based on supply and demand. However, according to Sullivan, Lourie and Bryant (2021), the transparency issues caused by market conditions,[15] policy risk[16] and commercial positioning[17] make Alberta credit prices volatile, with the most significant impact on market price being policy risk (Table 2).

Table 2. Alberta carbon-pricing impacts

Factor	Carbon-price impact
Market conditions	\$2-\$5/tCO_2e
Policy risk	\$5-\$10/tCO_2e
Commercial positioning	\$2-\$5/tCO_2e

Source: Sullivan et al. (2021).

14 The Alberta carbon market works with both emissions offsets and EPCs, which are collectively called "Alberta Credits" (Sullivan et al. 2021).

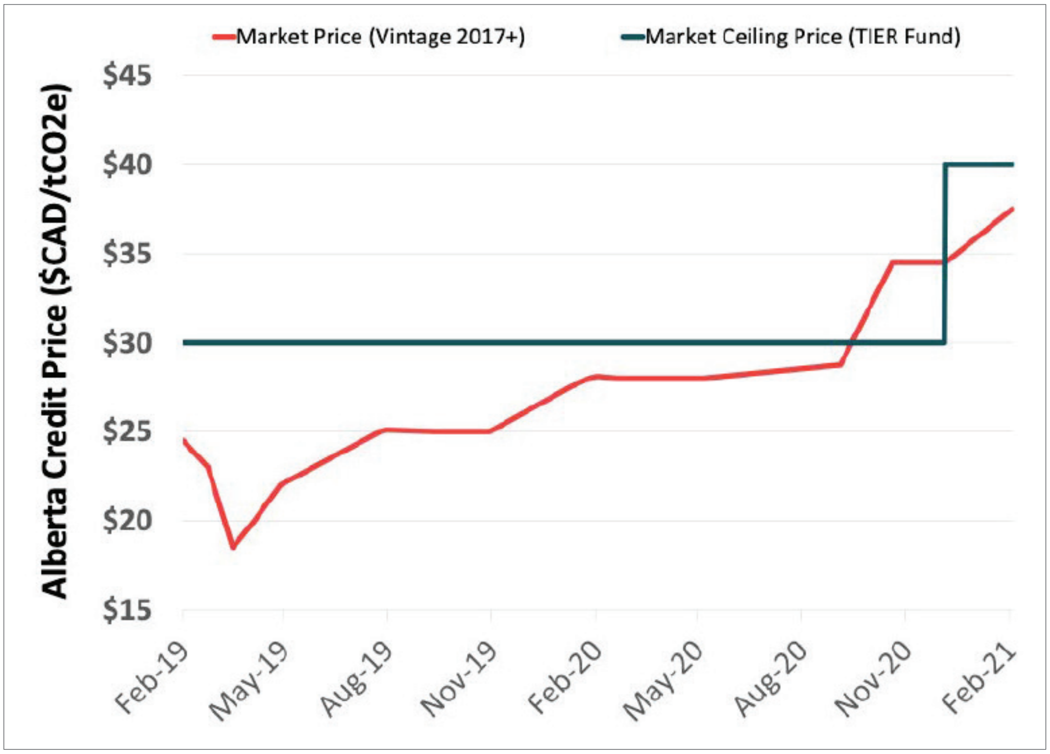
15 Market conditions: The cyclicality of demand and supply and perceived market fundamentals, such as the impact of market participants' banking behaviour.

16 Policy risk: The anticipated, speculated or actual changes to provincial and federal carbon-pricing programs and structures.

17 Commercial positioning: A market participant's percentage of total market supply or demand and the execution or influence of their trading strategy (Sullivan et al. 2021).

Month-to-month data reflecting the Alberta credit price demonstrate a significant rise from 2019 to 2021, exceeding the 2020 TIER fund price, which is $30 per tCO_2e (Figure 5). The 2021 TIER fund price is $40/$tCO_2e$. Sullivan et al. (2021) highlight the tendency of credit suppliers in Alberta to hold their credits for future higher-priced compliance years as a result of the growth in credit price.

Figure 5. Volatility of Alberta credit prices



Source: Sullivan et al. (2021).

The government of Alberta specifies 19 offset protocols that would have the potential to generate offset credits (Government of Alberta 2021a). Three protocols that cover the agriculture sector in Alberta focus on cropping systems, livestock and nitrous-oxide–emissions reduction (Appendix Table A2). Conservation cropping, the updated version of the expired Tillage System Management Protocol, is the most widely used protocol in Alberta and makes up 24 per cent[18] of the total offset credits generated by the system to date. Conservation cropping encourages direct seeding that increases the stored carbon in the soil to increase soil organic matter, so farmers can earn carbon offsets by increasing soil carbon levels and reducing GHG emissions. Nitrous-oxide–emissions reduction encourages farmers to employ the 4R Nutrient Stewardship principles (the right source at the right rate, right time and right place) to improve the efficiency of nitrogen fertilizer. Improved efficiency of nitrogen fertilizer would enable application of more

18 Source: Author's own calculations based on data from the "Alberta Emissions Offset Registry Listing," available at https://alberta.csaregistries.ca/GHGR_Listing/AEOR_Listing.aspx.

fertilizer to the crop and less in the air as nitrous oxide. Direct seeding is not a requirement to implement this protocol, yet if farmers choose to do so, they may also be simultaneously eligible to participate in the conservation-cropping protocol (Appendix Table A2) (Government of Alberta 2021a).

Alberta's livestock sector is examined in two ways: through feedlot and genetics protocols. Feedlot protocols focus on beef cattle located in confined feeding operations, with reductions in GHG emissions achieved by improving efficiencies to decrease the time cattle spend in the feedlot. Genetic protocols aim to breed cattle for more efficient feed use, to reduce methane and nitrous oxide. Both strategies help farmers to reduce GHG emissions with feed savings (Appendix Table A2) (Government of Alberta 2021a) and are also recognized by the federal Output-Based Pricing System (OBPS) (Government of Canada 2021a).

