CLEAN GROWTH IN CANADA'S AGRICULTURE AND AGRI-FOOD SECTOR

OCTOBER 2021

Smart Prosperity Institute

About Smart Prosperity Institute

Smart Prosperity Institute is a national research network and policy think tank based at the University of Ottawa. We deliver world-class research and work with public and private partners – all to advance practical policies and market solutions for a stronger, cleaner economy.
institute.smartprosperity.ca

Scott McFatridge, Mike Moffatt, Shabnam Khalaj,
Ryan Tougas-Cooke, Stewart Elgie, John McNally and Sonia Cyrus Patel

With contributions from Myra Van Die

October 2021

Smart Prosperity Institute (SPI) gratefully acknowledges financial support from Agriculture and Agri-food Canada for this research. We also thank Agriculture and Agri-food Canada for their comments on a draft of this report.

Financial support and review of this report do not imply endorsement. The views expressed in this report, as well as any errors or omissions, are Smart Prosperity Institute's alone.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Overview

In 2019, agriculture (including on-farm fuel use) accounted for 73 Mt of greenhouse gas (GHG) emissions, equal to 10% of the country's total GHG emissions. While the overall GHG emissions-intensity of agriculture is declining,[1] some concerning trends remain. Absolute emissions from crop production have increased significantly since 2005, and although Canada's soils continue to accumulate soil organic carbon, their annual sequestration rates have tapered off over the past fifteen years (ECCC, 2021b). Moreover, water quality has deteriorated – mainly due to the increased application of nutrients and pesticides – and the suitability of farmland for wildlife habitat has also declined over the past two decades (Clearwater, Martin & Hoppe, 2016).

These trends make clear that increasing the adoption of environmentally friendly practices and technologies is essential to meeting the growing global demand for food in a sustainable manner. This shift should be enabled by a deft agricultural innovation ecosystem, market signals that reward environmental performance, and behavioural interventions that encourage the use of beneficial management practices (BMPs), clean technology adoption, and sustainable consumption patterns.

In 2019, agriculture (including on-farm fuel use) accounted for 73 Mt of greenhouse gas (GHG) emissions, equal to 10% of the country's total GHG emissions.

Canada's Opportunity

Canada and the world are taking steps to reduce the environmental footprint of the agriculture sector, and corporate leaders are following suit. Canada has committed to reducing its GHG emissions by 40-45% below 2005 levels by 2030, and to achieve net-zero GHG emissions by 2050 (ECCC, 2021a). As part of these commitments, the federal government has set a national target to reduce GHG emissions from nitrogen fertilizers by 30% below 2020 levels by 2030. Canada has also committed to protecting 25% of its terrestrial area and its oceans and shorelines by 2025 (ECCC, 2020a).

An increasing number of agriculture and agri-food business leaders are also recognizing the need to produce and source their food sustainably. To name only a few examples: Maple Leaf is the first major food company in the world to go carbon neutral (Maple Leaf Foods, 2019), and in 2010 Unilever committed to sustainably sourcing 100% of its raw agricultural materials by 2020 (Unilever, n.d.).

These targets and initiatives come at a time when Canada's agriculture and agri-food sector is on the cusp of an extraordinary economic growth opportunity. Demand for high-value food (e.g. proteins and functional foods) is expected to increase significantly in the coming decades, as a result of population growth and an increase in the size and purchasing power of the global middle class. As the world's fifth-largest agricultural exporter, Canada has the opportunity to leverage its position as a trusted global leader in supplying safe, nutritious food in the 21st century (Farm Credit Canada, 2020).

In recognition of this economic growth opportunity, the federal government's Economic Sector Strategy Table for agri-food adopted an ambitious target of $85 billion in agriculture, agri-food and seafood exports and $140 billion in domestic sales by 2025. This represents a sizeable increase from the 2017 values of $64.6 billion and $110 billion for agri-food exports and domestic sales, respectively (ISED, 2018). To hit these growth targets, the sector must achieve a compound annual growth rate (in dollar terms) of over 3% per year.

Seizing these export growth opportunities partially depends on recognizing that market access is increasingly based on a country's ability to uphold strict environmental and safety standards. This can be seen from changing consumer preferences and from the inclusion of environmental provisions in trade agreements such as the Trans-Pacific Partnership and the Comprehensive Economic and Trade Agreement. The upshot is that leveraging Canada's reputation for safe, nutritious, sustainable, and affordable food (the 'Canadian Brand') on the international stage offers a promising pathway to diversifying Canada's export markets.

Unlocking Clean Growth in the Agriculture Sector

Canada's agri-environmental cost-share programs play an important role in rewarding environmental stewardship and encouraging the adoption of BMPs. Some provinces have adopted a number of innovative program designs for their cost-share offerings in recent years, such as rolling out more targeted programs and introducing cost-share programs for producer groups. However, these programs are still grappling with a number of problems, such as: (1) 'selection bias', where environmentally motivated farmers are more likely to participate in cost-share programs, rather than those in greatest need of environmental improvement; (2) producers mostly adopting BMPs that are highly visible, easy to trial, or that primarily provide private economic benefits; and (3) a paucity of rigorous impact evaluations that assess what environmental and economic outcomes would have been in the absence of the cost-share programs. Concerns with the performance of the cost-share programs suggest that new policies will be essential to meeting Canada's clean growth objectives.

To provide insight on the best way to approach Canada's clean growth opportunity, Smart Prosperity Institute (SPI) convened a workshop in Ottawa in January 2020 that featured representatives from government, industry, academia, and environmental non-governmental organizations. Workshop participants discussed two key themes for unlocking clean growth opportunities in Canada's agriculture and agri-food sector: (1) gauging the economic and environmental performance of existing federal/provincial/territorial agri-environmental programs (especially the cost-share programs under the Canadian Agricultural Partnership) and how they might be improved; and (2) potential focus areas for new policy interventions – grounded in specific geographies and food production systems – that could make a substantial contribution to the sector's economic and environmental objectives.

Focus Areas

SPI presented a list of six potential focus areas to workshop participants:

1. **Improving the efficiency of nitrogen fertilizer management**;
2. **Enhancing soil health**;
3. **Commercializing next-generation crop production technologies**;
4. **Reducing GHG emissions reductions in the beef and dairy livestock sectors through improved animal genomics**;
5. **Reducing GHG emissions reductions in the beef and dairy livestock sectors through better livestock feeding practices**;
6. **Circular economy approaches to agriculture and agri-food**.

The focus areas were identified based on three key criteria: the scope of the environmental challenges; the size of the economic opportunity; as well as the scalability of the policy and/or technological solutions. In addition workshop participants suggested additional case study topics of their own.

Nearly all of SPI's proposed focus areas were received favorably by workshop participants, but some case studies clearly stood head and shoulders above the others. For instance, participants were overwhelmingly in favour of focussing on nitrogen fertilizer management, improving soil health, and circular economy approaches to agriculture and agri-food – due to their ability to build on existing policies and for their potential to realize a broad array of economic and environmental benefits. There was also significant enthusiasm for a case study assessing a broad suite of GHG mitigation opportunities across the beef and dairy livestock sectors (e.g. improved livestock feeds, animal genomics, carbon sequestration on prairie grasslands, etc.). Many of these focus areas studies will be the subject of in-depth research and convening in future years.

Among the case studies proposed by workshop participants, changes to business risk management programs and ecosystem service approaches to agriculture were particularly well received – the former because it builds upon an existing program framework to incentivize BMP adoption, and the latter because of the potential for realizing integrated environmental-economic benefits for producers and society. The ecosystem services approach also has the potential to simultaneously advance a number of federal, provincial, and territorial government objectives, such as nature-based solutions to climate change mitigation, and natural infrastructure for enhancing climate change adaptation and resilience.

Policy Options

New policies will also be necessary to help Canada make the most of this clean growth opportunity. This report examines five complementary policies for driving clean growth in the sector: (1) behavioural economics approaches; (2) taxes on environmental externalities (or agricultural inputs linked to these externalities); (3) voluntary ecological certification; (4) targeted agri-environmental subsidies (especially reverse auctions and spatially targeted payment schemes); and (5) offsets for greenhouse gas emissions, water quality, and for biodiversity.

Each of these policies has their respective strengths and weaknesses and each can play an important role in further unlocking clean growth within the sector. To best address the sector's environmental challenges in an actionable way, these policy tools need to be grounded in solid analysis and piloted (and then scaled up) in key production systems across the country.

Canada is facing an unprecedented opportunity to foster clean growth in the agriculture and agri-food sector while contributing to Canada's environmental objectives. But current approaches are not enough to get us there. Through innovative policy approaches, federal, provincial, and territorial governments can help increase technology deployment and BMP adoption to the benefit of producers, industry, the environment, and all Canadians. Canada's clean growth opportunity awaits us – but only if Canada acts. And the time to act is now.

KEY MESSAGES

1. Canada's agriculture and agri-food sector is on the cusp of an extraordinary economic growth opportunity. Demand for high-value food (e.g. **proteins** and **functional foods**) is expected to increase significantly in the coming decades, as a result of population growth and an increase in the size and purchasing power of the global middle class.

2. In recognition of this opportunity, **the Economic Sector Strategy Table for Agri-Food adopted an ambitious target of $85 billion in agriculture, agri-food, and seafood exports and $140 billion in domestic sales by 2025.** As the world's 5th largest agricultural exporter, Canada has the opportunity to leverage its position as a trusted global leader in supplying safe, nutritious food to diversify its exports markets.

3. Meeting these targets and satisfying the growing global demand for food in a sustainable manner should be a top priority for Canada. In 2019, agriculture (including on-farm fuel use) accounted for 73 Mt of greenhouse gas (GHG) emissions, equal to **10% of the country's total GHG emissions**. In addition, soil carbon sequestration rates, water quality indicators, and the suitability of farmland for wildlife habitat have been in decline.

4. Canada has already taken the first steps toward reducing the environmental impact of the agriculture sector. The federal government has committed to reducing its GHG emissions by 40-45% below 2005 levels by 2030, and as part of these commitments, has set a national target to reduce GHG emissions from nitrogen fertilizers by 30% below 2020 levels by 2030. In addition, leaders in the agri-food industry have started to adopt sustainable sourcing commitments throughout their supply chains.

5. Reconciling the economic opportunity with the environmental challenge will be no small feat and no single instrument or practice will be sufficient to do the job. For example, the adoption and use of beneficial management practices or clean technologies is pivotal to reducing the environmental impact of the agriculture sector; however, there are several concerns facing Canada's Federal-Provincial-Territorial cost-share programs — one of the main vehicles for promoting the adoption of environmentally friendly management practices. These concerns include:

- Selection biases that result in environmentally motivated farmers being more likely to participate in the cost-share programs, rather than those in greatest need of environmental improvement.
- The tendency for producers to mostly adopt BMPs that are highly visible, easy to trial, or that primarily provide private economic benefits.
- A paucity of rigorous impact evaluations that assess what environmental and economic outcomes would have been in the absence of the cost-share programs.

6. To unlock clean growth opportunities in Canada's agriculture and agri-food sector, there are several key areas to focus on. Participants at SPI's workshop in January 2020 identified **nitrogen fertilizer management**, **improving soil health**, and **circular economy approaches** to agriculture and agri-food as some of the most promising opportunities for clean growth in Canada's agriculture sector.

7. Decoupling economic growth from environmental harm requires a well-targeted and comprehensive package of policies for the agriculture sector. Some of the most promising policy options moving forward include:

- Behavioral Economics Approaches
- Taxes on Environmental Externalities
- Voluntary Ecological Certification
- Targeted Agri-environmental Subsidies
  - Reverse Auctions
  - Spatially Targeted Payment Schemes
- Offsets for Greenhouse Gas Emissions, Water Quality, and Biodiversity.

8. Canada is facing an unprecedented opportunity to foster clean growth in the agriculture and agri-food sector, while also contributing to Canada's environmental objectives. But current approaches are not enough to get us there. Through innovative policy approaches, federal, provincial, and territorial governments can help increase technology deployment and BMP adoption to the benefit of producers, industry, the environment, and all Canadians.

1. INTRODUCTION

Canada and the world are acting on climate change and biodiversity, and corporate leaders are following suit. Canada has committed to reducing its greenhouse gas (GHG) emissions by 40-45% below 2005 levels by 2030, and to achieve net-zero GHG emissions by 2050 (ECCC, 2021a). The federal government has also set a national emissions reduction target for fertilizers, outlining a 30% reduction by 2030, relative to 2020 levels. The *A Healthy Economy and Health Environment* plan, released in late 2020, states that the government intends to work with fertilizer manufacturers, farmers, and provincial and territorial governments to decide on the best way to reduce fertilizer-related emissions and states that better fertilizer products and fertilizer practices are essential to protecting Canada's natural resources. Canada has also committed to protecting 25% of its terrestrial area and its ocean and shorelines by 2025 (ECCC, 2020a).

A growing number of agri-business leaders are also waking up to the need to produce and source their food sustainably. To name only a few examples: Maple Leaf is the first major food company in the world to go carbon neutral (Maple Leaf Foods, 2019); in 2010 Unilever committed to sustainably sourcing 100% of its raw agricultural materials by 2020, and has reached 62% as of 2019 (Unilever, n.d.); McDonald's Canada is promoting integrated pest management and has committed to sourcing at least 30% of its Quarter Pounder beef from producers certified under the Canadian Roundtable for Sustainable Beef (CRSB, 2020); and Danone, Kellogg's, Loblaws, McCain, Nestlé, and others are pledging to protect and restore biodiversity in their product portfolios, as part of the "One Planet Business for Biodiversity" coalition (OP2B, n.d.). These government and corporate sustainability commitments pose a challenge for producers and processors, but they also provide new avenues for product differentiation, resource efficiency, attracting and retaining new customers, as well as enhanced brand capital.

At the same time, Canada's agriculture and agri-food sector faces an extraordinary economic growth opportunity. Demand for high-value food (e.g. proteins, functional foods) is expected to increase significantly in the coming decades, as a result of population growth and an increase in the size and purchasing power of the global middle class. As the world's fifth-largest agricultural exporter, Canada has the opportunity to leverage its position as a trusted global leader in supplying safe, nutritious food in the 21st century (Farm Credit Canada, 2020).

Canada's agriculture and agri-food sector faces an extraordinary economic growth opportunity. Demand for high-value food (e.g. proteins, functional foods) is expected to increase significantly in the coming decades, as a result of population growth and an increase in the size and purchasing power of the global middle class.

Although Canada is well-positioned to meet this opportunity, the sector has a significant environmental footprint that needs to be reduced if Canada wants to simultaneously meet its commitments to reduce GHG emissions, conserve biodiversity, and sustainably manage Canada's natural capital. Designing policies to simultaneously realize the twin goals of economic growth and environmental improvement requires an understanding of the strengths and weaknesses of Canada's current agri-environmental policies, as well as identifying the key opportunities (production systems, technologies, beneficial management practices, policies, etc.) for achieving these goals.

To provide insight on these critical issues, Smart Prosperity Institute (SPI) conducted research and hosted a workshop in Ottawa on January 30th 2020 with representatives from governments, industry, academia, environmental non-governmental organization (ENGOs), and other sector representatives. Workshop participants provided their opinions on the strengths and shortcomings of federal, provincial, and territorial agri-environmental policies and programs, as well as their perspectives on six clean growth opportunities for SPI to examine in future research and stakeholder convening (e.g. workshops, online webinars, or consultations). These six focus areas are:

1. Improving the efficiency of nitrogen fertilizer management.
2. Measures to improve soil health.
3. Commercializing next-generation crop production technologies: gene-editing/CRISPR.
4. GHG emissions reductions in the beef livestock and dairy sectors: the role of animal genomics.
5. GHG emissions reductions in the beef livestock and dairy sectors: improved feed practices.
6. Circular economy approaches for Canada's agriculture and agri-food sector.

The rest of this report is structured as follows: section two reviews projections of global food demand and their implications for Canada's export growth opportunities.

Section three focuses on the environmental challenges facing the sector, and their implications for environmental policy and decoupling economic growth from environmental impact.

Section four provides a detailed assessment of the environmental and economic strengths, weaknesses, opportunities, and threats (SWOT) facing Canada's agriculture and agri-food sector, and assesses their ramifications for meeting Canada's export growth opportunity and for demonstrating a sustainable 'Canadian Brand.'

Section five examines current agri-environmental policies in Canada, outlining the positive aspects of current policies as well as areas for improvement.

Section six provides a concise overview of five key policy instruments for clean growth in the agriculture sector – namely behavioural economics approaches; taxes on environmental externalities (or agricultural inputs linked to these externalities); voluntary ecological certification schemes; targeted agri-environmental subsidies – especially reverse auctions and spatially targeted payment schemes; as well as offsets for GHG emissions, water quality, and for biodiversity.