Alberta is one of the three Prairie provinces in which most of Canada's crop farming takes place. With respect to the number of farms,19 Alberta Agriculture and Forestry (2018) reported an increase of six per cent in oilseed and grain farms (i.e., soybean, oilseed (except soybean), dry pea and bean, wheat, corn, other grain farming) in 2016. From 2011 to 2016, Alberta saw a 4.5-per-cent increase in farm acreage planted in wheat, but the number of farms where the biggest cash crop was wheat increased by 39 per cent (Alberta Agriculture and Forestry 2018). Despite the six-per-cent decrease in census farms in Alberta (Alberta Agriculture and Forestry 2018), Alberta continued to have the second-largest number of farms in Canada following Ontario (Government of Alberta 2018). Further, Alberta reported the second-largest total farm area over which farmers had stewardship in 2016, following Saskatchewan. Canola dominated Alberta's field-crop area in 2016, followed by spring wheat and barley (Statistics Canada 2017).

With respect to livestock farming, Alberta dominated the provincial distribution of cattle and calves in 2016, accounting for 41.6 per cent of the national herd and 59.6 per cent of total feeder cattle[20] (Statistics Canada 2017). Moreover, Alberta ranks first in Canada's beef-cattle–ranching farms, accounting for 34.1 per cent of the national total (Government of Alberta 2018). Alberta's beef breeding stock[21] represents 42.3 per cent of the national total. Compared to other provinces, Alberta has a comparative advantage for its beef sector because of the close proximity to processing capacity and its availability of feed and pasture land (Statistics Canada 2017).

Further, the agriculture sector is an important part of the Alberta economy, accounting for approximately 2.2 per cent of Alberta's GDP (Government of Alberta 2021b). Alberta is also the largest emitter of GHG in Canada, accounting for 38 per

19 The "number of farms" is defined by the major cash crop in the respective year.

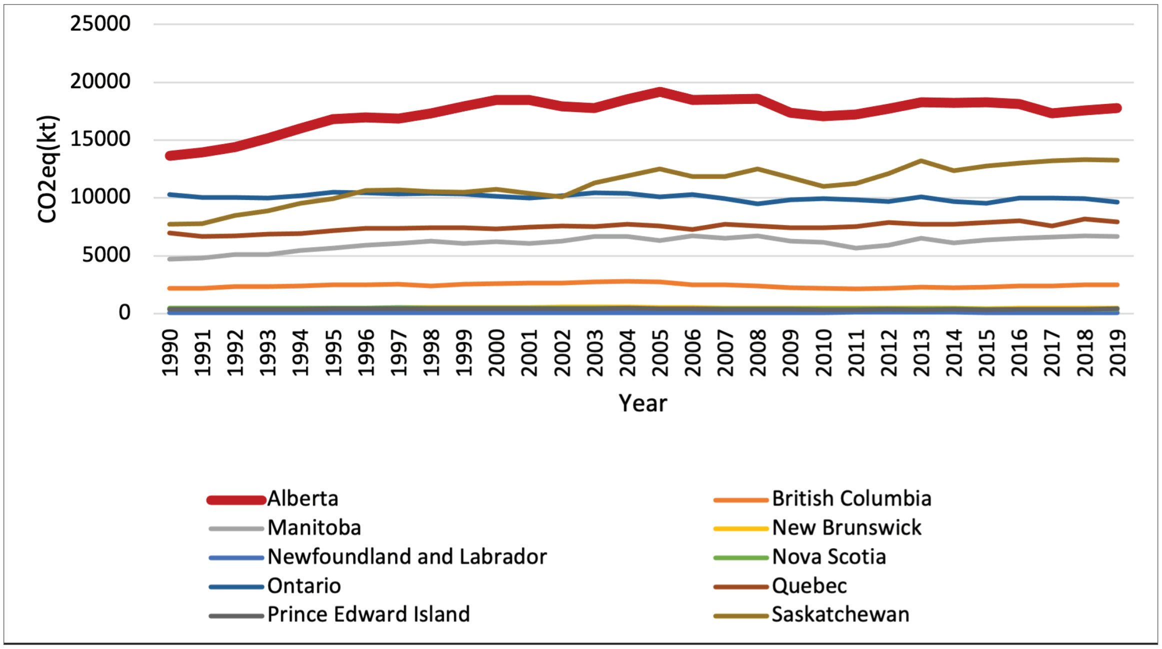
20 Steers and heifers for feeding or slaughter.

21 Beef cows and heifers for beef herd replacement.

cent of the national total (Environment and Climate Change Canada 2020) and Alberta was responsible for the highest agricultural GHG emissions from 1990 to 2019 (Figure 6).

Given the significant role agriculture and especially livestock farming plays in Alberta, developing strategies to reduce the sector's carbon intensity without compromising its contribution to the provincial economy poses a challenge. The next section reviews existing research on the implementation and use and of carbon-offset (or carbon-credit) systems in agriculture to date.

Figure 6. Total agricultural emissions by province



Source: Environment and Climate Change Canada (2020).

LITERATURE REVIEW ON CARBON-CREDIT/ CARBON-OFFSET SYSTEMS

Carbon pricing, whether in the form of carbon tax, cap-and-trade systems, baseline-and-credit systems, or offset mechanisms, will have differential impacts among various sectors. However, considerable research has been undertaken to examine carbon taxes and their impact on different sectors. Hence we begin with a brief review of such studies, focusing on those that study carbon-credit systems, to be consistent with the objective of this study. We provide a global focus on carbon-credit markets, however our goal is to understand the suitable carbon-offset policies for Canadian agriculture. Since the recommendations given by those studies that focus on developed countries will be useful in making recommendations for the Alberta agriculture sector, the next section reviews the global credit market with respect to the agriculture sector in developed countries (the U.S., Australia and EU countries) and then narrows down to Canada, with specific focus on Alberta. Therefore, the literature review is organized as follows: (1) Carbon tax and its impact on different sectors, (2) global focus on carbon-credit systems, (3) carbon-credit systems in agriculture: perspectives of developed countries (the U.S., Australia and Canada) and (4) carbon-credit systems in agriculture: focus on Alberta (and Western Canada).

CARBON TAX AND ITS IMPACT ON DIFFERENT SECTORS

Extant literature is evident for both positive and negative impacts of carbon tax. According to Zhou et al. (2018), the carbon taxes implemented in Sweden, Norway, the United Kingdom, Denmark, Finland, Japan, France, Germany and others provide examples of practical and efficient measures to reduce carbon emissions. Rausch and Reilly (2012) consider a carbon tax as a "Win–Win–Win" solution for the United States. Nakata and Lamont (2001) find a decrease in CO_2 emissions after examining the impact of carbon tax on energy systems in Japan. Bureau (2011) highlights the potential of a carbon tax to reduce carbon emissions through minimizing traffic pressure. Rivers and Schaufele (2015) study the impact of exemptions granted to the agricultural sector in British Columbia's carbon tax and suggest that these exemptions might be induced by public pressure, thus governments may tend to introduce inefficient and unnecessary provisions that are not advocated by empirical evidence.