Section seven outlines the six focus areas presented at the workshop, along with feedback and additional suggested focus areas from workshop participants.

Section eight synthesizes the workshop participants' assessment of the focus and outlines some next steps.

Section nine concludes with a synthesis of key messages.

2. THE OPPORTUNITY: TAPPING INTO MULTI-BILLION DOLLAR EXPORT MARKETS

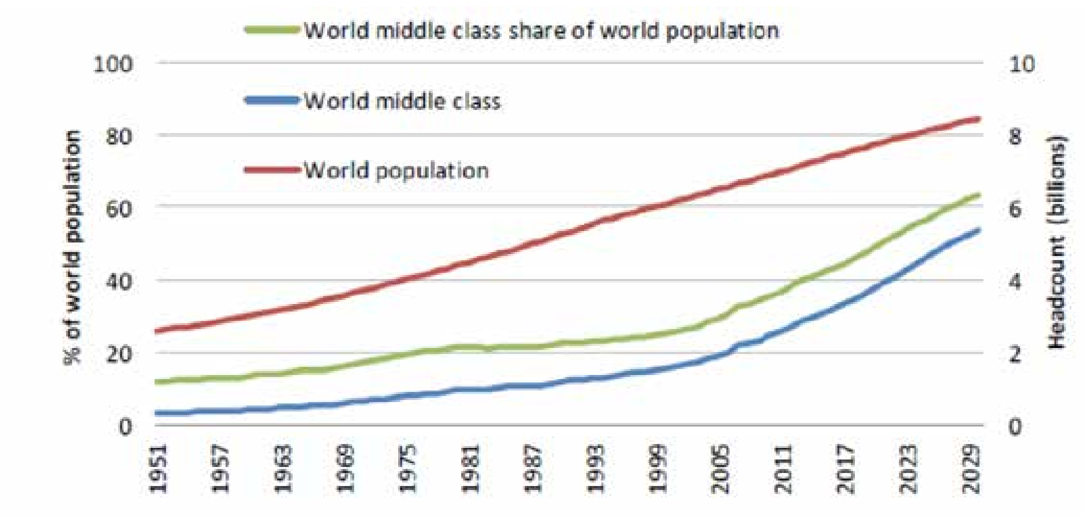
Canada's agriculture and agri-food sector is on the cusp of a tremendous economic growth opportunity. The 2017 recommendations from the federal government's Advisory Council on Economic Growth ('the Barton Report') call for aggressive economic growth in the sector (ACEG, 2017). The Barton Report set an export goal of $75 billion by 2027; a year later, the Economic Sector Strategy Table for agri-food adopted an even more ambitious target of $85 billion in agriculture, agri-food and seafood exports, and $140 billion in domestic sales by 2025. The latter targets represent a particularly substantial increase from the 2017 values of $64.6 billion and $110 billion for agri-food exports and domestic sales, respectively (ISED, 2018). To hit these targets, the sector must achieve a compound annual growth rate (in dollar terms) of over 3% per year.

While these export and production growth targets certainly are ambitious, Canada is well-positioned to meet this opportunity. As the world's fifth-largest agricultural exporter in 2019, Canada has the potential to become a trusted global leader in supplying safe, nutritious food in the 21st century (Farm Credit Canada, 2020). Burgeoning global population and per capita income growth are driving demand in global export markets. The Organisation for

Economic Co-operation and Development (OECD) forecasts that global gross domestic product (GDP) will more than double from today's levels and reach USD $218 trillion in 2050 (OECD, 2018), while the United Nations forecasts that the world's population will reach 9.7 billion by 2050 (UN Department of Economic and Social Affairs, 2019). Moreover, 90% of the next one billion entrants into the global middle class are predicted to come from Asia, where demand for safe, dependable food – and for protein in particular – is rising (Mccarron et al., 2018).

As the world's fifth-largest agricultural exporter in 2019, Canada has the potential to become a trusted global leader in supplying safe, nutritious food in the 21st century.

Figure 1. Estimates of the size of the global middle class, percentage of the world population (left axis) and headcount (right axis), 1950-2030[2]



This growing middle-class population and demand for high-value food in export markets will continue to be the growth frontier for Canada's agriculture and agri-food sector. Global demand for food is forecasted to increase by up to 70% by 2050. Canada has already established itself as the world's largest exporter of canola, wheat, and lentils (AECG, 2017). Canada now needs to build off this reputation by simultaneously maintaining its competitive advantage and seizing emerging market opportunities, while reducing environmental impacts and demonstrating strong sustainability credentials (for more information on environmental impacts, see section 3).

These emerging market opportunities include increasing Canada's share of value-added products ('moving up the value chain) and diversifying Canada's trade partners by identifying the fastest growing importers and supporting trade with these countries.

Moving up the value chain will require Canada to capitalize on both domestic and international food trends – such as the emerging popularity of functional foods. At the international level, Canada is well-positioned to harness synergies between functional foods and growing global protein demand. For instance, in June 2020 Merit Functional Foods received $100 million dollars in government financing to grow its commercial-scale protein extraction facility. The company adds value to protein products by improving the solubility, flavour, and purity of plant proteins and its facility is one of the first in the world to produce food-grade canola protein that can be marketed for human consumption (AAFC, 2020c). The value-added to grain products and plant proteins will allow Canada to capture a larger share of the growing global protein demand and cement its reputation as a safe, high-quality, and nutritious supplier of agri-food products.

Canada's aging population also provides a growing opportunity to market functional foods within domestic markets. In 2012, approximately 13% of the Canadian population was over the age of 65, but by 2041 this proportion is estimated to increase to 25%. With one quarter of the population falling into this demographic, this will also present Canada with a strong domestic marketing opportunity for functional foods (Duncan et al., 2012). Researchers from the University of Guelph found that in a survey of older adults (60+), over 75% consumed functional foods on a daily basis. The most common functional foods consumed by this group included cereal with increased fiber content, yogurts with probiotics, and eggs that contain omega-3 fatty acids. Over 85% of the older adults surveyed said that their motivation for consuming functional foods was to improve their health (Duncan et al., 2012). Canada can easily capitalize on the demand for functional foods by differentiating its products through marketing tactics that highlight the health benefits and value-add for the aging population.

In terms of **end-market diversification**, the forecasted increase in protein demand provides Canada with the opportunity to continue growing its pulse exports (AECG, 2017). The market for pulses has exhibited an average annual growth of over 8% between 1999 and 2017. In 2018, Canada captured less than one quarter (23%) of the global export market for pulses. In order to grow that market share, Canada needs to identify and cement trade relations with the two main emerging segments of the global export market: the higher income segment (consisting of countries such as Italy or Spain, where there is a growing demand for pulse crops); and the segment of importers from low and middle-income countries (Farm Credit Canada, 2019).

With regards to **higher-income export markets**, Spain is the third largest consumer of pulse crops in the entirety of the EU, and between 2006 and 2016 over 3500 new pulse products were launched across the country. Canada is currently Spain's second largest exporter; however, Canada only captured a little over 20% of Spain's pulse imports in 2016 (AAFC, 2017a). Italy represents a similar opportunity, since it is the EU's fourth largest importer of lentils. Lentil imports in Italy grew by about 12.5% between 2014 and 2016, with Canada supplying under 50% of their total lentil imports in 2016 (AAFC, 2017b). Capturing a greater share of these markets means cementing ties with key partners under existing trade agreements (such as Spain, Belgium, or Germany that are linked with Canada through CETA) (Farm Credit Canada, 2019).

Examples of viable **low and middle-income export market opportunities** could include countries like Mozambique, whose demand for wheat is expected to increase quickly (Farm Credit Canada, 2019); India, which has increased its pulse imports by 20% since 2000 (Farm Credit Canada, 2019); or Indonesia, where there is a growing import demand for pulse crops and a dramatic forecasted increase in demand for meat products by 2050 (McCarron et al., 2018). Indonesia is already a large importer of Canadian cereal products and is Canada's largest export market in the Association of Southeast Asian Nations (ASEAN) region (Government of Canada, 2020).

Seizing these export growth opportunities partially depends on recognizing that market access has increasingly become based on a country's ability to uphold strict environmental and safety principles. This is demonstrated by the inclusion of environmental provisions in trade agreements, such as those relating to the transition to a low-carbon economy or the conservation of endangered wildlife and marine ecosystems within the Trans-Pacific Partnership (UNCTAD, 2016). Furthermore, the environmental provisions in the European Union's Farm to Fork Strategy will force Canada to uphold its environmental laws and to promote sustainable food production in order to continue to access European agri-food markets (McInnes, 2021). Other key trade agreements, like the Comprehensive Economic and Trade Agreement (CETA), also include environmental provisions that promote environmental protection, discourage the relaxing of environmental protections to encourage trade or investment, and promote public awareness of environmental information (GAC, 2017a).

The upshot is that leveraging Canada's reputation for safe, nutritious, sustainable, and affordable food (the 'Canadian Brand') on the international stage offers a promising pathway to diversifying export markets. Canada already has a positive reputation as an agri-food exporter, and there are multiple opportunities to further differentiate the 'Canadian Brand' through stewardship claims from public, private, and third-sector initiatives. These have the potential to act as a value-add for Canadian products. The concept of leveraging a 'Canadian Brand' is further discussed in section 4 of this report.

Meeting future food demand sustainably while strengthening the 'Canadian Brand' of safety and environmental sustainability requires the sector to embrace technological change and innovation (Ng & Ker, 2019), and accelerate the adoption of existing beneficial management practices (BMPs). Changes to technologies and practices can help producers meet this demand without further damaging ecosystems and the environment.

But the benefits don't stop there. Investments in sustainable agriculture and agri-food technologies also have the potential to increase the sector's competitive advantage, while creating exportable intellectual property (IP). The use of new technologies on the farm opens up prospects for growth in novel, well-paid occupations in on-farm robotics, artificial intelligence, precision agriculture, and advanced food processing and manufacturing. Farmers will also need to work with a range of service providers – such as data analysts, technicians, and agronomic consultants – to help adopt and master these new technologies (RBC, 2019).[3]

With these high-level trends in mind, this report will now turn its attention to the other side of the coin for Canada's export growth strategy – namely, environmental trends and challenges in the agriculture and agri-food sector.

3. ENVIRONMENTAL CHALLENGES

The previous section made clear that Canada's agri-food sector is poised to realize a multibillion-dollar growth opportunity over the next five to ten years by further tapping into global export markets as well as domestic markets (ACEG, 2017). At the same time, the sector has a significant environmental footprint and recent federal targets have signalled that reducing emissions from fertilizers (by 30% below 2020 levels) is a priority action. Improving nutrient management practices will be a key factor in meeting Canada's ambitious domestic and international commitments to reduce GHG emissions, conserve biodiversity, manage soil health and improve water quality. These sentiments are echoed in consumer preferences, as they are shifting toward products with fewer negative environmental impacts. This means that many of the measures to reduce the environmental impacts of agricultural production will also help Canadian firms maintain their reputation and access the new and changing markets (ECCC, 2020a).

Agriculture also contributed approximately 29% of national methane (CH_4) emissions and 78% of nitrous oxide (N_2O) emissions in the same year, both of which are potent GHGs with approximately 25 times and 298 times the global warming potential of CO_2 (over a 100-year period) respectively.

This section reviews some of the key trends in environmental impacts from the agriculture and agri-food sectors, to better understand opportunities for improving environmental and economic performance. It begins with a discussion of GHG emissions from agricultural production, followed by an overview of the productivity and environmental impacts of key agricultural inputs such as agricultural land, soil quality, as well as water use and consumption. It then reviews some of the other environmental externalities arising from agriculture, including impacts on water quality and biodiversity, as well as food loss and food waste (and associated GHG emissions) across primary production and processing in the Canadian agri-food system. This is followed by a recent analysis that quantifies some of the non-market costs and benefits of the environmental externalities from Canadian primary agriculture, to provide a better sense of how changes in some of these environmental indicators translate to changes in human welfare. The section concludes with a set of reflections on these environmental trends and their implications for decoupling economic growth from environmental impact in the sector.

3.1 GHG Emissions and GHG Intensity in the Agriculture Sector

3.1.1 GHG Emissions

Canada's agricultural sector emitted 73 Mt of carbon dioxide (CO_2) equivalent in 2019 (including on-farm fuel use) – around 10% of the country's total GHG emissions for that year. Agriculture also contributed approximately 29% of national methane (CH_4) emissions and 78% of nitrous oxide (N_2O) emissions in the same year, both of which are potent GHGs with approximately 25 times and 298 times the global warming potential of CO_2 (over a 100-year period) respectively. CH_4 is estimated to remain in the atmosphere for a relatively short period of time, about 12 years; by contrast, N_2O lasts for an estimated 114 years in the atmosphere (ECCC, 2021b). The main driver of emissions trends over the years is the variation in the size of livestock populations (dairy and beef cattle) and the increasing application of inorganic fertilizers for crop production (ECCC, 2019b).

While livestock production currently contributes approximately 60% of all GHG emissions (excluding on-farm fuel use) in the agriculture sector, this share has dropped significantly since 2005 (-13%). Total agricultural emissions from crops and livestock were at 60 Mt of CO_2 equivalent in 2005, reflecting a peak in Canada's livestock population. Dramatic declines in livestock numbers occurred due to a variety of compounding issues, such as bovine spongiform encephalopathy (BSE, otherwise known as 'mad cow disease') and country of origin (COOL) labeling for food sold in the US, which decreased total agriculture sector emissions to 55 Mt of CO_2 equivalent in 2011. The decreased livestock emissions helped offset the rise in fertilizer use over that same period, especially in Western Canada (ECCC, 2019b). However, while livestock production emissions remained relatively stable from 2011-2018, emissions from crop production continued to increase over the same period. As result, N_2O emissions now comprise a slightly greater share of the sector's GHG emissions than CH_4 (ECCC, 2019b).

Figure 2. GHG Emissions from Agriculture Sector (Mt C02 eq) Canada (1997-2019)[4]

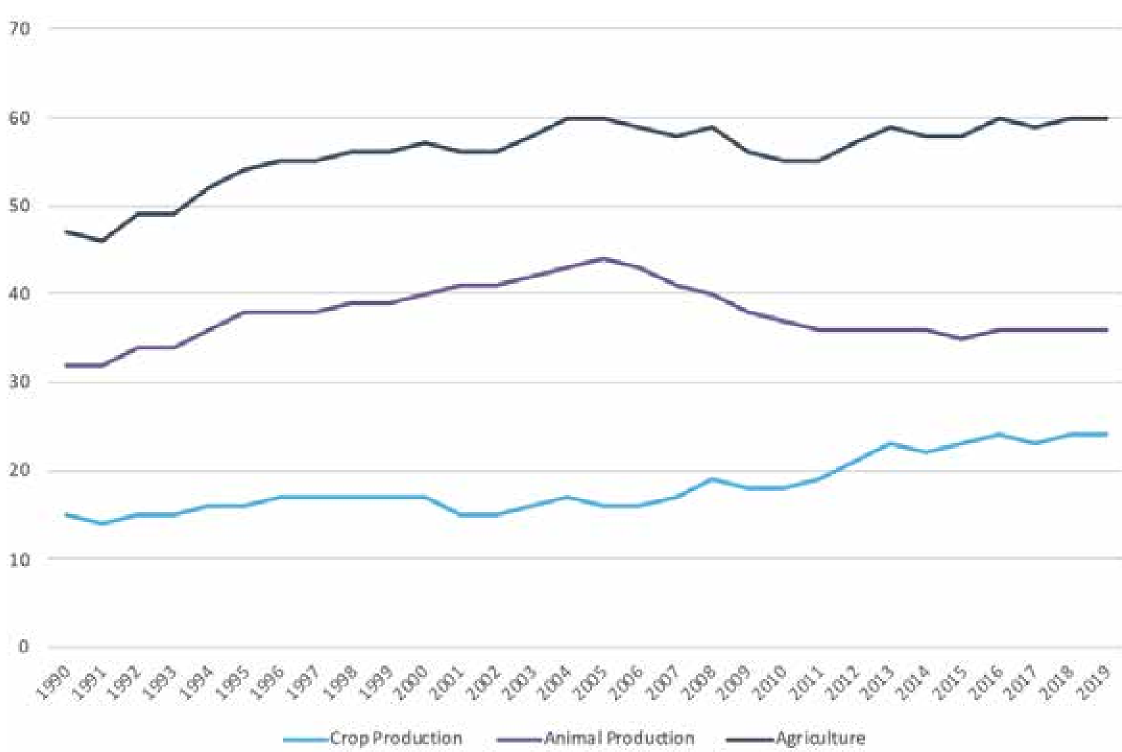
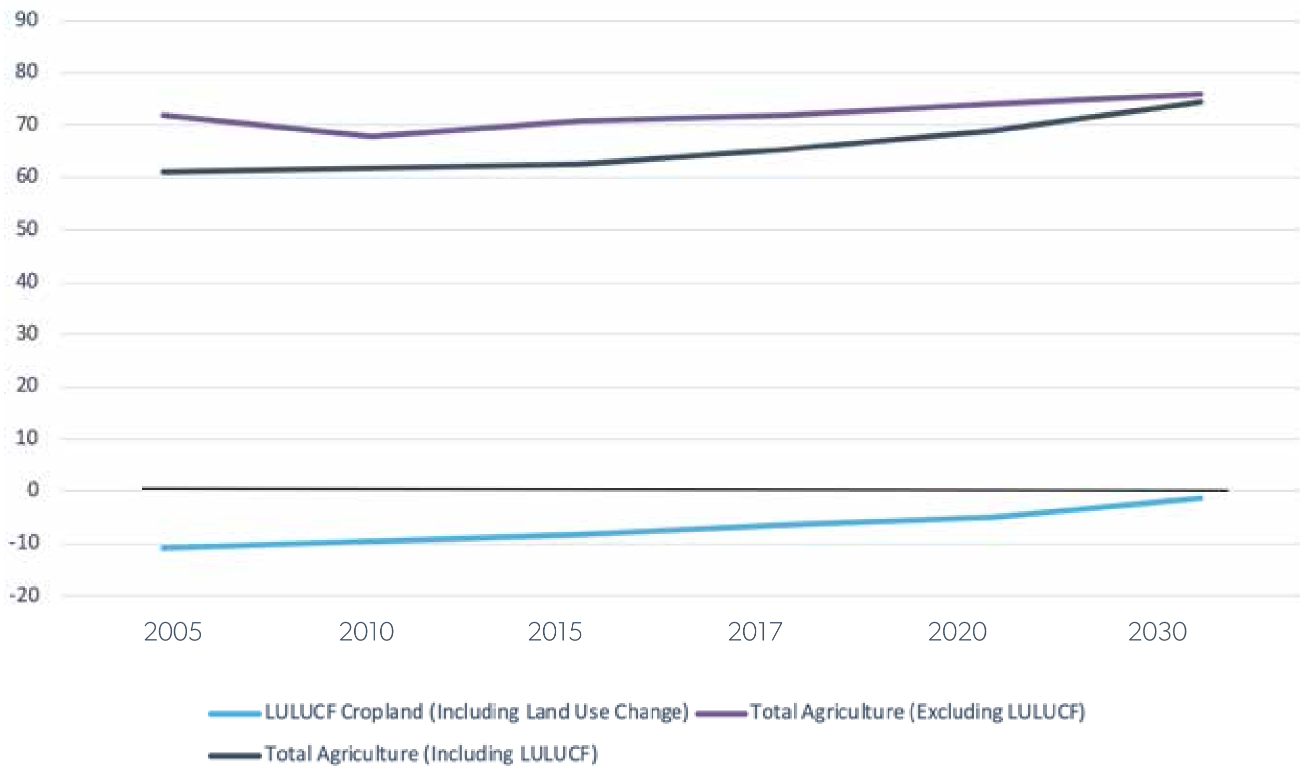


Figure 3. Agriculture Sector Emissions Trends Between 2005 and 2030



Canada's Fourth Biennial Report to the UNFCCC predicts that emissions from the agriculture sector will continue to rise in the coming years. The 'With Measures' scenario[5] predicts that the agriculture sector's emissions will increase to 76 Mt by 2030. Crop production is expected to contribute the largest share of this increase (2 Mt), with animal production contributing an additional 1 Mt and on-farm fuel use remaining relatively stable. The 'With Additional Measures' scenario[6] is slightly more optimistic and predicts emissions from the sector will remain stable and amount to 74 Mt by 2030 (ECCC, 2019a).

The 'A Healthy Environment And A Healthy Economy' climate plan estimated agricultural emissions would rise to 77 Mt by 2030 in their reference case. This updated case builds upon the scenarios presented in the Fourth Biennial Report but takes into account the impact of COVID-19, and revises oil and natural gas production and price assumptions. The climate plan also models the impact of the some of the new measures included within it, such as estimating that nature-based solutions and agricultural measures will reduce emissions by about 10 Mt by 2030 (ECCC, 2020b).

Overall, LULUCF contributions are expected to fluctuate significantly between now and 2030, rising to a peak sequestration potential of 25 Mt and then reducing to 17 Mt by 2030 in the new climate plan's reference case (ECCC, 2020b).

With regard to agriculture in particular, the Fourth Biennial Report predicts that sequestration potential for cropland is predicted to decline significantly, decreasing from 6.6 Mt in 2017 to 1.5 Mt by 2030. This trend is primarily due to a reduction in the sequestration potential of cropland remaining cropland, as emissions from land converted to cropland are expected to be relatively stable and even decline slightly by 2030 (ECCC, 2019a).

Figure 3 below represents the trends discussed above, provides an author calculation of total agricultural sector emissions including LULUCF cropland sequestration, and shows the emissions projections to 2030 from Canada's Fourth Biennial Report to the UNFCCC (ECCC, 2019a).

3.1.2 GHG Emissions Intensity

Canada has also made significant gains in reducing the GHG **emissions intensity** (emissions per unit of GDP) of its agricultural sector. From 1997-2017, the compound annual growth rate for sectoral GHG emissions (excluding on-farm fuel use) was only 0.4%, while real sectoral GDP grew on average by 3% per year – meaning that the sector is already making significant progress towards decoupling economic growth from GHG emissions. To better understand what is driving these trends, SPI analyzed GHG intensity in crop and livestock production separately.

While the overall GHG intensity of crop production has declined by 35% during the 1997-2005 period, there have been some moderate increases since 2005. GHG intensity decreased from 1.26 megatonnes per billion dollars of GDP (Mt/$B GDP) in 1997 to 0.82 Mt/$B GDP in 2005 (its lowest point ever in the referenced time series), due to a number of factors including maintaining forage crops (i.e. perennial crops like alfalfa and hay) over longer periods of time, to sustain the beef herd that was growing due to BSE and associated border closures in the early-mid 2000s.[7] However, the shift from perennial to annual cropping systems – particularly in Eastern Canada – and intensification of fertilizer use has resulted in a slow-but-steady upward trend in the GHG intensity of crop production since 2005 (reaching 0.94 Mt/$B GDP in 2017).

The emissions intensity of the livestock sector has declined by 34% over the sample period from 9.86 Mt/$B GDP in 1997 to 6.46 Mt/$B GDP in 2017. The main drivers of these trends were improved reproductive efficiency, reduced time to slaughter, reductions in the dairy cow herd (facilitated by increased milk production per cow which maintained production levels), and a shift toward high-grain diets enabled earlier marketing in the cattle sector (Clearwater et al., 2016).

While these aggregate trends toward decreased GHG intensity are encouraging, ensuring that agriculture makes further contributions to Canada's 2030 and 2050 emissions targets will require concerted efforts to continue stabilizing and ultimately reduce the GHG emissions associated with crop and livestock production, while enhancing biological carbon sinks on farmland (for further discussion, see section 7 on potential case studies, especially 7.1–7.2 and 7.4–7.5).

3.2 State of Agriculture Inputs

Agriculture both depends on, and impacts, a robust set of natural capital inputs. Here, the report will focus on three key inputs: land productivity, soil health (as measured by soil organic carbon (SOC)), and water quantity.

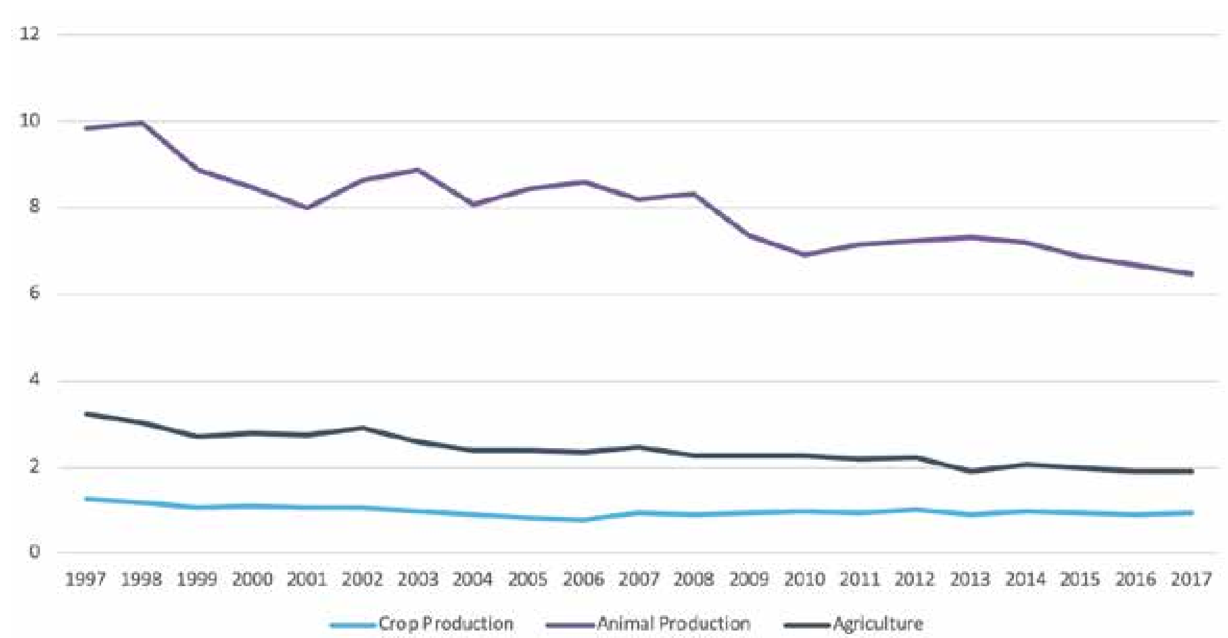
3.2.1 Productivity of Agricultural Land

Land productivity in the agriculture sector has increased on average by 1.58% per year from 1990-2012. In this period, real gross output increased by 1.97% per year, while land input grew only by 0.38%. In 2012, land productivity of crop and animal production was $1,195 per hectare, around 40% higher than 1990 levels (A. Murray, 2016). Production levels of specific crops have also changed dramatically since 1990, with canola, soybean, and corn production increasing by 18 Mt (+600%), 6.4 Mt (+492%), and 7 Mt (+100%), respectively, while wheat production decreased by 2 Mt (-6.3%) compared to 1990 levels (ECCC, 2019b). These changes in productivity could have been supported by the growth in inorganic nitrogen consumption, which has more than doubled since 1990. Approximately 2.6 Mt of nitrogen was consumed in 2018 (ECCC, 2019b).

3.2.2 Soil Health (as measured by SOC)

Although trends vary by region, the health of Canada's agricultural soils (as measured by SOC) have significantly improved on average compared to 1980s levels – mostly due to large increases in SOC sequestered in the Prairies. Changes in

Figure 4. GHG Emissions Intensity from the Agriculture Sector (Mt/$B GDP) Canada, 1997-2017[8]



land management practices such as the adoption of conservation tillage and reduction in summer fallow resulted in agriculture soils changing from a net GHG source of 1.2 Mt of CO_2 per year in 1981 to a net sink in 1997 (ECCC, 2019b)

However, national SOC sequestration rates peaked at 12 Mt in 2006. So while Canada's soils continue to accumulate carbon, the sequestration rate has slowed down. This is attributable to two main factors: the first is that a greater share of soil sinks have reached their equilibrium state, which was partially explained by the saturation of conservation tillage adoption rates (especially in Saskatchewan and Alberta). The second relates to the fact that many farms in Central and Atlantic Canada have shifted from perennial to annual cropping systems. Annual cropping systems typically leave less crop residue on the field, which reduces the amount of organic material available to decompose into SOC (Smuckler, 2019).

In light of these factors, annual GHG removals from agricultural soils have declined since 2006, reaching 6.2 Mt in 2018 (a decrease of nearly 50% relative to 2006 levels) (ECCC, 2019b). In the absence of policy interventions, this downward trend is projected to persist, which puts Canada's soils on track to sequester only 1.5 Mt CO_2 per year by 2030 (ECCC, 2019a).

Relative Soil Organic Carbon (RSOC) is an indicator that estimates how SOC levels are changing by comparing soil-specific baselines against different locations and land-use types. It provides an indication of where some of the greatest opportunities for improving SOC sequestration rates and stocks lie. Although only 9% of Canada's soils fall into the very low RSOC category at the national level, 42% Central Canadian soils and 20% of Atlantic Canadian soils fell into the very low RSOC category, respectively (Smuckler, 2019). As such, there are substantial opportunities to improve the country's SOC levels in Central and Eastern Canada.

3.2.3 Water Use and Consumption

On average, 39.4 billion cubic metres (m^3) of water are withdrawn from Canada's water sources annually (ECCC, 2017), of which only 7.5% (or 2,950 million m^3) are for agricultural purposes (Statistics Canada, 2019). However, the sector consumes around 83% of its annual water withdrawals[9], which is equivalent to half of Canada's annual average national water consumption. Agricultural water consumption increased by 4% between 2005 and 2013, although these trends weren't uniform. Consumption grew by about 29% between 2005 and 2009, but this figure peaked in 2009 and by 2013 consumption had declined by 25% from 2009 levels (ECCC, 2017).

While the majority of Canadian crops are rain-fed, approximately 691,000 ha of land was irrigated in 2018, a slight increase of +0.3% from 2016 (Statistics Canada, 2019), representing approximately 1.1% of all farmland (approximately 64 million hectares). According to the 2018 Agricultural Water Survey, field and forage crops received approximately 96% of irrigation water, while fruit and vegetable crops accounted for 3% and 1%, respectively. Irrigation water was sourced from off-farm sources in 68% of the cases, with on-farm surface water and on-farm groundwater making up the remaining 27% and 3%, respectively (Statistics Canada, 2019).

Although there are irrigation systems in every province, Statistics Canada's 2018 Agricultural Water Survey reported that over 90% of all irrigated land area was located in Saskatchewan, Alberta, and British Columbia (Statistics Canada, 2019). This is because the water supply is not evenly distributed across the country – crop production is dependent on irrigation in drier regions and soil drainage in more humid regions. However, prolonged increases in temperature and shifts in rainfall patterns, like those experienced this summer (2021) in Western Canada and the Prairies, can increase the need for supplemental irrigation. As a result, periodic droughts can cause seasonal soil moisture deficits during crop production, leading to decreases in crop quality and yield (Statistics Canada, 2021a).

Water is also a necessary input for growing livestock and for ensuring dairy production in dairy cattle. A typical dairy cow in the milking stage consumes on average 115 litres of water per day, whereas a typical short-keep feedlot beef cow consumes 41 liters of water (OMAFRA, 2019a). Livestock watering is more common in PEI, Manitoba, and Newfoundland, where it makes up over 42% of on-farm water usage. In other provinces, the average for livestock watering accounts for about 27 to 35% of farm water usage (Beaulieu, Fric & Soulard, 2007). These usage rates do not include water used for on-farm cleaning or sanitization activities.

In order to ensure that water is used efficiently for both crop and livestock production, a number of provinces have developed legislation to manage some aspects of agricultural water usage. For instance, British Columbia has imposed drought-related water use restrictions through their Riparian Areas Protection Act, Ontario has used the Clean Water Act to ensure risk mitigation measures are incorporated in activities potentially impacting drinking water, and PEI has implemented a moratorium on high-capacity wells to protect its supply of groundwater.

3.3 Other Environmental Impacts Associated with Agricultural Production

3.3.1 Water Quality

AAFC's Agri-Environmental Indicators series includes a Water Quality Index that examines a number of trends associated with agricultural water quality (Clearwater et al., 2016). The indicators include the risk of water contamination by pesticides, nitrogen, residual soil nitrogen, phosphorous, and fecal coliforms.

While overall levels of water contamination risk were not considered high on a national scale, risk to water quality nonetheless deteriorated across Canada from 1981-2011 (the most recent years for which data are publicly available). The main contributing factors were increased application of nutrients (both nitrogen and phosphorus) as fertilizer and manure, and increases in pesticide application.