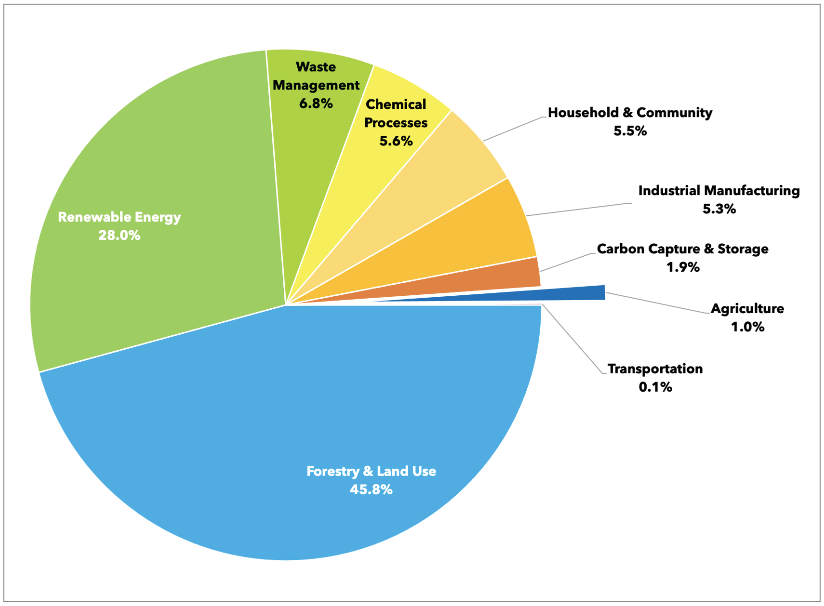
Despite these positive reviews, negative impacts of carbon tax are observed by several studies. Wissema and Dellink (2007) find welfare reduction in Ireland, while Parry and Mylonas (2017) emphasize an increase in total welfare costs in Canada. Meng, Siriwardana and McNeill (2013) and Zhang et al. (2016) provide evidence for the adverse impacts caused by carbon taxes on GDP in Australia and China, respectively. According to Timilsinas (2018), a carbon tax causes a loss of competitiveness of domestic industries, especially emission-intensive, trade-exposed industries. Losing competitiveness encourages industries to move to locations where a carbon tax does not exist or the rate is low if it does exist (Jaffe et al. 1995). Therefore, Timilsinas (2018) questions the efficacy of a carbon tax because, due to emission leakage, it is not as effective as it should be in reducing global GHG emissions.

Carbon crediting is another carbon-pricing method that has received an equal amount of attention as carbon taxes, but has been subject to less scholarly research to date, especially with respect to the agricultural sector. The rest of the literature review is devoted to highlighting the global focus on carbon-credit systems, which is followed by a review of studies related to the agriculture sectors of developed countries and Alberta.

GLOBAL FOCUS ON CARBON-CREDIT SYSTEMS

According to the World Bank (2021b), among domestic crediting systems, 25 mechanisms issue credits while six more carbon-credit mechanisms are currently under development (Appendix Table A3). Domestic crediting mechanisms report a 25-per-cent rise from 2019 to 2020 in credits issued, led by the California Compliance Offset Program and the Australia ERF (World Bank 2021c). Nevertheless, half of the credits issued in 2020 came from independent standard-setting organizations, such as Verra and the Gold Standard, that manage best-practice standards for climate and sustainable-development interventions. Ninety-six per cent of the growth in voluntary-market transactions are represented by corporations, led by consumer goods companies, financial institutions and energy industries. However, the agriculture sector's contribution to carbon credits is significantly low. To date, the agriculture sector has generated only one per cent of carbon credits (Figure 7) (Ellis 2021). Past studies have attempted to identify the causes for the disinclination shown by farmers to participate in the carbon-credit market. The next section presents the perspectives of developed countries on agricultural carbon credits.

Figure 7. Percentage share of carbon credits issued by area of scope of projects



Source: Ellis (2021).

CARBON-CREDIT SYSTEMS IN AGRICULTURE: PERSPECTIVES OF DEVELOPED COUNTRIES (THE U.S., AUSTRALIA AND CANADA)

In the opinion of Aiken (2021), the agricultural carbon-credit market essentially consists of the two largest players: speculators and pilot-project developers. The speculators foresee a remarkable growth in carbon markets in the next few years and are attempting to contract as many acres as they can so they can sell their carbon credits at a large profit. The pilot-project developers are often connected with agribusiness partners or connections, and some of the acres they develop will be used to verify the eligibility of improved management practices to sequester more carbon in farm or ranch lands. These project developers act as intermediaries between agricultural producers and carbon markets or carbon-credit buyers (Aiken 2021).

Studies focusing on U.S. farmers reveal the financial barriers that farmers face to participate in the credit market. Sellars et al. (2021) mention that sale of carbon credits is an opportunity for farmers to gain financial benefits, however carbon prices may not be able to cover the costs of switching to environmentally beneficial agricultural practices. Plume (2021) also highlights U.S. farmers' struggles to break into thriving carbon-credit market. Farmers claim that costs of cover-crop seed and hiring specialized labour are not covered by the returns they gain by selling carbon credits. Carbon prices will need to be at least US$50 to US$100 per metric ton of CO_2 by 2030 to reduce emissions in a cost-effective way, according to the Paris agreement (World Bank 2020; Sellars et al. 2021). However, because their efforts result in improved soil fertility and reduced fertilizer costs, some farmers expect to continue in the offset market while expanding their crop selections (Plume 2021).

The Growing Climate Solutions Act of 2021 was passed by the U.S. Senate to give authority to the U.S. Department of Agriculture to help farmers, ranchers and private forest landowners participate in carbon markets. But big U.S. farming operations that have more potential to sequester carbon on their vast acreages receive the most funding from federal incentives, where 10 per cent of the largest farms have received 78 per cent of subsidies over the past 25 years (van der Pol et al. 2021). Thus, the opinion of van der Pol et al. (2021) is to refrain from crediting farms for adapting practices that are considered as profitable in their regions, because soil carbon increases as farmers tend to continue regenerative agricultural practices even without policy incentives. Nevertheless, Plume (2021) recognizes that some farmers are not willing to recoup the costs of creating credits without any subsidy.

However, Wozniacka (2020) mentions that regenerative agriculture has so far remained a niche practice due to the limitations of upfront investments, although it has gained popularity outside farming circles. Companies such as General Mills, Danone, Cargill, McDonalds, Target and Land O'Lakes have already planned to advance regenerative agriculture on millions of acres of North American farmland.

European countries also encourage farmers to switch to regenerative farming to reduce GHG emissions coming from the agriculture sector. Agreena is a Dutch start-up that mints, verifies and sells carbon credits generated by farmers who actively engage in regenerative farming. It economically incentivizes farmers to switch from traditional arable farming to regenerative farming by issuing them a "CO_2e-certificate" which can be sold between farmers and potential buyers. This approach is different from other companies, such as Nori and Indigo (both U.S. based) and Soil Capital (U.K./France-based), that are in the voluntary carbon market because it offers a vertically integrated approach towards agricultural carbon offsets (Butcher 2021).

However, the agriculture sector has not been considered under the EU emission-trading system and, therefore, the EU's climate policy's focus on incentivizing farmers to reduce GHG emissions has been minimal (Verschuuren 2018). The EU Carbon Farming Initiative was to be launched by the end of 2021 and would target agriculture and forestry sectors. Farmers are to be incentivized to use results-based "carbon farming" activities (COWI et al. 2021). Following a two-year study, COWI et al. (2021) suggest that results-based carbon farming is a feasible and effective way to mitigate GHG emissions in peatland restoration and rewetting. But with respect to agroforestry, soil organic compound (SOC) maintenance and sequestration, and livestock farming in the EU, results-based farming would face difficulties. COWI et al. (2021) highlight the importance of advisory, technical and upfront investment support that is needed to encourage farmers for results-based farming. Authors also emphasize how high costs of monitoring, reporting and verifying (MRV), and uncertainty associated with sequestration, constrain results-based activities in SOC maintenance and sequestration. With respect to the EU livestock sector, the knowledge, experience and technical capacity, which are required to initiate results-based carbon-farming mechanisms, are adequate to incentivize emission reductions using whole-farm carbon-audit tools. However, COWI et al. (2021) do not guarantee a one-size-fits-all approach for the EU livestock sector because of the differences in the local context (i.e., objectives, farmer/consultant knowledge and interest, and geography). Since carbon-crediting mechanisms that cover the EU agricultural sector are still in their infancy stage, no published studies exist with respect to the EU agricultural carbon credits, to the best of our knowledge.

In contrast, Australia has been active in the carbon-credit market since 2011,[22] allowing farmers and landowners to earn carbon credits by storing carbon or reducing GHG emissions on the land. Verschuuren (2017) states that Australia is the only country that has a comprehensive set of methodologies in place that cover all kinds of carbon-farming projects to award credits to farmers. Although zero or reduced tillage are widely recognized as among the best management practices that help reduce agricultural GHG emissions, Maraseni and Cockfield's (2011) study on selected grain crop rotations in the Darling Downs region of Queensland,

22 The Australian Carbon Farming Initiative (2011–2015) became the Emissions Reduction Fund (Fleming et al. 2019).

Australia finds that switching to zero tillage results in a relatively small (yet positive) net effect on GHG emissions. Moreover, Maraseni and Cockfield (2011) and Maraseni and Reardon-Smith (2019) emphasize the ability of sequestered carbon to release back into the atmosphere at any time. Hence, emission reductions from the land and agriculture sectors, especially through carbon sequestration, might create vulnerability to climate change, even though it can be a cost-effective way to achieve Kyoto Protocol targets (Maraseni and Reardon-Smith 2019). Maraseni and Cockfield (2011) suggest that the consequences arising from these circumstances could have a huge impact on carbon credits offered from volunteer carbon markets for converting conventional tillage to reduced-tillage systems.

Another Australian study by Fleming (2019) states that farmers are less willing to enter the carbon market when they are encouraged to see carbon farming as a financial opportunity. According to Kragt et al. (2018), farmers who do not believe that climate change is happening are less willing to pay for reducing Australia's GHG emissions than the farmers who believe that their actions are responsible for climate change. Kragt et al. (2018) find that, on average, farmers' willingness to pay for one megatonne of CO_2-equivalent reduction is $1.13. Therefore, Fleming (2019) recommends that when carbon farming is framed with co-benefits and economic incentives in addition to potential financial opportunities, farmers would be more willing to perceive and adopt carbon farming.

Overall, the studies conducted by Kragt et al. (2018), Fleming (2019), COWI et al. (2021), Plume (2021) and Sellars et al. (2021) reveal the impact of higher transaction costs on farmers' contribution to generate carbon credits; hence, the review above is evidence for the need to incentivize farmers in order to encourage them to participate in the carbon-credit market. Further, reduced-tillage practices are not recommended by Maraseni and Cockfield (2011) and Maraseni and Reardon-Smith (2019), while the adoption of regenerative agricultural practices is favoured by many researchers (van der Pol et al. 2021; Wozniacka 2020; Butcher 2021) for reducing GHG emissions.

While these recommendations can be useful in implementing policies pertaining to Canadian agriculture, it is of pivotal importance to review the studies that directly focus on the agricultural carbon-credit systems in Canada. As mentioned in the background section, the Alberta Emission Offset System is the only crediting mechanism that is currently active in Canada to allow the agricultural sector to contribute to reduce GHG emissions; but, unfortunately, its feasibility and economic impacts have been hardly assessed by researchers. Instead, wide attention has been given to British Columbia's offset system and forest carbon offsetting. Anderson, Long and Luckert (2015) and St-Laurent, Hagerman and Hoberg (2017) identify the main barriers for developing forest carbon offsets in B.C. Both studies find financial limitations to be a significant barrier, while St-Laurent et al. (2017) point out further obstacles, such as deficiencies of carbon markets, climate uncertainty, negative public opinion, limited and uncertain property rights and governance issues. Further, Man et al. (2016) highlight the sensitivity of forest carbon credits to the initial age-class structure of the forest estate, the harvest-priority algorithm, the starting target harvest level, and the timing of harvest adjustment from the starting level to the baseline level.