The main trends for indicators within the index are as follows (Clearwater et al., 2016):

- The risk of **water contamination by pesticides** is within an acceptable range. However, the level of risk has increased on 50% of farmland over the past 30 years, with the highest risk recorded in the Prairies in the 2006-2011 period. These trends are primarily driven by the shift from livestock to crop production and the increasing prevalence of conservation tillage practices (which increases susceptibility to weeds and pests).

- **Residual soil nitrogen** (RSN) levels were in the moderate risk class in 2011. Rising use of inorganic nitrogen fertilizer has resulted in RSN values increasing by more than 150% from 1981 to 2011, especially after 1996. In 2011, 28% of farmland was in the high or very high-risk category of RSN – mostly in Quebec, Nova Scotia, and Manitoba.

- In 2011, the majority of farmland (75%) was at a very low **risk of contaminating water with nitrogen (N)**, although the overall level of risk has increased over the past 30 years, with areas in Central and Atlantic Canada being at higher risk. Across Canada, the risk of annual N loss through leaching has increased by 36%, and the N concentration in leached water has increased by a factor of 2.8, which is the product of weather conditions as well as intensified fertilizer. Since 1981, the proportion of farmland in a very low-risk class for N contamination of water has decreased from 88% to 75%.

- The index for the **risk of water contamination with phosphorous (P)** deteriorated from good to moderate in 2011. The risk of P contamination increased in 50% of watersheds over the 1981-2011 period due to the increased use of mineral fertilizer and greater concentration of livestock production. There was a dramatic increase in risk from 2006 and 2011 due to atypically high levels of run-off in some areas of the Prairies in 2011, which flushed large quantities of built-up soil-bound phosphorous into surface waters.

3.3.2 Biodiversity

AAFC's Biodiversity Compound Index provides an understanding of how Canada's farmland is performing in terms of its capacity for maintaining biodiversity. It is a weighted average of two main indicators: The Soil Cover and Wildlife Habitat Capacity (WHC), respectively. Soil cover has ramifications for many dimensions of environmental quality and promotes biodiversity through its impact on wildlife habitat, water quality, and air quality. By contrast, the WHC specifically describes farmland's ability to support species diversity. When their original habitat is removed, the likelihood of recovery for species impacted by land-use changes is relatively low (Clearwater et al., 2016).

Figure 5. Changes in Water Quality Compound Index, 1981-2011[10]

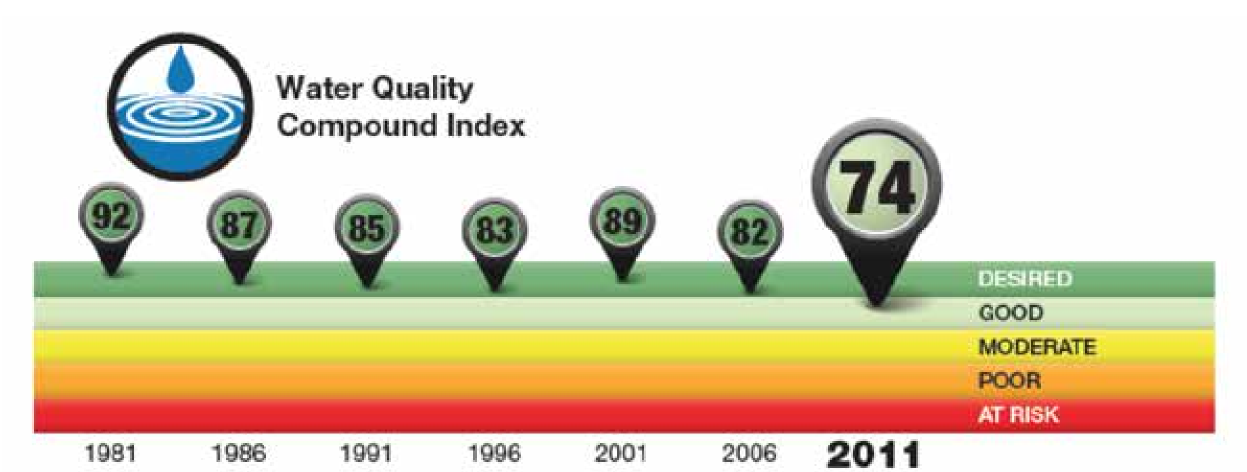
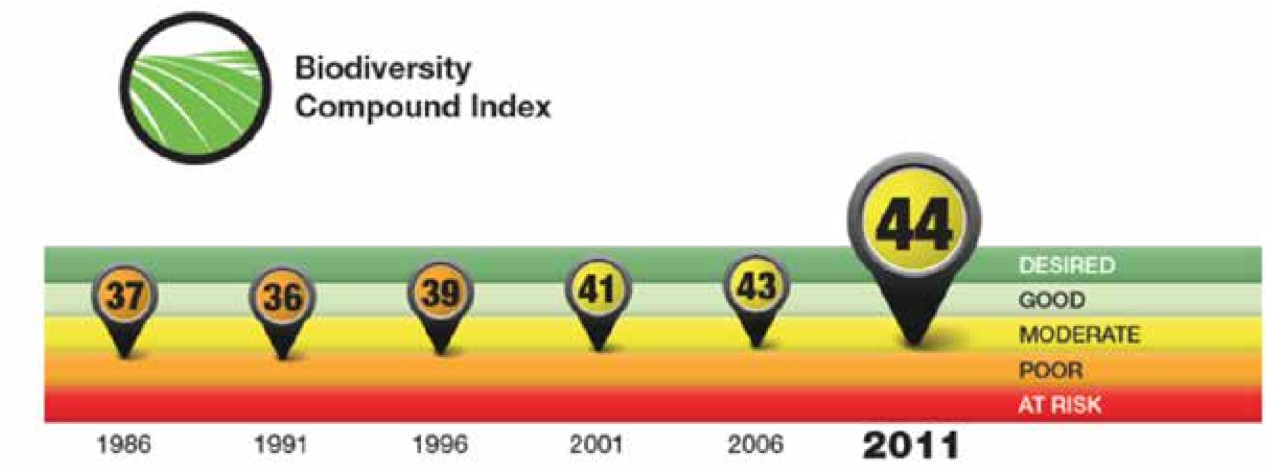


Figure 6. Changes in Biodiversity Compound Index, 1986-2011[11]



Agriculture threatens biodiversity both through agricultural intensification more broadly (e.g. increased tillage and manufactured input use, increased simplification of cropping systems), and as well as through habitat loss and non-point source pollution (McCune et al., 2019). As such, when assessing the state of Canada's biodiversity in agricultural landscapes, other indicators such as agricultural runoff from pesticides, nitrogen, and phosphorous should be kept in mind (however, since these trends were summarized in section 3.3.1, so they are not reiterated here).

The Biodiversity Compound Index currently ranks in the moderate risk class in Canada. Overall, the index has improved consistently over the 1986 and 2011 period, largely due to enhanced soil cover from changes in tillage practices.

The trends for the two composite biodiversity indicators are as follows (Clearwater et al., 2016):

- The **soil cover index** has increased steadily in the 1981-2011 period, reaching a moderate level in 2011. The adoption of no-tillage and reduced tillage from the early 1990s are the major contributing factors to these improvements, as they reduce the amount of time the soil spends exposed to erosion and increases crop residue, compared to summer fallow. The combination of reduced tillage practices and reduction of summer fallow, mainly in the Prairie regions, resulted in a 7.6% increase in Canada's overall soil cover over 30 years. Some other regions of Canada – specifically in eastern Ontario, western Quebec, and PEI – have performed less favourably on this metric, decreasing by about 10 soil cover days on average (although these setbacks are more than offset by gains in the Prairies). The adverse trends in these Eastern Canadian provinces are due to a shift away from forage and pasture lands toward annual cropping systems.
- The **WHC** index was stable in the 1986-1996 period on 97% of Canadian farmland. However, the index showed a decline between 1996 and 2011, primarily due to the intensification of farming and the loss of natural and semi-natural land (Clearwater et al., 2016). This indicator was updated in 2017 but has experienced little change, with 95% of land remaining stable since its last evaluation in 2011. Minute increases (+3.4%) in WHC were recorded from 2011-2017 – mainly in the Prairie regions – while similar rates of decline (- 3.1%) were observed across Canada, mainly in British Columbia, Manitoba, Ontario, and Quebec (ECCC, 2018).

3.3.3 Food Loss and Food Waste (and associated GHG emissions)

Food loss and food waste (FLW) is an indicator of potential efficiency losses in the agriculture and agri-food system, since it imposes economic and environmental costs to producers, industry, and to society as a whole. Some of these inefficiencies would be cost-effective to reduce or avoid with the right incentives and infrastructure in place. Total annual avoidable and unavoidable FLW in Canada's food chain is estimated to be 35.5 Mt, of which 32% (11.2 Mt) is estimated to be avoidable. The value of avoidable FLW from all sectors combined has been estimated to be as high as $49.5 billion, or 3% of Canada's GDP in 2016 (Nikkel et al., 2019).

An estimated 71% of FLW occurs during primary production, processing, and manufacturing (Nikkel et al., 2019). Some estimates suggest that up to 6% of the FLW occurring in primary production, 20% in food processing, and 23% in food manufacturing could be avoided. The economic costs of avoidable FLW in these components of the value chain have been estimated to be as high as $2.88 (primary production), $9.77 (processing), and $11.17 billion (manufacturing), respectively. This is equal to 21% of Canada's GDP for agriculture and agri-food in 2016.[12] While the values cited in this paragraph and the preceding one are likely to be upper-bound estimates of economic costs, they do illustrate that both the environmental and social costs are substantial.

Using a life cycle estimate including agricultural production, post-harvest handling and storage, food processing, distribution, consumption, and end-of-life activities, FLW was found to account for around 60% of the food industry's GHG footprint, when comparing total CO_2 equivalents emitted from food system inputs to total CO_2 equivalents emitted from FLW. Food system inputs include estimated emissions from production, manufacturing, processing, transportation (from vehicles and distance traveled), and energy consumption in retail, households, hotels, restaurants, and institutions. Total GHG emissions from FLW in Canada are estimated at 56.5 Mt of CO_2 equivalent, of which 22.2 Mt of CO_2 equivalent is avoidable (Nikkel et al., 2019).

3.4. Environmental Costs of Agricultural Externalities

In addition to food production, agricultural activities generate environmental costs and benefits to society that have economic value. For instance, GHG emissions produced by agricultural activities, and the water quality issues mentioned previously in this section impact human health, aquatic life, and cost societies through health care system costs and water treatment costs. These costs are not accounted for in farmers' production decisions, since they are not incurred directly by farmers. Understanding the non-market costs and benefits of agricultural activities to broader society (technically referred to as 'externalities') can help inform the design of policies that enhance efficiency and social welfare.

A recent publication from the Canadian Agri-Food Policy Institute (Skolrud et al., 2020) provides some illustrative estimates of the costs and benefits of three different environmental externalities in Canadian agriculture from 1981 to 2011.[14] Using the Government of Canada's 2016 central value estimate for the social cost of carbon ($39/tonne at 2012 prices), they find that the indirect costs associated with GHG emissions in Canada's agriculture systems dropped from $1.7 billion in 1981 to $1.5 billion in 2011. The externalities associated with ammonia (NH_3) emissions increased by 14% during the sample period reaching $1.5 billion in 2011, whereas the costs associated with agricultural Particulate Matter (PM) emissions dropped by 60% during this period (due to decreases in the PM index over the same time period), standing at $ 1.6 billion in 2011.

As demonstrated in the discussion in section 3.3.1, water quality has deteriorated in Canada between 1981-2011. The reduction in water quality has imposed significant costs on society. The cost of water pollution from all pollutant sources increased from $ 1.4 billion in 1981 to around $2 billion in 2011. N contamination followed by pesticides were the main factors behind these escalating external costs. The environmental costs of water

Table 1. Negative, positive, and net environmental externalities over time for the Western and Central Provinces (millions of 2012 dollars) [13]

	Negative externalities							
Externality	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**	**Percentage change (1981-2011)**
GHG[6]	1,679	1,628	1,609	1,768	1,659	1,628	1,503	-10%
Ammonia (NH_3)	1,319					1,696	1,499	14%
PM	3,989	3,651	3,278	2,986	2,544	2,061	1,601	-60%
N-water	706	857	806	810	942	981	985	39%
P-water	48	52	52	54	57	56	55	14%
Pest-water	539	592	655	701	754	813	869	61%
Coliform-water	43	41	42	42	42	44	42	-3%
Soil erosion	2,843	2,950	2,828	2,733	2,637	2,226	2,049	-28%
Wildlife/biodiversity	286	274	266	271	266	264	253	-12%
Total negative	**11,452**	**10,043**	**9,535**	**9,365**	**8,901**	**9,768**	**8,856**	**-23%**
	Positive externalities							
Externality	**1981**	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**	**Percentage change (1981-2011)**
Wildlife habitat	38	36	35	35	35	34	32	-6%
Landscape aesthetics	4,607	4,739	4,739	4,748	4,705	4,693	4,506	-4%
Total positive	**4,644**	**4,774**	**4,773**	**4,783**	**4,739**	**4,728**	**4,539**	**-2%**
Total net	**-6,808**	**-5,269**	**-4,762**	**-4,582**	**-4,162**	**-5,040**	**-4,318**	**-37%**

contamination by nitrogen rose by 40% between 1981-2011, reaching $985 million in 2011. The external costs of water pollution from pesticides also increased by 60% over the same period, costing $870 million in 2011 (Skolrud et al., 2020).

When it comes to soil erosion, environmental costs have been declining for all regions except Quebec (for reasons discussed in section 3.2.2) with costs declining by 28% from 1981 to 2011 – from $2.84 billion to $2.05 billion, respectively. Western Canada was able to reduce soil erosion costs by over 30%, while Central Canada performed less favourably - only reducing their soil erosion costs by about 12% over the same period (Skolrud et al., 2020).

The total cost of biodiversity and wildlife habitat damage declined from $286 million in 1981 to $253 million in 2011, reflecting a 12% reduction. Despite the aggregate reduction at the national scale, this cost element increased by 1.3% in Western Canada whereas it declined by 14% in Central Canada (Skolrud et al., 2020).

As mentioned previously, agriculture also provides some positive environmental externalities for Canadians, including providing wildlife habitat for certain species, as well as landscape aesthetics. Positive impacts from biodiversity and wildlife habitat ranged between $32-38 billion in the 1981-2011 period. Central Canada accounted for 90% of the wildlife benefits with only 10% of wildlife and biodiversity benefits stemming from Western Canada. However, this trend is reversed in terms of landscape aesthetics with benefits in the range of $4-5 billion, mostly from Western Canadian landscapes.

As can be seen from Table 1 on page 13, accounting for all the above-mentioned environmental costs of agriculture, the total external costs from agriculture fell by a quarter over the study time period – from $11.5 billion in 1981 to $9 billion in 2011. When considering both negative and positive externalities from agricultural activities, these activities imposed $4.3 billion in net costs to Canadian society in 2011. Although the net environmental costs have declined by approximately 37% from 1981 levels, the environmental costs to Canadian society are still substantial – equivalent to 17% of GDP for primary agriculture[15], or $324[16] in net environmental costs per household (mostly in the form of GHGs, air and water pollution).

Although these valuation estimates should be interpreted as illustrative (providing a 'ballpark estimate' of the value of these externalities), these findings nonetheless reinforce that much more needs to be done to enhance the sustainability of Canada's agricultural sector and that well-designed policies which account for and address these costs can enhance economic efficiency and the welfare of Canadians.

3.5 Implications

The scale of the challenge to decouple economic growth in the agriculture and agri-food sector from environmental impacts such as GHG emissions, deteriorating water quality, and biodiversity decline, calls for concerted efforts from policymakers to ensure that the lion's share of economic growth in the sector comes from increases in value-added crops, or from the production of higher-value crops, rather than simply increasing overall production. It also calls for the design of new policies to further reduce the environmental impacts of primary agriculture and potentially create new revenue streams for producers to incentivize practice change.

Although the sector has made significant progress in terms of decoupling GHG emissions from production, notably in the livestock industry, there is a critical need for policies to accelerate this trend across the entire sector so that they are in line with Canada's 2030 Nationally Determined Contribution and its 2050 net-zero GHG emissions targets. While there are significant opportunities to further reduce livestock sector emissions, equal attention must be paid to GHG mitigation policies for crop production, given the recent increases in emissions intensity from the latter. Moreover, the sector's track record on other dimensions of environmental performance is far more mixed (e.g. several dimensions of water quality, habitat suitability on farmland), and climate change will likely exacerbate these issues in the future.