However, there are studies, such as Ghafoori, Flynn and Checkel (2007) and Campbell, Herremans and Kleffner (2017), that have specifically focused on carbon credits/offsets with non-agricultural aspects, such as anaerobic digestion and biogas plants, yet their findings could influence the agricultural sector in Alberta. Based on a study in Red Deer County, Alta., Ghafoori et al. (2007) find that the anaerobic digestion treatment of manure from mixed farming areas requires a cost that is higher than the estimated carbon-credit value (i.e., $125 per tonne of CO_2), so it is not economical. Campbell et al. (2017) highlight how participation is affected by the uncertainty in the Alberta carbon-offset development process, using the ECB Lethbridge Biogas facility[23] as the focal study area, and emphasize the potential for uncertainty to negatively impact the reputation of the province in terms of achieving its emission-reduction targets.

The barriers recognized from these studies, such as financial limitations, climate uncertainty, and issues in the development process of Alberta carbon offsets, are useful in identifying the potential constraints that Alberta farmers will face in generating carbon credits from their farming activities. However, to substantiate these possibilities, the next section is devoted to reviewing the handful of studies aimed at farmers' participation in the Alberta Emission Offset System.

CARBON-CREDIT SYSTEMS IN AGRICULTURE: FOCUS ON ALBERTA (AND WESTERN CANADA)

Scholarly work on Alberta agricultural carbon credits reveal consistency with the findings of studies from other developed countries, as explained above. Studies focused on the livestock sector have paid more attention to understanding the willingness of Alberta cattle producers to participate in the carbon market, while crop-farming studies have examined the efficiency of zero- and reduced-tillage practices.

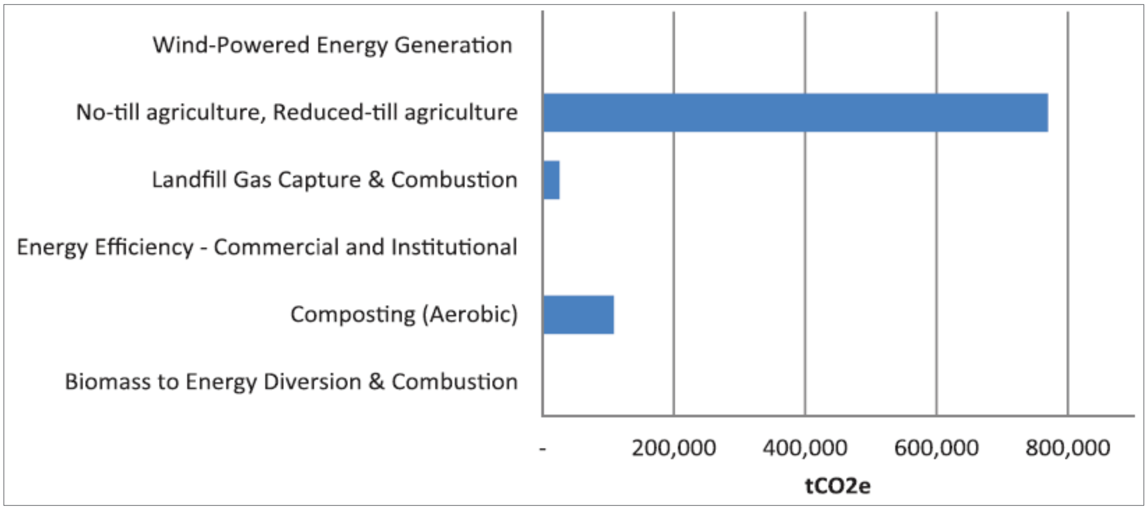
Studies conducted by Boaitey and Goddard (2016), Boaitey (2017) and Boaitey, Goddard and Mohapatra (2019) highlight the lack of willingness of Alberta cattle producers to participate in the carbon market, even though producers can earn additional revenue by participating in a carbon-offset system. According to the findings of these studies, the cause for the producers' reluctance is the inadequacy of the revenue coming from the offset scheme to cover the forgone costs, given carbon prices and the emissions levels per farm. Instead, producers tend to adjust their stocking rate with more feed-efficient cattle breeds to take advantage of decreased feed costs; hence the aversion to participating in the carbon-credit

23 The ECB Lethbridge Biogas facility is a biogas cogeneration plant that processes agricultural, food, and food-processing waste to make biogas (essentially methane), which is then combusted in two combined heat and power units to generate electricity (Campbell et al. 2017).

market is extreme in regions or periods that produce higher pasture yields (Boaitey and Goddard 2016; Boaitey 2017; Boaitey et al. 2019).

With respect to crop farming, Tarnoczi (2017) mentions that the uncertainty around the record-keeping for larger aggregation projects creates a risk for zero- and reduced-till agriculture projects. Tarnoczi (2017) illustrates that zero- and reduced-till agriculture projects have had the greatest risk of being revoked or removed from the Alberta offset credit system (Figure 8) and states that these invalidated offset credits lead to significant financial costs. Paustian (2019) also examines the carbon offsets generated through soil carbon sequestration from zero- or reduced-till practices on agricultural lands (cropland and grazing land) in Alberta and highlights the importance of maintaining a proper system to evaluate transaction and verification costs irrespective of the scientific robustness of specified protocols.

Figure 8. Volume of offset credits (tCO_2e) revoked or removed in the Alberta Emission Offset Credit System by project type



Source: Tarnoczi (2017).

Even though researchers' attempts to assess the feasibility of crediting mechanisms pertaining to Alberta's agricultural sector have been restricted, published literature is evident for the efforts put into identifying farmers' willingness to adopt several GHG-mitigation strategies, and the associated changes in net revenue and GHG emissions. These feasibility assessments will implicitly impact farmers' participation in carbon-credit markets as well. As mentioned in Appendix Table A2, the government of Alberta recognizes breeding cattle for more efficient feed use as an effective strategy to reduce methane and nitrous oxide from Alberta's livestock farming (Government of Alberta 2021a). From a nationwide survey of cow-calf producers, with 34 per cent located in Alberta, Boaitey (2017) finds that cow-calf producers' willingness to pay for genomic information on feed efficiency and birthweight is relatively higher.24 Conversely, Boaitey (2017) also finds that cow-calf producers are not willing to realize the benefits of feed efficiency in the absence of a rewarding mechanism that would allow them to offset extra costs associated with the genomic bull.25 Moreover, Goddard et al. (2016) and Boaitey (2017) suggest that the presence of misalignment of incentives in the beef supply chain, such as substantial rewards to the producers who do not incur any additional cost from the adoption of the innovation, further discourages the probability of adopting.

Boaitey (2017) also highlights the positive environmental outcomes associated with breeding for feed-efficient cattle. However, these outcomes are likely to differ among the three agro-ecological zones considered, Southern Alberta, Northern Alberta and Central Alberta; hence, environmental and economic benefits might be spatially heterogeneous. Boaitey (2017) suggests that the highest environmental benefits are achieved when the selection for feed efficiency is combined with limits on stocking rates. According to the estimates of Boaitey et al. (2017), a unit reduction in feed intake (kilogram as fed/day) leads to an average increase of $13.23 in net returns and a reduction of 33.46 tonnes in emissions at the end of the feeding period. However, in the view of Boaitey (2017) and Boaitey et al. (2019), it is policymakers' responsibility to implement a differential payment scheme that takes into account the spatial heterogeneity in environmental and economic trade-offs.

Although not exclusively focused on Alberta cattle farms,[26] Alemu et al. (2017) conclude that improved management efficiency has the potential to reduce average emission intensity by 31 per cent on Canadian cow-calf production systems. Furthermore, the authors state that Canadian cow-calf operations result in a large variation in emission intensity, despite the size or location of the farms. Alemu et al. (2017) estimate average emission intensity as 23.9 kilograms CO_2 equivalent per kilogram total live weight sold from weaned calves and culled cows, and 2,178 kilograms CO_2 equivalent per hectare. According to Alemu et al. (2017), enteric fermentation is accountable for the majority of total farm emissions (65 per cent), while manure storage represents 23 per cent. Moreover, the authors find several approaches that ensure efficient calf production, such as provision of diets with higher digestible energy and crude protein, growing fewer annual crops for feed relative to perennial forage, maintenance of higher culling rates and avoiding compost manure.

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24 However, these preferences are subject to change according to risk perceptions, calf-retention practices and familiarity with genomics (Boaitey 2017).

25 Cow-calf producers can choose between a regular bull and a genomic bull, where producers may have to bear additional costs in breeding genomic bulls who produce more feed-efficient calves (Boaitey 2017).

26 Seventy-nine per cent of the cattle farms surveyed for the study represent the farms located in Western Canada: Alberta (100 farms), Saskatchewan (79 farms), Manitoba (35 farms), British Columbia (18 farms) (Alemu et al. 2017).

With respect to the conservation cropping protocols listed in Appendix Table A2, Goddard (2021, 95) divides Alberta into two zones, the dry prairie and Parkland,[27] and specify different soil-carbon–sequestration rates (0.41 tonnes per year for the dry zone and 0.59 for the Parkland) that can be expected when converting to zero tillage from full tillage. However, the government of Alberta states that the carbon yield is fixed at 0.06 tonnes per acre in the dry prairie and 0.11 in the Parkland (Government of Alberta 2021a).

De Laporte, Schuurman and Weersink (2021) compare the economic impacts of 4R practices that have the potential to reduce nitrous-oxide emissions. According to the estimates given by De Laporte et al. (2021) pertaining to the Prairie provinces, the lowest ($2.85 per hectare) and the highest ($17.51 per hectare) mean annual change in net revenue can be expected from split nitrogen application ("right timing") and variable rate application ("right placement"), respectively (Appendix Table A4). However, De Laporte et al. (2021) suggest that adopting 4R practices as a package would be more efficient than single practices. When the costs of adopting 4R practices are compared with crops that are extensively cultivated in Prairie provinces, De Laporte et al. (2021) find higher program costs for spring wheat and canola. However, only a few canola producers are currently employing more advanced 4R strategies; thus, higher program costs might be a result of larger amounts of croplands on the Prairies. Further, low nitrogen application and differences in dryland agriculture would lead to low emission reductions resulting in increased per-hectare costs (De Laporte et al. 2021).

Further, De Laporte et al. (2021) project future adoption possibilities of 4R practices and find that these practices would never be adopted by some producers, whereas those who do adopt would advance over time. The authors believe that barriers to adoption are beyond economic concerns; hence, direct payments equivalent to the adoption-inducement cost may not effectively support producers for the transition. From the authors' viewpoint, expert agronomic services, which facilitate evaluation and relevant testing to minimize risks, are essential for a successful implementation of 4R practices; therefore, farmers need to be incentivized for a cost-share of the agronomic services.[28] Furthermore, production of prescription maps will strengthen 4R adoption, because mapping results in great reductions in agronomic services (De Laporte et al. 2021).

The key takeaway message from this review is that the implementation of projects that ensure mitigation of GHG emissions from crop and livestock farms is associated with high transaction costs; consequently, active involvement of farmers in carbon-credit markets cannot be observed. Given that, farmers should be incentivized to carry out the GHG-mitigation strategies recognized by literature, such as the adoption of feed-efficient cattle breeds and regenerative agricultural

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27 The dry zone has Brown Chernozem soils and the Parkland has Black Chernozem (Goddard 2021).

28 De Laporte et al.'s (2021) results of provision of agronomic services to the farmers implementing 4R practices at 50-per-cent cost share are presented in Appendix Table A5.

practices, provision of expert agronomic services, etc. While these findings can be useful for the development of Alberta Emission Offset System that fulfills the needs of agricultural-sector stakeholders in Alberta, Sellars et al. (2021) emphasize the uncertainty associated with long-term costs and returns for carbon-sequestration practices. In addition, agricultural carbon markets are still in the developing stage and there are no universal standards for measuring, reporting or verifying agricultural carbon credits (Sellars et al. 2021; Shockley and Snell 2021; van der Pol et al. 2021). Verschuuren (2017) recommends designing projects aimed at farm level, and that these projects should ensure the delivery of real, additional, measurable and verifiable emission reductions, while a robust and reliable MRV system must be in place (Verschuuren 2017). However, according to Aiken (2021), the present agricultural carbon-credit market is still the "wild west," with no rules and regulations that are clearly specified.

POLICY IMPLICATIONS AND RECOMMENDATIONS

The Alberta Emission Offset System has been hardly recognized in the published literature related to agricultural GHG emissions, even though Alberta is responsible for the highest agricultural GHG emissions in Canada. Canadian agriculture (especially the Canadian beef industry) relies heavily on Alberta's crop and livestock framing. Consequently, to achieve Canada's 2030 Paris targets, the performance of the agricultural sector in Alberta should be prudently monitored.