These challenges make clear that achieving the ambition of decoupling economic growth and environmental impacts will require identifying key opportunities for advancing economic and environmental improvements. As sections 6 and 7 will show, this will require building an agri-food innovation system that encourages the development, commercialization, and diffusion of novel technologies (section 7.3, 7.4, and 7.6); stronger economic incentives for improving environmental performance from food producers, processors and manufacturers (sections 6.2-6.5; section 7); as well as behavioural interventions to encourage BMP adoption on farms, and change social norms around food production and consumption (section 6.1).

Finally, policymakers will need to ensure that future agri-environmental policies do not unintentionally trade-off one set of environmental gains for another. The discussions of the trends driving the sectors changing environmental performance provide some compelling examples of this dynamic: for instance, the reduction in herd size and shift to high-grain diets reduced GHG emissions from the livestock sector – but at the same time, this contributed to a number of the negative environmental impacts associated with crop production over this same period, including conversion of permanent pasture to crop production (leading to increased GHG emissions and negative impacts on biodiversity), and increased pesticide applications (with negative impacts for biodiversity and water quality). Similar trends hold in relation to the link between the increased adoption of conservation tillage and increased pesticide applications in the Prairies. Future policies need to be designed with these potential trade-offs and perverse incentives in mind, with an eye for managing 'hard choices' and, where possible, improving multiple dimensions of economic and environmental performance simultaneously.

4. ASSESSMENT OF CANADA'S AGRICULTURE & AGRI-FOOD SECTOR

Canada has what it takes to seize the export growth opportunity while minimizing environmental impacts, but it will not happen on its own – well-designed policies that build off Canada's competitive advantage and address existing challenges will be needed. This section sets the stage for the rest of the report by providing a synoptic overview of Canada's economic and environmental **strengths, weaknesses, opportunities, and threats** in relation to the export growth targets and a sustainable 'Canadian Brand'. Sections 5 and 6 will then discuss the policies and systems changes needed to realize the environmental dimension of this opportunity.

Canada's strengths lie in five key areas: natural resources, substantial knowledge base and agri-food processing clusters, an excellent food safety inspection regime and reputation for food safety, strong government support for agricultural research, as well as a relatively low GHG footprint for key commodities such as beef, dairy, eggs, and chicken.

4.1 Strengths

Canada's strengths lie in five key areas: natural resources, substantial knowledge base and agri-food processing clusters, an excellent food safety inspection regime and reputation for food safety, strong government support for agricultural research, as well as a relatively low GHG footprint for key commodities such as beef, dairy, eggs, and chicken compared to peer countries.

Canada's abundant natural resources gives us a compelling head start in the race to keep up with the forecasted growth in global food demand. Canada ranks seventh in the world for total area of arable land (FAOSTAT, 2016), Canada's rivers discharge close to 9% of the world's renewable water supply (NRCan, 2017), and Canada also ranks favourably in terms of water stress among peer countries such as the United States (US), the United Kingdom (UK), Australia, and some European Union (EU) countries (Gassert et al., 2013).

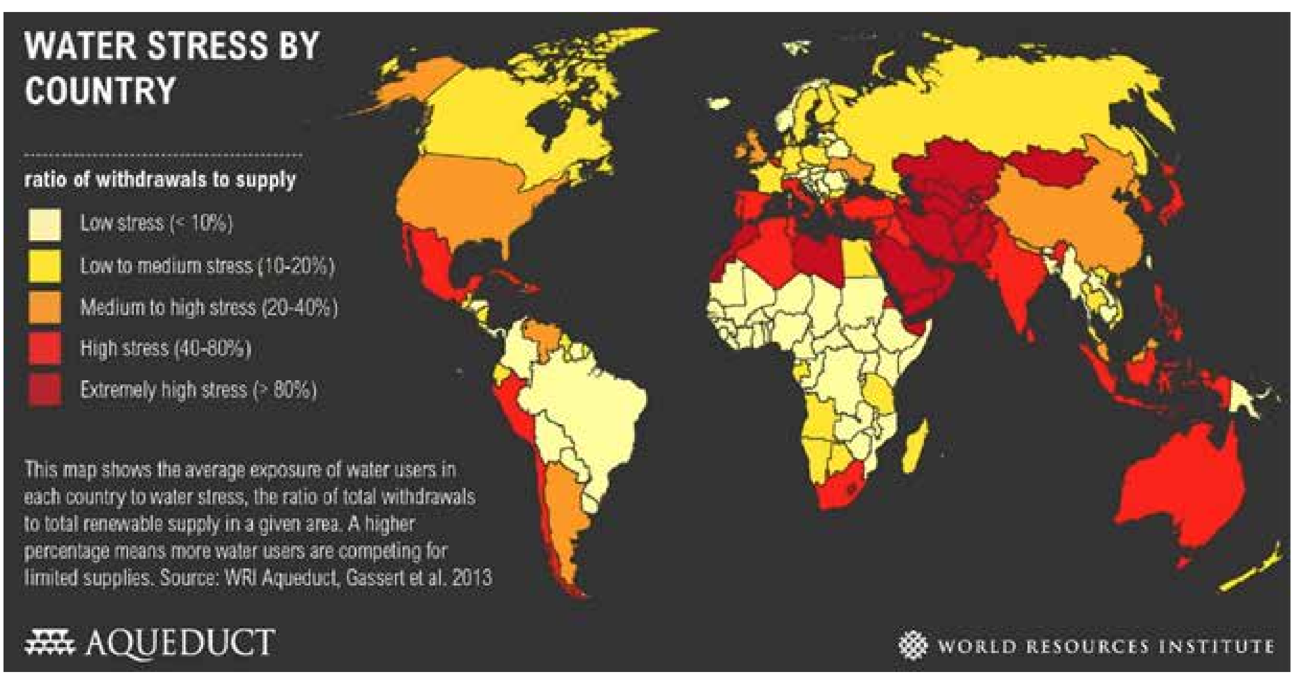
Canada's technologically sophisticated workforce and strong agri-food processing sector represents another area of strength for Canada. Canada has important agri-food clusters in Ontario, Quebec, British Columbia, and the Prairie provinces providing processed food products to domestic and global markets. Some of the most prominent processed agri-food products in Canada include processed meats, bread and bakery items, and confectionery products; the Prairie provinces also have an established protein processing cluster. Additionally, agri-food processing in Canada is relatively low cost compared to peer countries. When comparing the aggregate costs of doing business across G7 countries, Canada presents the lowest cost of all its G7 counterparts (GAC, 2017b).

Canada's strict food regulation and inspection practices also provide strength to its agri-food processing sector. Canada has a well-established reputation for producing safe, high-quality, and nutritious food, which allows any processed agri-food products coming out of Canada to share that distinction. Leveraging the brand that Canada has established adds a layer of differentiation to processed agri-food products and promotes these high domestic standards on the global export market (GAC, 2017b).

Canada also has a strong profile in terms of public agri-food R&D, encompassing multiple universities, and research agencies. Canada's researchers have been a valuable innovation pioneer for commodities such as canola, pulses, and chilled pork (ACEG, 2017) and Canada ranks first when compared to the top nine agricultural exporting nations in terms of public investment in R&D on agricultural science[17] (OECD, 2019a).

The federal government provides strong support for agricultural research. Agriculture and Agri-Food Canada (AAFC) was ranked among the top three Canadian federal departments in terms of spending on research and development in 2018/2019. Combining the National Research Council, AAFC, and the Department of National Defence constitutes over 60% of Canada's federal research and development spending (Statistics Canada, 2020). For context, AAFC's Departmental Plan earmarks over $615 million in spending for agricultural science and innovation in the 2021-22 fiscal year alone, which will help further strengthen production and increase the sector's capacity to adopt new technology or practices (AAFC, 2021d).

Figure 7. Water Stress by Country[18]



AAFC also supports the adoption of sustainable practices through programs like the Agricultural Climate Solutions program and the On-Farm Climate Action Fund, as well as the jointly funded federal-provincial-territorial cost-share programs under the Canadian Agricultural Partnership (see section 5 for discussion). Recent announcements made in Budget 2021, like the reinvigorated Agricultural Clean Technology program, have dedicated additional federal spending to improving the environmental sustainability of Canadian agriculture by focussing on farm-level solutions to climate change.

Canada's agricultural sector is also built on a more solid economic foundation in that it is far less subsidized per unit of GDP contribution than other large agricultural exporters. In 2019, Canada provided agricultural subsidies equivalent 8.84% of gross farm receipts — the second-lowest level after Brazil of the top 9 global exporters of agricultural products (OECD, 2021). Meanwhile, in the US in 2019, the government provided subsidies equal to 12.1% of gross farm receipts, while the EU average for subsidies as a percent of gross farm receipts was 19.02% (OECD, 2021).

Finally, Canada ranks fairly well on lifecycle GHG emissions for select commodities compared to global and OECD country averages. Canada outperforms the global and OECD average for beef (Gerber et al., 2013; Legesse et al., 2016) and eggs (FAO, 2019), performs better than the global average and is at par with the OECD average for dairy (FAO, 2019), and performs better than the global average for chicken (FAO, 2019).[19]

4.2 Weaknesses

Although Canada's agriculture and agri-food sector brings many strengths to the table, it is still facing challenges on several fronts. These challenges have direct implications for Canada's competitiveness – Canada ranked 14th out of 36 OECD countries on its Global Competitiveness Index in 2017-2018 (World Economic Forum, 2019). Challenges in the agriculture and agri-food sector include difficulties moving up the value chain, low shares of private sector investment and R & D, few large-scale firms, transportation inefficiencies, and regulatory barriers.

Although Canada has several strong agri-food processing clusters, and there are clear opportunities for Canada to move up the value chain (as discussed in section 2), Canada's agri-food sector still only processes 50% of its primary agricultural products. Moreover, many firms are struggling to move up the value chain due to underinvestment in the agri-food sector and associated transportation network issues (ACEG, 2017). Canada's food manufacturing sector R&D, as a percentage of sales, is only 0.2%, and this figure has dropped by nearly one-quarter since 2008.

Similarly, the share of food manufacturing investment in machinery and equipment as a percentage of sales has fallen from 2.3% in 1998 to 1.2% in 2016 (ISED, 2018). Thus, instead of relying solely on the export of raw materials, Canada should strengthen its processing capacity and increase its margins through value-added food products.

For comparison, countries like United States and France reinvest about 0.6% of sales into agri-food R&D, triple the Canadian value mentioned earlier (0.2%) (ISED, 2018). While global leaders in agricultural technology, like the Netherlands, see food & beverage firms, and agricultural companies reinvest 2.72% and 1.56% respectively of the sector's total added value to the economy (OECD, 2019a).

Challenges in the agriculture and agri-food sector include difficulties moving up the value chain, low shares of private sector investment and R&D, few large-scale firms, transportation inefficiencies, and regulatory barriers.

The sector also has challenges with low levels of private sector investment. For instance, when comparing outstanding farm debt classified by lender, 36% of all outstanding debt was lent by a federal or provincial agency, while only 10% was lent by a private individual or supply company. Chartered banks made up the other main lending agency, with a total of 35% of outstanding debt (Statistics Canada, 2021b). Factors contributing to the private sector's under-investment include the time gap between investment and commercialization and a lack of incentives for the private sector to invest in agricultural technology. Research suggests that this trend could be reversed by offering special tax provisions for potential agri-investors or increasing the incentive to innovate by enforcing intellectual property rights for new agricultural products or technologies (AIC, 2017).

Many of the existing private initiatives are backstopped by or partially funded in cooperation with the government, such as the Canadian Agricultural Loans Act (CALA) or the Commodity Loan Guarantee Program in Ontario. Enhancing these types of public-private partnership programs could increase funding for both scientific research and applied research projects that would bring technology closer to commercialization (AIC, 2017).

In addition to low shares of private investment, the sector also suffers from a comparatively small share of private sector R&D. For instance, a report by the Agriculture Institute of Canada (AIC) comparing the difference between public and private investments noted that the private sector invested approximately $73 million in primary agriculture R&D, while federal and provincial sources invested $649 million in R&D for both primary agriculture and food processing combined (AIC, 2017). To put this in perspective, the private sectors' share of agriculture R&D in Canada is only 11%, while its share in the US is 73% (RBC, 2019).

Canada also struggles to create large-scale enterprises in both primary agriculture and agri-food, as about 94% of food and beverage processing facilities in Canada fall into the 'small' category and have less than 99 employees. The small size of the majority of agri-food businesses limits them from achieving economies of scale and from adopting new technologies – since novel technology adoption primarily occurs within large firms (ISED, 2018).

At the farm-level, up to 83 cents from every dollar in sales is consumed by farm expenses, it is especially difficult for farmers to invest in new equipment without subsidies or private sector support (RBC, 2019). Moreover, this capital-intensive structure can also pose barriers to entry for young and new farmers, who do not have the capital to cover the high operating costs, let alone spend on technological innovation (RBC, 2019). Despite the availability of support programs for young and new farmers from Farm Credit Canada and other organizations, capital-intensity and low credit availability act as a deterrent for new entrants in the Canadian farm system (RBC, 2019).

Transportation inefficiencies also pose challenges to the efficient integration of the food-processing supply chain throughout the country. Transportation networks also play a crucial role in moving goods to global markets, which has implications for farmers' income risk. In 2013-2014, transportation inefficiencies created backlogs to shipping Canada's grain harvest, costing farmers around $6.5 billion in total between 2013 and 2015 (ISED, 2018). New programs, such as AAFC's Local Food Infrastructure Fund, could help reduce some of these inefficiencies by providing funding to support the transition to a more local, food-secure future via investments in transportation, storage, and food processing infrastructure (AAFC, 2021b).

Regulatory barriers are another critical challenge facing the agriculture and agri-food sector and recent reports have called for a modernization of the Grain Act and the process for achieving approvals on new technologies (ISED, 2018). First and foremost, the lengthy processing time for permits and approvals has been identified as stifling innovation in the sector. For example, the plants with novel trait (PNT) regulations have been identified as a significant barrier to innovation in the domestic plant breeding sector (Smyth, Gleim & Lubieniechi, 2020). Furthermore, surveys on the bioproduct industry have shown that the cost of complying with and gaining regulatory approval as well as the length of time required to receive regulatory approval have been a significant barrier for bioproduct organizations in Canada (Sparling, Cheney & Cranfield, 2012).

Finally, the agriculture and agri-food sector also faces a number of challenges in relation to environmental sustainability, including significant levels of food loss and waste (potentially leading to foregone opportunities for developing novel food, biofertilizer, or bioenergy products – see section 7.6 discussion), several deteriorating water quality indicators (e.g. phosphorous and pesticide risks), as well as a loss of wildlife and biodiversity on farmland. Canada also has higher lifecycle GHG emissions for cereals (in the aggregate, trends for individual cereal crops may vary) and for pigs (FAO, 2019).

4.3 Opportunities

Canada's opportunities for increasing export growth and domestic sales lie in two key areas: harnessing a national food brand ('Canadian Brand'), as well as a strong production profile in the face of future climate change.

Leveraging a strong 'Canadian Brand' on the international stage could play a key role in accessing new export markets. Communicating and documenting credible stewardship claims, such as 'sustainably sourced' can potentially attract higher prices on export markets and induce the development of novel intellectual property. The added value of verified stewardship claims helps differentiate Canadian products from other exporters and draws attention to the sustainability of the 'Canadian Brand' (Canada 2020, 2019).

For instance, in 2019 Maple Leaf Foods announced that they were the world's first major food company to become carbon neutral. Maple Leaf Foods now affixes a certification stamp on all its products to communicate to consumers that they are committed to environmental stewardship and reducing their impact on the planet (Maple Leaf Foods, 2019). More broadly, studies have shown that consumers are engaged in the sustainable food movement. The 2019 Pricewaterhouse Coopers Consumer Insight Survey revealed that 33% of Canadian consumers surveyed attempted to buy products that they believed were sustainable in order to protect the environment, while 28% indicated they bought from brands that promoted sustainable practices. Furthermore, 33% were willing to pay a price premium for ethical and environmental considerations and 34% were willing to pay a premium to brands that were known for their environmental practices (PwC Canada, 2019).

Canadians are not alone in this shift, consumer preference studies in the EU reveal that 47% and 17% of consumers pay 'some' or 'a lot' of attention, respectively, to the impact their food choices have on the environment. Further to that point, 59% of EU consumers in the sample stated that sustainability concerns have at least 'some' influence over their eating habits (BEUC, 2020). These consumer preferences have also translated into changes in consumption patterns. In the 2016-2017 period, retailers in the EU observed a 12% increase in total food sales and an 18% increase in sustainable food sales (ITC, 2019). These trends emphasize the importance of upholding sustainability standards in the food sector, if Canada aspires to grow consumption domestically and gain access to and expand its share of exports on the global market.

To realize this opportunity, Canada should consider a new national data strategy, which would support collaborative branding efforts led by governments, industry, and ENGOs while also collecting information on these initiatives for reporting purposes (Canada 2020, 2019). In addition to a new data strategy, policymakers and industry should consider developing or adopting a credible performance index to assess compliance with Environment, Social and Governance (ESG) criteria.[20] One such performance index is being developed by a group of public and private partners led by McInnes (2021). The aim is to develop an agri-food sustainability performance index to benchmark the sustainability of Canadian agriculture, with the hopes of introducing a preliminary version of the index in 2022. This new performance index could be used to set standards for trade products and processes – furthering the differentiation of the 'Canadian Brand' on the international stage (Canada 2020, 2019).

New techniques also provide an opportunity for Canada to produce low and even carbon negative agricultural commodities. Alternative cropping methods with a focus on soil sequestration techniques and the rotational cropping of nitrogen-fixing legumes have demonstrated the ability to cultivate pulses, & wheat in a carbon-negative fashion (Gan et al., 2014). Rotationally cropping legumes and pulses have also demonstrated 20% reductions in the emissions intensity of canola production (though with significant reductions in synthetic fertilizer application) (Macwilliam et al., 2018). Increasing the production of nitrogen-fixing pulses in Canada thus provides an opportunity to reduce the emissions intensity of commodity crops through intercropping, and subsequent reduction in N fertilizer requirements.

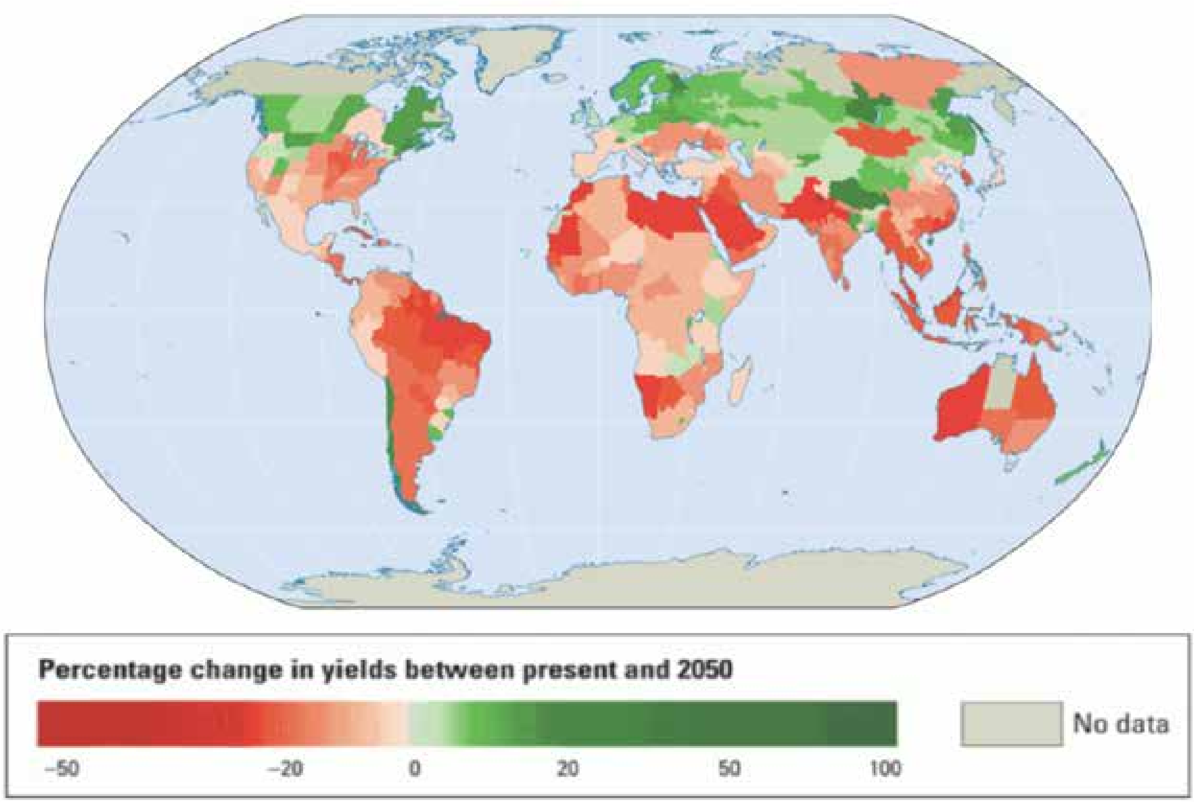
Building off the strong natural resource base, Canada also has a significant opportunity to sequester carbon through a variety of on-farm practices. A recent report by Nature United (Drever et al., 2021) highlights that by 2030 Canada has the potential to

By 2030 Canada has the potential to mitigate about 57 Mt of CO_2e through a variety of natural climate solution pathways. About 23 Mt of this mitigation is available at or below an abatement cost of \$50 per tonne of CO_2e.

mitigate about 57 Mt of CO_2e through a variety of natural climate solution pathways. About 23 Mt of this mitigation is available at or below an abatement cost of \$50 per tonne of CO_2e; however, only about 6 Mt is available at or below \$10 per tonne of CO_2e. Specific pathways are discussed in more detail in section 5 in the Carbon Offsets section.

Canada's geographic location is also projected to provide new opportunities for agricultural production in light of future climate change. One IPCC report forecasts improved conditions for food production in countries located at mid-to-high latitudes due to longer and warmer growing seasons (IPCC, 2017). The changing potential for crop production could open up new revenue streams or expand existing ones for Canadian farmers. For example, areas

Figure 8. Global change in yield between present and 2050[21]



of British Columbia, especially near Prince George, and areas of northern Alberta may become more well-suited to spring seeded grain crops, canola, and other previously unsuited crops, while soybean production may be able to extend into northern parts of Saskatchewan and corn production may become more favourable in the Prairies under future climate conditions (Campbell et al., 2014).

The World Resources Institute also predicts that Canada's crop yields in 2050 will be higher than current levels, under a 3°C warming scenario, which will place Canada's agri-food sector in a comparatively strong production position under future climate change (Searchinger et al., 2019).[22] However, despite the potential for increased yields and the opportunity to grow more diverse crops, there are also a number of associated risks with the changing climate – discussed in the threats section below.

4.4 Threats

A number of near-term and long-term threats also loom on the horizon for the sector, including long-term climate risks for producers, threats linked to trade policy (such as a lack of trade agreements with key markets), as well as the effects of COVID 19 and its aftermath in the agriculture and agri-food sector, especially in terms of import substitution both within Canada and abroad.

Although a longer, warmer growing season under future climate change does present a number of revenue growth opportunities for the sector, there are also a number of climate-related risks to consider as well.

Although a longer, warmer growing season under future climate change does present a number of revenue growth opportunities for the sector, there are also a number of climate-related risks to consider as well. Primarily, changing climatic conditions will distort the current growing season, which will impact the suitability of existing agricultural land to grow certain crops. More generally, the new climate conditions will likely induce more catastrophic weather events, as well as introduce new, more diverse pest populations to control (Campbell et al., 2014). Extreme weather events have the potential to destroy an entire season of crop production, underscoring the urgency of measures to adapt to conditions like late frosts or extended droughts, and the need to develop novel insurance products. New invasive pest species can drive up the cost of pest control and dramatically impact yield levels. This trend could be exacerbated if invasive pest species cause novel or unanticipated impacts on Canadian farm ecosystems, where adaptation solutions are not readily available.

A number of threats related to trade policy could also pose challenges to Canada meeting its export growth targets. In particular, Canada lacks trade agreements with some of the highest potential markets for agri-food exports such as China, India, and Japan. China is the single largest importer of soybeans (one of Canada's most popular field crops), and India has huge potential to be a market for Canadian pulses (Farm Credit Canada, 2019). Without preferential trade agreements in place, Canada risks losing out on these export growth opportunities.

Not only is Canada lagging behind in terms of preferential trade agreements, but there are a host of new countries vying for a portion of the growing export demand. Developing countries are some of Canada's biggest competitors in this space. Between 2000 and 2018, developing countries increased their share of agricultural exports by about 8% globally, with notable increases in export share coming from countries in the southern hemisphere (Glauber, 2020). If Canada is not able to establish preferential trade agreements, then it will have fewer opportunities to seize this explosion in demand over the next 30 years.

Specific agricultural trade policies among Canada's competitors such as export subsidies, import tariffs, and export taxes are also creating challenges for the nation's agriculture sector. For instance, India offers huge export potential for Canada; however, high import tariffs and significantly variability in trade volumes due to the price sensitivity of Indian consumers limits the ability to expand exports into this market (CAFTA, n.d.). Competition from countries that highly subsidize their agriculture and agri-food products potentially threaten Canada's competitive advantage. However, subsidies also reduce the incentive to innovate, as it allows countries to establish market share without motivating any improvements to actual practices. For these reasons (and many others), SPI does not recommend that Canada increase protectionist measures for its own agricultural products.

Another major threat relates to the risk of poor environmental performance affecting Canada's ability to access certain export markets. At the macro level, international trade agreements such as the aforementioned Trans-Pacific Partnership and CETA have incorporated enforceable environmental provisions that, if not upheld, could severely limit Canada's access to the global export market. These types of provisions promote the tethering of market access to sustainable development (UNCTAD, 2016). Moreover, studies of consumer behaviour in wealthier export markets, such as the European Union, have shown that consumers explicitly consider the environmental impacts of their food purchases and adjust their buying habits to at least some extent (ITC, 2019; BEUC, 2020).

Canada's poor comparative rates of private R&D investment by its agri-food firms also threatens to reduce the impact from what is supposed to be national comparative advantage, Canada's higher rate of Public Agricultural R&D funding (ISED, 2018). Canada's low capital expenditure on new equipment by agri-food firms, not only shrinks the domestic market for high-value agricultural technology, but also creates an environment where firms that are supported by government investment de-camp to other jurisdictions to attain an initial customer base. Without a strong uptake of novel agricultural technology by the Canadian agricultural sector, Canada's high rates of public R&D expenditures could become a liability, subsidizing the growth of agricultural technology economies in non-Canadian jurisdictions. Increasing private investments by Canadian agri-food companies in R&D and equipment will be critical to enabling Canada to capture a higher share of the agricultural technology market.

The final and most recent threat for the agricultural sector is the 'new normal' wrought by COVID-19 and its aftermath. During the 2019 growing season, producers and agribusinesses struggled with shortages of temporary foreign workers, product waste, issues with cash flow, and disruptions to supply chains. More recent analysis by Weersink et al. (2021) has shown that despite the shocks, agricultural prices and production levels have largely returned to pre-pandemic levels. This quick recovery is attributed to certain characteristics of the food delivery system in Canada, such as the reliance on low-reserve, just-in-time deliveries that most food systems have in place.

The COVID-19 pandemic has significantly increased online shopping, which may allow smaller farmers or food processors to market directly to consumers, presenting them with new opportunities to sell their products (Weersink et al., 2021).

Weersink, von Massow, and McDougall (2020) speculated that Canada's agriculture system could become more localized and less reliant on international supply chains as a result of the pandemic. This foreshadowed increases in local production capacity and associated infrastructure in order to achieve greater self-sufficiency and 'resiliency' in the face of future global lockdown scenarios. Weersink et al. (2021) reiterate this concern and propose that consumers may display a preference for food that has resiliency characteristics, such as being grown locally. If other countries were to follow suit, then this could result in significant reductions in global demand for food exports, which would hold Canada back from capitalizing on the forecasted demand growth in international markets.

Weersink et al. (2021) also note that the pandemic's aftershocks will likely motivate farmers to rely more on automation to avoid labour shortages, and that the economic struggles in the midst of the pandemic may have increased market concentration, as a number of smaller players who are unable to sustain themselves over the course of the pandemic have left the market. Alternatively, the pandemic has significantly increased online shopping, which may allow smaller farmers or food processors to market directly to consumers, which may present new opportunities to sell their products. The agriculture sector seems to have recovered quite well in the short-term; however, the full extent of the long-term impacts of COVID-19 have yet to be fully understood.

While re-localizing a greater share of food production could potentially reduce some aspects of the agriculture and agri-food sector's environmental footprint, it is worth keeping in mind that the environmental benefits are case-specific. GHG emissions from transportation generally makes up a relatively small fraction of lifecycle GHG emissions from agricultural production, and unless Canada has a comparative advantage (due to its climate, resources, and skills endowment) in producing the crops or livestock in question, food import substitution is unlikely to yield significant environmental benefits and indeed may exacerbate environmental externalities from agriculture (all else being equal) (Rausser, Sexton and Zilberman, 2019).

4.5 Summary of Strengths, Weaknesses, Opportunities, and Threats

Table 2 summarizes some of the high-level strengths, weaknesses, opportunities and threats facing Canada's agriculture sector:

Table 2. Canada's agriculture and agri-food Strengths, Weaknesses, Opportunities, and Threats analysis

Strengths	Weaknesses
High performer – fifth-largest agricultural exporter globally, largest exporter of certain crops (e.g. canola)	Difficulty moving up the value chain due to regulatory barriers, underinvestment in food manufacturing, and under-developed transportation networks
An abundance of natural resources relative to other countries (e.g. water, land)	Relatively low private sector investment in R&D
Strong agri-food processing clusters in select provinces and a strong knowledge base	Very few large-scale enterprises in agriculture and agri-food
Excellent food health and safety regime and a positive global reputation as a trusted supplier of safe food	Significant levels of environmental impacts in some areas such as food loss and waste (foregone opportunities), water quality, and higher lifecycle GHG emissions from pig production and from cereal crops (in general, trends may differ by commodity) compared to global and OECD country averages. This could potentially affect the strength of the 'Canadian Brand', especially in wealthier export markets (e.g. the EU)
Strong federal, provincial and territorial support for R & D in agriculture and agri-food	
Comparatively reduced level of market altering agricultural subsidies in relation to other large agricultural exporters	
Favourable lifecycle GHG emissions footprint compared to global and OECD averages (e.g. beef, dairy, eggs, chicken)	
Opportunities	**Threats**
Rapidly emerging market demand for higher-value food (e.g. proteins, functional foods)	Yield loss and/or increased pest management costs from invasive pest species introduced by climate change
Leveraging national food brand ('Canadian Brand') to access new markets	Lack of preferential trade agreements with major trade partners for three of its five highest-potential markets for agri-food exports: China, India, and Japan
Well positioned to weather growing global supply constraints in land, water, energy, and carbon emissions due to natural resource base	Potential reductions in export market share as developing countries increase their agriculture exports
Revenue potential from novel high-value or cash crops becoming available due moderate levels of climate change	Poor environmental performance could reduce preferential access to select markets (e.g. EU)
	Lack of domestic uptake of novel agricultural technology is hurting the competitiveness of the domestic agricultural technology innovation ecosystem
	COVID 19 leading to decreased trade in food and more emphasis on local food production (threatens export growth targets)[23]

5. REVIEW OF FEDERAL-PROVINCIAL-TERRITORIAL AGRI-ENVIRONMENTAL POLICY PROCESS

This section provides an overview of recent trends in Canadian agri-environmental policies, with an emphasis on the joint Federal-Provincial-Territorial (FPT) agricultural policy frameworks, the Environmental Farm Plan (EFP) process, and cost-share programs. Based on the literature review and feedback from workshop participants, SPI will summarize the agri-environmental policy framework, highlight some recent innovations in the EFP process and cost-share programming, synthesize the modest evidence base on the effectiveness of the EFP process and cost-share programs, assess some of the barriers and limitations to these programs, and conclude with some suggestions for improving current programs.

The Canadian Agricultural Partnership (CAP) is the federal government's current flagship framework, a jointly funded FPT initiative allocating $3 billion over five years (2018-2023) to improve economic and environmental outcomes in Canada's agricultural sector.

5.1 Overview

Federal, provincial, and territorial governments jointly administer Canada's agri-environmental policies through a series of successive, 5-year agricultural policy frameworks that started in 2003; however, Canada's federal and provincial governments have supported environmental stewardship initiatives since the introduction of the AAFC Green Plan in 1995 (Eagle et al., 2015). The Canadian Agricultural Partnership (CAP) is the federal government's current flagship framework, a jointly funded FPT initiative allocating $3 billion over five years (2018-2023) to improve economic and environmental outcomes in Canada's agricultural sector (AAFC, 2019).