Nevertheless, Kennedy and Brinker (2021) highlight the potential of agricultural operations to generate offsets related to quantification protocols approved for solar and wind-powered electricity generation, distributed renewable energy, and energy-efficiency projects. This reveals the opportunities for the agricultural sector to benefit by earning an extra income, irrespective of the high level of agricultural emissions in Alberta. Since Alberta contributes immensely to Canadian agriculture, if farmers adopt climate-friendly agricultural practices that reduce GHG emissions, then farmers would economically benefit while contributing to the goal of achieving climate neutrality by 2050.

However, not all farmers appreciate these offset mechanisms in a similar manner. Hence, the real economic and ecological impacts should be properly investigated, while adoption of climate-friendly agricultural practices and participation in the carbon-credit market should be backed by scientific evidence. Literature is evident for the potential of agriculture-specific protocols (GHG-emission reductions from fed cattle, selection for low residual feed-intake markers in beef cattle, nitrous-oxide–emissions reduction) specified by the Alberta government to reduce GHG emissions (Government of Alberta 2021a), but research studies reveal the farmers' reluctance to follow these protocols due to the uncertainty and higher transaction costs.

According to the literature, participation of cattle producers in the Alberta Emission Offset System has not been able to cover their forgone costs. However, breeding for feed-efficient cattle, improvements in feed efficiency and enhanced cattle-farm management efficiency are recognized as potential GHG-mitigation strategies. In addition, provision of diets with higher digestible energy and crude protein, growing fewer annual crops for feed relative to perennial forage, maintenance of higher culling rates, and avoiding compost manure are the recommendations provided in literature to achieve efficient calf production. Given these possibilities, instead of participating in the offset system, cattle producers tend to adjust their stocking rate with more feed-efficient cattle breeds to take the advantage of decreased feed costs. Given that, from the regions or periods that produce higher pasture yields, greater aversion can be expected from farmers to participating in the carbon-credit market. Nevertheless, the absence of rewarding mechanisms, which allow farmers to offset extra costs associated with the adoption of efficient cattle breeds, confine these opportunities, despite cow-calf producers being willing to upgrade their farms with feed-efficient cattle breeds.

With respect to crop farming, the adoption of 4R practices as a package is considered more efficient than adopting single practices. Furthermore, studies emphasize the lower effectiveness of zero or reduced tillage in reducing GHG emissions, although these practices are widely used in Alberta. These reduced-tillage practices are likely to release sequestered carbon back into the atmosphere at any time and impose a higher risk of being revoked or removed from the Alberta Emission Offset System. Consequently, researchers favour the concept of regenerative agriculture, which is more likely to return better outcomes compared to tillage practices. According to Kennedy and Brinker (2021), a recently proposed federal enhanced SOC protocol would be a further opportunity for Alberta farmers to generate offsets that can be sold to large emitters subject to the federal OBPS, since no similar offset protocol is currently active in Alberta.

Literature highlights the impact of financial barriers on the participation of the Alberta Emission Offset System. Irrespective of the farming type (livestock or crop), farmers are reluctant to participate in the offset system unless they are rewarded with incentives. However, incentivizing farmers does not guarantee positive outcomes, due to the uncertainty of carbon markets. The outcome of participating in the offset system by generating carbon offsets pertaining to the agricultural sector depends on multiple factors, such as the spatial heterogeneity of costs associated with the adoption of GHG-mitigation strategies, differences in farms (herd size, types of cattle breeds, feeds used, crops cultivated, projects implemented at farm level, etc.) and delivery and verification of emission reductions. Therefore, policies should not just focus on emission reductions. According to Kragt et al. (2012), if we expect carbon-offset schemes to be effective and cost-efficient, future research should consider farmers' evaluation of the risks involved with participation in an offset market.

Conversely, carbon-credit markets are growing because of their nature to reward, instead of placing a cost on emissions (World Bank 2021b). Because agricultural GHG emissions are low compared to other high-emitting sectors, such as energy, waste and transportation, farmers may have more options to sell carbon credits in the future. Further, the increasing trend of the Alberta credit price would attract agricultural producers to participate in the Alberta Emission Offset System, yet, as Paustian (2019) suggests, there should be no expected increase in transaction costs in order to make offsets more realistic.

These possibilities would strengthen the continuation of the Alberta Emission Offset System. However, due to the scarcity of published studies, it is too early to project either the economic potential for farmers to earn revenue or the environmental prospects of the province's agricultural sector contributing to the long-term goals of the Paris agreement. Future research and scientific evidence is crucial to fill these gaps and to guarantee future protocols. As Sellars et al. (2021) suggest, selling carbon credits is a long-term decision that is mostly irreversible. Hence, literature recommends farmers to wait until the carbon market becomes more stable before making a decision, while suggesting the respective authorities endorse farmers for carbon-crediting mechanisms by emphasizing its co-benefits and associated economic incentives, instead of prioritizing its potential financial gains.

APPENDIX

Table A1. Global percentage share of total carbon credits issued by different types of agricultural projects, 2003–2020

Type of project	Percentage share of total carbon credits issued
Compost addition to rangeland	0%
Feed additives	0%
Improved irrigation management	0.04%
Manure methane digester	0.94%
Nitrogen management	0%
Rice emission reductions	0%
Solid-waste separation	0.02%
Sustainable agriculture	0.03%
Sustainable grazing	0%

Source: Ellis (2021).

Table A2. Agriculture-specific protocols for Alberta

		Beef	
Conservation cropping	Nitrous-oxide–emissions reduction	Feedlot: Reducing greenhouse-gas emissions from fed cattle	Genetics: Selection for low residual feed-intake markers in beef cattle
• Requires direct or two-pass seeding • Any soil disturbance must stay under the specifications set out in the protocol	• Focuses on improving nitrogen-fertilizer efficiency, putting more in the crop and less in the air as nitrous oxide	• Focuses on beef cattle located in confined feeding operations • GHG reductions are variable and the offsets are based on an improvement over a three-year baseline	• Focuses on breeding cattle • Research trials are underway in Lacombe and Brooks, Alta.
Provides opportunities for farmers to earn carbon offsets by increasing soil carbon levels through no-till management and reducing GHG emissions from lower fuel use	Reduces inefficient use of fertilizer on farm	Savings on feed	Variable GHG reductions with feed savings

Source: Government of Alberta (2021a).

Table A3. Domestic carbon-crediting mechanisms

	Status	Name	Type of jurisdiction covered	Registered activities as of Dec. 31, 2020	Credit name	Credits issued ($MtCO_2e$) as of Dec. 31, 2020	Credits retired or cancelled ($MtCO_2e$) as of Dec. 31, 2020	Geographic coverage	Price range, 2020 US$/$tCO_2e$
1	Implemented	Alberta Emission Offset System	Subnational	288	Alberta emissions offset	65.1	53.11	Province of Alberta	16–21
2		Australia ERF	National	922	Australia Carbon Credit Unit (ACCU)	88.3	0.2	Australia	12
3		Beijing Forestry Offset Mechanism	Subnational	4	Beijing Forestry Certified Emission Reductions (BFCERs)	0.2	0	Municipality of Beijing	2.1–9.28
4		Beijing Parking Offset Crediting Mechanism	Subnational	N/A	Parking Certified Emission Reductions (PCERs)	N/A	N/A	Municipality of Beijing	7–9
5		British Columbia Offset Program	Subnational	23	British Columbia Offset Units	7.65	3.31	Province of British Columbia	6–12
6		California Compliance Offset Program	Subnational	505	California Air Resource Board Offset Credits (ARBOCs)	214.1	92.8	United States	13.71
7		Chile Crediting Mechanism	National	N/A	N/A	N/A	N/A	Chile	N/A
8		China GHG Voluntary Emission Reduction Program	National	287	Chinese Certified Emission Reductions (CCERs)	53	0	China	1.5–3
9		Chongqing carbon-offset mechanism	Subnational	N/A	N/A	N/A	N/A	Chongqing	N/A
10		Colombia Crediting Mechanism	National	N/A	N/A	N/A	N/A	Colombia	N/A
11		Fujian Forestry Offset Crediting Mechanism	Subnational	12	Fujian Forestry Certified Emission Reduction (FFCERs)	2	0	Province of Fujian	1–3
12		Guangdong Pu Hui Offset Crediting Mechanism	Subnational	65	Pu Hui Certified Emissions Reductions (PHCERs)	1.657	0	Province of Guangdong	2
13		J-Credit Scheme	National	828	J-credits	6.2	3.09	Japan	20, Renewable energy 13.5, Energy saving and others

	Status	Name	Type of jurisdiction covered	Registered activities as of Dec. 31, 2020	Credit name	Credits issued ($MtCO_2e$) as of Dec. 31, 2020	Credits retired or cancelled ($MtCO_2e$) as of Dec. 31, 2020	Geographic coverage	Price range, 2020 US$/$tCO_2e$
14		Joint Crediting Mechanism	Regional	56	JCM credits	0.03	0	Mongolia, Bangladesh, Ethiopia, Kenya, Maldives, Vietnam, Lao PDR, Indonesia, Costa Rica, Palau, Cambodia, Mexico, Saudi Arabia, Chile, Myanmar, Thailand, Philippines	N/A
15		Kazakhstan Crediting Mechanism	National	5	N/A	N/A	N/A	Kazakhstan	N/A
16		Quebec Offset Crediting Mechanism	Subnational	16	Quebec offset credits	0.877	0	Canada	14.59
17		RGGI CO_2 Offset Mechanism	Subnational	1	RGGI CO_2 offset allowances	0.053	N/A	States of Connecticut, Delaware, Maine, Maryland, New Jersey, New York, Vermont	5
18		Republic of Korea Offset Credit Mechanism	National	472	Korean Offset Credits (KOCs)	33.53	0.279	Republic of Korea	20–36
19		Saitama Forest Absorption Certification System	Subnational	153	Forest Absorption Credits	0.01	0	Japan	N/A
20		Saitama Target Setting Emissions Trading System	Subnational	660	Offset credits	7.2	0.17	Saitama prefecture	4
21		Spain FES-CO_2 Program	National	719	Spain Carbon Fund Credits	2.8	0	Spain	11.39
22		Switzerland CO_2 Attestations Crediting Mechanism	National	142	Swiss CO_2 attestations	4.5	4.9	Switzerland	59–160
23		Taiwan GHG Offset Management Program	National	67	N/A	10.94	0	Taiwan	N/A
24		Thailand Voluntary Emission Reduction Program	National	226	TVER	6.011	0	Thailand	0.64–9.46

	Status	Name	Type of jurisdiction covered	Registered activities as of Dec. 31, 2020	Credit name	Credits issued ($MtCO_2e$) as of Dec. 31, 2020	Credits retired or cancelled ($MtCO_2e$) as of Dec. 31, 2020	Geographic coverage	Price range, 2020 US$/$tCO_2e$
25		Tokyo Cap-and-Trade Program	Subnational	1200	No formal umbrella name for offset credits	0.5	0.1	Japan	1.62–8.12, Excess emission reductions 43–58, Renewable energy credits
26	Under development	Canada Federal GHG Offset System							
27		Mexico Crediting Mechanism							
28		Nova Scotia Crediting Mechanism							
29		Saskatchewan GHG Offset Program							
30		South Africa Crediting Mechanism							
31		Washington Crediting Mechanism							

Source: World Bank (2021b).

Table A4. Annual change in net returns per unit for various 4R practices in Prairies, with negative values implying costs to implement

Practice	Annual change in net revenue			
	Low	Middle	High	Unit
Split nitrogen application (Right timing)	-30.52	2.85	39.78	$/ha
Enhanced fertilizers (Right source)	-125.24	-33.41	80.3	$/ha
Recommended rate (Right rate)	0.9	13.48	22.18	$/ha
Variable-rate application (Right placement)	-31.88	17.51	67.25	$/ha

Source: De Laporte et al. (2021).

Table A5. Agronomic service costs for implementing 4R across different levels

	Basic	Intermediate	Advanced	All
Spring Wheat: 8,126,399 ha				
% in 4R level	35	25	15	75
Area (ha)	2,844,240	2,031,600	1,218,960	6,094,799
Agronomic costs ($/ha)	11.44	17.51	29.65	17.11
Total costs ($)	32,540,835	35,576,373	36,145,327	104,262,536
GHG reduction (tCO_2e)	103,324	377,032	559,699	1,040,056
Abatement cost ($/$tCO_2e$)	314.94	94.36	64.58	100.25
Canola: 9,125,716 ha				
% in 4R level	35	25	10	70
Area (ha)	3,194,001	2,281,429	912,572	6,388,001
Agronomic costs ($/ha)	11.44	17.51	29.65	16.21
Total costs ($)	36,542,438	39,951,261	27,060,121	103,553,820
GHG reduction (tCO_2e)	127,941	460,788	619,639	1,208,369
Abatement cost ($/$tCO_2e$)	285.62	86.7	43.67	85.7

Source: De Laporte et al. (2021).

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