This framework consists of two main components. The first includes federal-only programs and activities, such as AgriScience, and AgriInnovate, while the second branch describes the variety of FPT cost-share funding programs available in each province. The CAP framework additionally supports producers through BRM programs that are the responsibility of the FPT governments in tandem. Although this section will focus on the EFP and FPT cost-share programs under CAP and its predecessor FPT policy frameworks, other federal programs supporting clean growth in the sector include the Agricultural Clean Technology Program (AAFC, 2020a), the Canadian Agricultural Strategic Priorities Program (AAFC, 2020b), the Agricultural Climate Solutions program (AAFC, 2021a), and the more recent On-Farm Climate Action Fund (AAFC, 2021e)

The EFP process has predominantly been the first step to accessing FPT cost-share programs to promote the uptake of BMPs under CAP. It is a voluntary system that helps farmers develop plans that outline on-farm environmental risks and devise management options to address them. The EFP process has been included in every major agricultural policy framework since 2003 and has proven to be a durable strategy because it allows solutions to be developed that are tailored to local contexts. Rollins and Boxall (2018) summarize the EFP process as follows:

> "A list of BMPs [beneficial management practices] is drafted and farms undertaking one of those BMPs can apply for a fixed percentage of the cost to be covered by the government up to a pre-defined limit. In most provinces [Saskatchewan is an exception], to be eligible for BMP funding farms must possess an EFP – a largely self-directed program that guides a producer through potential environmental risks on their farm." (Rollins & Boxall, 2018, pp. 3; edited to include text in square brackets).

The general model for EFP development has been more or less the same since the launch of the Agricultural Policy Framework (APF) in 2003, although subsequent federal agricultural frameworks have made some minor adjustments (Rollins & Boxall, 2018). The development of EFPs is voluntary for participating farmers. The formal EFP development requirements vary by province: in the majority of provinces (e.g. NL, NS, PEI, NB, QC, BC), dedicated EFP advisors help farmers complete their EFP; in Ontario and Manitoba, farmers are required to attend EFP workshops that explains how to conduct the environmental baseline and risk assessments needed within the action plan (Government of Ontario, 2019) (Government of Manitoba, n.d.); for Alberta and Saskatchewan, EFPs are usually developed online (although attending a workshop is also an option for Alberta farmers). Once a formal EFP is drafted, it is then reviewed by either a fellow agronomist, the EFP workshop leader, or by a locally-appointed review board. In each case, the reviewer examines the proposal and recommends potential methods to facilitate meeting the environmental targets identified in the EFP.

The development of EFP standards and approvals is directly carried out by the province or territory, and provincial service partners (such as the British Columbia Agriculture Council, the Agricultural Research and Extension Council of Alberta, the Ontario Soil and Crop Improvement Association, the Nova Scotia Federation of Agriculture, etc.), are then contracted to deliver the program.[24]

EFPs became popular because they helped address some of the unique challenges faced by FPT governments in designing effective agri-environmental policy. The first challenge in designing agri-environmental policy is significant heterogeneity across farms and farmers in terms of land-use, soil, local climate, regional characteristics, and personal preferences, so that no "one-size-fits-all" approach can be effective everywhere. Another challenge is that managing cropland requires the management of competing interests. Landowners may wish to undertake environmental conservation actions but may not be able to, due to competing priorities for capital, land-use, and time.

Since 2008 under the Growing Forward FPT agriculture policy agreement, the specific BMPs eligible for incentive funding are independently determined by each province or territory (Kelly et al., 2018). There is a wide range of cost shares and funding caps provided, which varies based on the jurisdiction and eligible BMPs. Cost shares for BMPs range from as little as 25% up to 90% of eligible capital costs. Similarly, the maximum funding eligible for BMPs usually spans from $500 to $100,000 depending on the BMP.

The promotion of BMPs, selected through EFPs, has proven to be a durable strategy because it allows solutions to be developed that are tailored to the local context and captures the valuable expertise of landowners. This results in the development of coordinated programs that have a higher perceived chance of supporting positive environmental outcomes at the local level.

5.2 Recent Innovations in EFP and Cost-share Programming

While the overall EFP and cost-share process generally remain standardized across Canada, provincial programs have implemented innovative approaches to designing cost-share programs and assessing the value of BMPs in an effort to improve the cost-effectiveness of the programs (Rollins & Boxall, 2018).

For instance, multiple provinces such as British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec have made efforts to incorporate spatial targeting into their programs. In British Columbia, policymakers have developed a framework that allows for the integration of different cost-sharing ratios and funding caps based on the region a given BMP is implemented in. Regions where the BMPs have been identified as providing the greatest environmental value, received a greater share of funding, which should increase the cost-effectiveness of programs (Government of British Columbia, 2018). Other provinces have established cost-share programs targeted toward specific regions, such as Ontario's Lake Erie Agriculture Demonstrating Sustainability (LEADS) program (OSICA, n.d.) and Manitoba's Watershed EG&S program (Agriculture and Resource Development, n.d.).

Alberta and Saskatchewan have supplemented their spatial targeting with a social targeting lens. This allows groups to apply for funding toward larger-scale projects deemed to be in the "regional interest". This approach has the potential to support higher-value conservation actions, and improve perceptions of fairness among agricultural landowners by incenting cooperation and providing more evenly distributed financial returns (Boxall, 2017). Provinces such as Quebec and Ontario also offer funding for collective action by multiple farmers (in addition to individual farmers), recognizing that these actions may be more effective at a regional or watershed scale. Similarly, Manitoba's Watershed EG&S program is targeted to Watershed Districts, who apply on behalf of single or multiple farmers (Agriculture and Resource Development, n.d.).

Provinces tend to deliver their agri-environmental cost-share programming via conventional or merit-based programs in Canada. A conventional first-come, first-served approach has a fixed cost-share amount assigned to each project type and reviews and approves applications in the order that they are received until funds are exhausted (OSCIA, 2014). Saskatchewan's Farm Stewardship Program (FSP) and PEI's Alternative Land Use Services (ALUS) program would both be examples of a conventional program operating with a first-come, first-served structure (Government of Saskatchewan, n.d.; Government of Prince Edward Island, n.d.).

Merit-based programs dedicate funding based on the public environmental benefits the submitted project is expected to achieve. There are two main types of merit-based programs. The first is a merit-based program using a first-come, first-served structure, wherein cost-share funding varies according to the level of public environmental benefits the project is expected to create (OSCIA, 2014). In contrast, merit-based programs with an intake period structure engage in a similar assessment of the project's benefits, but do not necessarily vary the cost-share funding for each project (OSCIA, 2014). Provinces like Newfoundland and Labrador have adopted a merit-based program with intake periods for their Soil and Water Sustainability cost-share programs, while New Brunswick operates their Environmental Sustainability and Climate Change program as a merit-based program with a first-come, first-served structure. It is also worth noting that Manitoba has a very well-developed set of merit-based assessment criteria through their environmental benefits index (Rollins & Boxall, 2018).

The majority of these provincial policy innovations emerged following the release of Growing Forward and Growing Forward 2, the two previous federal agricultural policy frameworks that ran from 2008-2013 and 2013-2018, respectively. The current CAP, running until 2023, is similar in scope to Growing Forward 2 – both frameworks allocated roughly $2 billion of their overall $3 billion funding package to cost-sharing programs and both use the cost-share framework to support BMP promotion in most provinces (Boxall, 2017) (Rollins & Boxall, 2018). It is expected that provinces will continue to implement policy innovations based on regional needs in the future.

However, it is worth noting that spending on the these programs has historically been in decline. Vercammen (2018) shows that expenditures on both the EFP and BMP program decreased by about $111 million dollars between Growing Forward and Growing Forward 2, resulting in the latter spending an estimated $62 million per year. Moreover, Growing Forward programming provided funding for an estimated 26 700 new BMP projects between 2009 and 2012; however, a goal of funding only 17 600 new BMP projects was set for Growing Forward 2 between 2015 and 2018 (Vercammen, 2018). In terms of CAP, AAFC's Departmental Sustainable Development Strategy estimates that up to $436 million in FPT cost-share funding is available for the adoption of climate-friendly BMPs and to raise farmer awareness of climate risks over the 5-year span of CAP. On annual basis, this would be equivalent to about $87 million dollars per year (AAFC, 2021c).

5.3 Effectiveness of the EFP Process and the Cost-share Programs

Review of Recent Studies

There have been no comprehensive assessments of the environmental impacts of the EFP or cost-share programs in nearly a decade (the most recent was Holmes, Bradshaw, Yang, & Smithers, 2011). This report will instead offer a selective overview of case studies of EFP and cost-share programs in various provinces, mostly consisting of studies published since the previous review. It should be noted from the outset that current administrative arrangements make it challenging to formally evaluate the impact of Canadian agri-environmental policies – these challenges will be discussed later in this section.

A recent review study of agri-environmental cost-share programs, primarily focused on the prairie provinces, noted that while the EFP process and associated cost-share programs have led to the implementation of BMPs with positive environmental benefits, the spatial distribution of BMP adoption indicates they were not necessarily encouraging actions with the greatest environmental value. Rollins and Boxall (2018) identified that government spending on programs was disproportionately directed toward areas where environmental quality was already high or improving (Rollins & Boxall, 2018). This suggests that funding was probably not targeting areas at high risk of environmental degradation, and that BMP adoption is more likely to be influenced by social networks and spatial proximity than the level of environmental risk faced by farmers. In a related publication, Boxall noted that this barrier could be addressed through increased spatial targeting of farmers to ensure that they adopt BMPs in the places that would offer the greatest public benefit (Boxall, 2017).

Other studies have found that adoption rates for BMPs targeted by cost-share programs can differ substantially between regions within the same province: one assessment of BMP adoption in British Columbia from 2005 to 2009 found that the majority of the four BMPs assessed in the study (livestock watering, riparian buffers, irrigation management, and wildlife damage prevention) were adopted by farms in the southern regions of the province (Kitchen, 2012). The impacts of the BMPs were found to be mixed. Most respondents noted that they felt the impacts of implementing BMPs were positive, but research identified that BMPs designed to mitigate environmental risks (such as installing fencing or riparian buffers) were sometimes ineffective in mitigating those risks, or resulted in the diversion of negative impacts to neighbouring farms (Kitchen, 2012). Overall findings still noted the BMPs adopted in the study were generally successful in achieving environmental objectives, albeit to varying degrees depending on region and project design. An additional study of the EFP process in Ontario came to similar conclusions: uptake varied significantly by region and by subsector, and the EFPs had uneven distributional impacts across regions and projects (Robinson, 2006a).

For cost-share programs that have employed some form of prioritization mechanism, their effectiveness depends in part on what is being prioritized: cost minimization, environmental benefits maximization, or the highest cost-benefit ratio (Kelly et al., 2018). A 2018 assessment of BMPs targeted at reducing phosphorus run-off in Manitoba noted that benefit-cost targeting offered a 10% more cost-effective path than uniform BMP subsidies (Kelly et al., 2018). However, the same study noted that unless the environmental benefits were substantial enough to warrant the additional transaction costs, it may simply be more cost-effective to retain the current policy of uniform subsidies.

A 2008 report from the University of Alberta noted that while the EFP delivery model does have some features that are attractive to producers, such as ensuring equity and maximizing participation, these features also limit the model's cost-effectiveness (Boxall et al., 2008). The cost-share programs are very successful at promoting BMPs that provide private benefits for landowners, but they are considerably less effective at promoting actions that provide positive public benefits that also impose private net costs to landowners. Boxall (2017) identified that even when funding levels for individual BMPs were adjusted in Alberta's cost-share program to account for the value of public benefits, farmers still preferred to adopt BMPs that offered significant private benefits instead (Boxall, 2017).

Rollins, Simpson, and Boxall's (2018) evaluation of Alberta's National Farm Stewardship Program also noted that BMPs that were low-cost or low-effort, easy to trial, and compatible with existing operations were adopted at higher rates. Key factors appearing to influence uptake included observability of benefits and perceived impact, with larger landowners being more likely to implement BMPs than their peers (Rollins et al., 2018).

Similarly, a British Columbia study found that many farmers preferred installing bird and bat houses due to the perception that they would be meaningfully supporting biodiversity, despite perceptions that other actions would offer considerably greater benefits to biodiversity, such as enhancing the connectivity of grasslands and woodlands (Semmelink, 2015).

The observability of impacts was also identified as a driving factor by Marr and Howley (2019) for farm-level decision making in Ontario, but the authors also noted that observability is not necessarily correlated with overall environmental improvement. On the contrary, farmers often undertook activities that they viewed as environmentally beneficial, but which in fact imposed other environmental trade-offs over longer time scales. For instance, farmers placed a great deal of focus on weed and pest removal, which farmers believed to be more environmentally beneficial compared to other management practices (Marr & Howley, 2019). However, conservationists noted that these actions often had negligible or even negative impacts on local biodiversity

Challenges to Evaluating Program Performance

As was mentioned previously, very few Canadian agri-environmental programs have been publicly evaluated, whether by governments or by academics. This is exacerbated by the ways in which programs are designed and administrated, and by limitations in data sharing. The principal problem lies in the fact that virtually none of the programs are evaluated in terms of a counterfactual. In other words, existing evaluations do not attempt to assess whether the BMPs incentivized through cost-share would have been adopted (or what environmental outcomes would have accrued) in the absence of the program – such as by identifying treatment and control groups, or statistically matching participants and non-participants (Naidoo, Boxall & Adamowicz, 2012). In the absence of this information, it is difficult to make credible assessments about program impacts.

To provide one prominent example, a 2008 review of conservation measures in the APF by the Auditor General noted that AAFC did not formally conduct any evaluations of the overall environmental impacts of projects and their value to habitat conservation (Office of the Auditor General of Canada, 2008). Although AAFC stated in their response to the Auditor General that future programs would incorporate formal evaluation measures, the Auditor General's formal review of the efficacy of Growing Forward focused primarily on administrative costs, rather than evaluations of each project's environmental outcomes (Rollins & Boxall, 2018)

Another study noted that it should be possible to at least partially evaluate some of the projects and programs using data held by AAFC and provincial governments, but this data is not made accessible to the public or the research community (Rollins & Boxall, 2018). Provincial-Territorial (PT) governments collect administrative data for funded BMPs such as project descriptions, geographic information system (GIS) coordinates, total producer and government expenditures, and (in some cases) characteristics of BMP adopters,[25] but interested parties typically need to file a formal access to information request for this information to be disclosed. AAFC also compiles data on BMP adoption by type and by province and follows up this data collection with qualitative interviews in order to situate their results accurately within the context. If these data were to be accessed and deployed for analysis, then provincial and federal datasets could be linked to assess baseline levels of BMP adoption, their potential additionality, as well as the environmental impacts of the adopted BMPs. These would help policymakers better evaluate whether targeted beneficiaries were being engaged, and how overall funding could be deployed to achieve greater overall environmental impact. Moreover, this data could also be used to demonstrate the environmental stewardship credentials of Canadian agricultural production, thereby assisting with access to export markets and potentially capturing a higher price in these markets.

5.4 Barriers

Historical barriers to BMP adoption include a lack of investment capital; a potential lack of technical expertise to implement projects; a perceived lack of trust in government officials administering the program; concerns about confidentiality and disclosure risks; and a perceived lack of urgency regarding the need to reduce environmental risk (Holmes et al., 2011)

Historical barriers to BMP adoption include a lack of investment capital; a potential lack of technical expertise to implement projects; a perceived lack of trust in government officials administering the program; concerns about confidentiality and disclosure risks; and a perceived lack of urgency regarding the need to reduce environmental risk.

Workshop participants corroborated several of these trends identified in the literature. In particular, workshop participants identified insufficient incentives for environmental stewardship as another major barrier to achieving economic and environmental objectives in the sector. Participants believed that the incentives provided by current program designs in Canada are insufficient to motivate behaviour change or BMP adoption among farmers. However, workshop participants did mention some other drivers of BMP adoption, such as sustainable sourcing pressures from food processors, restaurants, and retailers (see section 7.10 for further discussion).

Another related theme concerned the distrust of government (or 'big government') interventions by some producers. The level of trust in government programs varies across the country – for instance, participants noted that there is a higher aversion to government programs in the Prairies than in Quebec or PEI. Participants believed that using 'close-to-home' messengers to communicating the intentions of a policy and promote BMPs would help mitigate this challenge, since the messenger would be more connected to the local environment and production context in which producers operate.

5.5 Limitations with the EFP and Cost-share Program Process

The literature review and workshop participants also identified a number of limitations with the EFP and cost-share programs, including instances where they could inadvertently incentivize or disincentivize certain forms of environmental action. As previously noted, Marr and Howley (2019) found in a survey of farmers from England and Ontario that the agri-environmental actions undertaken at the highest rates were actions that offered dual benefits for both agricultural yields and the environment such as the adoption of organic farming principles, conservation tillage, installing windbreaks, and planting cover crops (Marr & Howley, 2019). The authors noted that this tendency to adopt BMPs offering cost-savings and improved profit margins could be occurring because of the type of funding supports offered within BMP programs (Marr & Howley, 2019). Funding to promote BMPs under on-farm stewardship programs is generally structured as one-time support payments to partially offset the capital cost of projects or BMPs (e.g. installing livestock exclusion fencing in riparian areas), which may render it less attractive for investments into actions with high levels of environmental benefits but which may negatively impact production capacity over the long-term (e.g. wetland conservation or restoration on land that could potentially be used for crop production).

Robinson (2006) additionally noted that a key motivation for some farmers to participate in the voluntary EFP process was to avoid or delay the implementation of regulatory requirements (Robinson, 2006). The author noted that threats of "punitive regulation" have spurred certain communities to undertake environmental actions. As such, in some cases, regulatory approaches that set minimum environmental standards – or alternatively, requirements for environmental cross-compliance, where business risk management (BRM) support funds are made contingent on BMP adoption – could potentially dissuade participation in the EFP process if farmers felt that their stewardship actions were not being appropriately recognized, or if they saw the imposition of regulations as a breach of the social contract (Robinson, 2006). On the other hand, there are some programs which appear to have successfully combined regulations and subsidies. For instance, PEI requires the establishment of mandatory riparian buffers of 15 meters while offering subsidies through ALUS for expanding buffer length above this limit (Government of Prince Edward Island, n.d.).

Workshop participants also noted some of the perceived limitations to the effectiveness of current programs. Several participants argued that farmers perceive there is more funding available for administering the EFP process than there is for actual cost-share measures. These perceptions are generally not supported by the actual data on funding allocations, given that a greater share of funding has historically been allocated to cost-share programs than the EFP process. This perception may have arisen from the lower costs of engaging farmers in the EFP process. In jurisdictions where the costs of engaging the average farmer in an EFP workshop, training, or consultation are less than the cost of funding BMP adoption under a cost-share program, then by definition some of the BMPs will be oversubscribed relative to the number of farmers who have completed an EFP and who are interested in adopting the practice. Although further research is required prior to making any definitive recommendations, this suggests there may be merit in further increasing the share of funding allocated toward cost-share programs relative to EFPs.

Participants also highlighted the voluntary nature of many Canadian agri-environmental programs (including EFP and cost-share) as another limitation. Because participation in many programs is voluntary, programs are more likely to attract farmers who are already motivated to participate. Workshop participants argued that farmers with the most innovative practices are already involved in agri-environmental programs, but they are generally not the group that is contributing most significantly to environmental degradation. This being said, it is worth noting that over half of all farmland in Canada is covered by an EFP, so while it may not be attracting producers with relatively poor environmental performance, it does capture more than just top performers.

5.6 Suggested Improvements to Current Programs

Workshop participants highlighted a few changes to existing programs that they believed would improve outcomes. They stressed the value of incorporating heterogeneity into program design and moving toward results-based payments schemes – as opposed to the current suite of practice-based payment schemes. These programs should recognize that not every farmer operates in the same context and that broad programs need to be able to account for these differences to be effective. Moreover, farmers tend to prefer annual payments to one-time payments, which is particularly important for BMPs that have recurring costs beyond the initial capital investment. Hence, participants suggested policymakers should consider combining one-time adoption payments with supplementary annual payments – possibly based on environmental performance. These were believed to provide greater incentives for BMP adoption.

Workshop participants stressed the value of incorporating heterogeneity into program design and moving toward results-based payments schemes – as opposed to the current suite of practice-based payment schemes.

Other workshop discussions centered around the need to dampen the consequences of failure in agri-environmental programs – both for governments and for producers. Governments should support farmers in trying new practices even by compensating them when they are not successful, but just as importantly, they need to assess which programs are succeeding and why, to ensure that programs are effective as possible. This counts as another reason in favour of using quasi-experimental program designs to assess which BMPs and policy interventions are successful in cost-effectively accomplishing their objectives, and in promoting continuous learning and improvement in program design.

Finally, participants also noted that some BMPs were not necessarily effective in achieving results unless coordinated with other BMPs (e.g. combining efficient fertilizer application rates with cover cropping). This could prove challenging for farmers and stymie environmental outcomes, as some farmers would need to adopt a second BMP to make any noticeable difference. In that light, some workshop participants suggested restructuring on-farm stewardship programs so that they incentivize the adoption of a bundle of interrelated BMPs, which might make them more efficient, or to ensure that this is covered in EFP recommendations.

6. POLICY INSTRUMENTS FOR CLEAN GROWTH IN AGRICULTURE AND AGRI-FOOD

The discussion in the previous section made clear that although Canada's agri-environmental programs are fostering environmental improvements, they are clearly not sufficient to address scale of the challenge in decoupling economic growth from environmental impacts. This section critically assesses five policy instruments that show promise in addressing the environmental problems facing Canada's agriculture sector, while improving the economic competitiveness and farmers' livelihoods: (1) behavioural interventions; (2) taxes on agricultural inputs; (3) voluntary ecological certification; (4) targeted agri-environmental subsidies; and (5) offsets for carbon, water quality, and biodiversity.

6.1 Behavioural Interventions

Characteristics

Policy interventions based on behavioural economics have recently been gaining momentum in the agri-environmental space due to their potential to design novel approaches for encouraging BMP and technology adoption (Colen et al., 2016; Palm-Forster et al., 2019) . Researchers in behavioural agri-environmental policy have identified nine broad classes of behavioural interventions (or 'nudges')[26], summarized through the mnemonic MINDSPACE (Dolan et al., 2012 as cited in Palm-Forster et al. 2019) :

- **Messenger**: People are strongly influenced by who communicates to them.
- **Incentives**: Responses to incentives are shaped by mental shortcuts.
- **Norms**: People are strongly influenced by what others do.
- **Defaults**: People "go with the flow" with pre-set options.
- **Salience**: People's attention is drawn to what is novel or relevant to them.
- **Priming**: Acts are often influenced by subconscious cues.
- **Affect**: Emotional associations can powerfully shape people's actions.
- **Commitment**: People seek to be consistent with their public promises.
- **Ego**: People act in ways that make them feel better about themselves.

To date, most of the literature on behavioural interventions in an agri-environmental context have focused on BMPs to improve water quality (Wallander et al., 2017); (Christensen et al., 2011), water-use efficiency (Byerly et al., 2018), soil health BMPs such as cover crops and conservation tillage (Clot et al., 2017), and engaging farmers in land and wildlife conservation initiatives.

Nudges have a number of potential advantages relative to more traditional environmental policy instruments. Nudges usually do not introduce direct regulatory or economic distortions, or impose significant financial burdens on farmers. Designing and implementing nudge policies can increase the cost-effectiveness of new and existing policies, and may have lower absolute costs compared to other kinds of agri-environmental policies (Czap et. al., 2019). They have the potential to encourage farmers to communicate and share practices with one another, resulting in social networks (Fooks et al., 2016) and knowledge spillovers (Banerjee, 2018) that can coordinate land-management practices for increased environmental benefits (Buchholz et al., 2018; Peth et al., 2018). Nudges can also help highlight more effective ways of transferring knowledge to and between agricultural stakeholders (Hanna et al., 2012; USDA, 2012). Nudges have also been shown to be effective in competitive economic environments, including agriculture (Messer, Ferraro & Allen, 2015).

Moreover, behavioural research can also identify non-financial motivations that influence farmers' behaviour, such as adherence to social norms, maintaining a positive self-image, as well as how policies are framed and communicated (Sheeder & Lynne, 2011) (Schwarze et al., 2014). These can be used to identify and test interventions that complement traditional agri-environmental payment schemes.

Economic Aspects

The bulk of existing nudge interventions attempt to encourage adoption of pro-environmental practices through one of three means. First, nudges can attempt to make the public benefits of environmentally beneficial technologies or practices (desired outcome) more salient, so that farmers assign greater weight to them when making decisions (Chabé-Ferret et al., 2019) (Cason et al., 2003). Secondly, nudges can be used to provide social incentives (e.g. recognition for stewardship), utilizing the 'ego' channel of MINDSCAPE. These first two approaches could be especially effective in catalyzing farmers to adopt 'win-win' practices that provide both environmental and economic benefits. Finally, nudge insights can be used to alter the structure of financial incentives (e.g. a payment scheme that is calibrated to farmers' risk preferences or discount rates), keeping in mind that an individual's response to an incentive is determined by a set of mental shortcuts (or 'heuristics'), rather than a detailed benefit-cost calculation. Altering the structure of incentives can increase the farmers' real or perceived benefit from adopting the environmental practice (N. V. Czap et al., 2015)(Li & Just, 2019).

Previous research has found that nudge tactics are generally low-cost and easy to implement, since they tend to make use of pre-existing agricultural networks and infrastructure (Hellerstein et al., 2015); (Messer et al., 2015. Although the impacts of nudges (as measured by study effect sizes) are somewhat low (ranging from 0-15%), the fact that they are generally inexpensive to design and administer can still render nudges highly cost-effective (Czap et. al., 2019).

The effects of nudges are generally most pronounced immediately after they have been implemented, whereas some of the desired behavioural changes may not be sustained over longer timescales. As such, their cost-effectiveness might level off over time (H. J. Czap et al., 2011)(Byerly et al., 2018). Specifically, nudges modeled in a positive punishment[27] style or those relying solely on affective nudge tactics[28] were found to be susceptible to reduced effectiveness when used repeatedly (H. J. Czap et al., 2011); (Peth et al., 2018). On the other hand, there is some field evidence from the domain of residential water use that using a combination of information, moral suasion, and social comparison nudges can lead to persistent changes in behaviour (Bernedo, Ferraro, and Price, 2014).

This potential for the effects of nudges to diminish over time can be addressed through a number of ways. First, evidence from non-agricultural domains (e.g. water and electricity utilities) suggests that when nudges lead to changes in the overall capital stock (environmentally improved technologies), then treatment effects are more likely to persist (Brandon et al. 2017). Second, the persistence of nudge effects can be enhanced by combining them with financial incentives (Peth et al., 2018; S. Wu et al., 2017). For example, in a laboratory experiment comparing the effectiveness of affective nudging and financial incentives, both tactics were found to increase the amount of (simulated) conservation tillage that the participants engaged in, but the most significant increase (almost 28%) was observed when combining the two together (N. V. Czap et al., 2015)

Social Acceptability and Scalability

One of the weaknesses associated with some nudges is that they can be perceived as a form of manipulation. Several nudge tactics attempt to enhance the saliency of existing social pressures, information cues, and motivating factors; however, depending on the farmers' interests or objectives, this may not always be perceived as fair or socially acceptable. Indeed, the use of nudge tactics that are perceived as cynical or manipulative may actually dissuade farmers from adopting BMPs. This emphasizes the need to design nudges in ways that farmers themselves would find socially acceptable, and that respects their autonomy.[29]

Moreover, although the results are case-specific, other experimental studies have found that indiscriminately combining various nudges can lead to poorer environmental outcomes. One study that made use of priming, salience, and norms in the same experimental condition found that participants tended to engage in fewer BMPs, and this result was attributed to the possibility of participants realizing that their decision environment was being manipulated (Peth et al., 2018). More specifically, it was found that using just two of the three nudges - priming and salience nudges - rendered participants three times more likely to make management decisions that would improve water quality (Peth et al., 2018). On the other hand, when the researchers added a social comparison of how many farmers were already in compliance with water protection rules on top of the other nudges, 16% more farmers made decisions that would negatively impact water quality, and non-compliance increased by almost 9% (Peth et al., 2018). A similar trend was observed in an experimental context using messenger, norm, and ego tactics at the same time (Griesinger et al., 2017).

Some of the more extensive nudge programs may also require significant investments of human capital and social capital (e.g. training, external partnerships, and monitoring of environmental conditions). The time, money, and human resources needed to implement some of these approaches might hamper their scalability, especially those that are more labour-intensive (e.g. certain forms of messenger, salience, or norm-based tactics that require lots of face-to-face interaction). However, as with all other policy interventions, the upfront costs of the interventions should be compared with the benefits (since some of these interventions may be justified even if they tend to have higher upfront costs).

Finally, the results of some nudge studies are very context-specific, partly because many behavioural hypotheses are first tested using experiments that are conducted in a highly controlled laboratory environment, and which may or may not be subsequently tested in field experiments (Roe & Just, 2009). This can cause difficulties for policymakers seeking to extrapolate the results from laboratory studies to on-farm settings for hypotheses. For example, a laboratory study using norm and incentive nudge tactics was successful in spatially coordinating land-use to increase environmental benefits (Banerjee, 2018); however, in a real agricultural context, physical property boundaries and non-contiguous land parcels often limit the ease with which spatial coordination can be implemented. On the other hand, this provides policymakers with a golden opportunity to become part of the knowledge-generating process themselves, by taking promising laboratory or field experiments and piloting them with real farmers in a new context.

Some recent large scale experiments in both Canada and the US have found nudges to be effective at increasing farmer participation rates. Although not an agri-environmental survey, Statistics Canada conducted an experiment using defaults and reminder letters to increase participation in the Farm Financial Survey in 2016. The results found that changing the default option (i.e., farmers must call Statistics Canada to make an appointment vs. Statistics Canada will call the farmer to make an appointment) and sending a reminder letter (i.e., to address participant inattention) increased the national response rate by almost 7% and the provincial response rate by up to 15% (both stated as a percent change relative to the control group). The reminder letter alone, while not statistically significant, was able to increase the national response rate by just under 4% (percent change relative to the control group) (Innovation Hub, 2017).

Studies in the US have also identified a statistically (and economically) significant effect of randomly assigned letters but for agri-environmental program participation rates. For instance, Wallander et al. (2017) found that sending reminder letters to eligible participants in the Conservation Reserve Program (CRP) had a benefit-cost ratio ranging from 20:1 and 90:1, whereas Czap et al. (2019) specifically the Conservation Stewardship Program (CSP) found that invitation letters increased participation in the Conservation Stewardship Program at a cost that was equivalent to a 2.5-5 cent (USD) increase in annual per-acre payments.

Although both studies found that letters were a cost-effective intervention for encouraging program participation, their findings on what sorts of behavioural nudges were most effective at encouraging program participation (and for which populations) were ambiguous. For instance, Wallander et al. (2017) administered three different treatments among landowners eligible to enrol in the CRP: a simple invitation and reminder letter; an invitation and reminder letter with a social norm messaging; as well as an invitation and reminder letter containing a combination of social norm messaging, private benefits messaging, and a peer comparison. They found that all three treatments were equally effective in encouraging participation among producers who were 'informed' landowners (i.e. those who had expiring CRP contracts) – the letters did not have a statistically significant effect on unenrolled producers in any of the treatment arms (Wallander et al., 2017).

By contrast, Czap et al. (2019) ran an experiment in 36 Nebraska counties with low historic participation in the CSP. This study administered three treatments: a basic invitation letter for the landholder to participate in the program; a letter including a photocopied empathy message with a simulated signature from a conservationist; and a letter including an empathy nudge coupled with a handwritten empathy message from a research assistant. Although all three letters increased program participation in a statistically significant manner, they found that the third treatment –'personalized letters with a handwritten phrase appealing to people's empathetic tendencies toward environmental conservation' – was the most effective. The photocopied empathy message performed worse than both the generic invitation letter and the letter with the handwritten empathy message (although the difference was not statistically significant) (Czap et al., 2019).

6.2 Taxes on Agricultural Inputs

Characteristics

Nitrogen, phosphorous, and pesticide runoff are among the major contributing factors to water quality degradation, and N_2O emissions from nitrogen fertilizer applications are a major source of GHG emissions in the agricultural sector. Water pollution imposes high environmental, economic, and social costs such as the cost of water treatment and poor water quality, as well as adverse impacts on ecosystems, livestock, and the fishing industry (OECD, 2012). There are virtually no agricultural input tax programs in Canada, with the exception of the fertilizer manufacturing industry's inclusion in the federal and provincial output-based pricing schemes for emissions-intensive, trade-exposed industries (which could be considered an indirect input tax).

By making production decisions more reflective of their social costs – and by providing all actors with equal incentives to engage in pollution abatement – environmental taxes can potentially be part of an optimal policy mix to address environmental externalities in the agricultural sector (Skevas et al., 2012). Most agricultural pollution and GHG emissions stem from non-point sources, which limits policymakers' ability to directly regulate or price emissions. Therefore, instead of directly taxing residuals emission, agri-environmental tax schemes typically target polluting inputs instead (Petsakos & Jayet, 2010); (Söderholm & Christiernsson, 2008). Input tax schemes have been used or proposed to address various environmental damages in agriculture, including nutrient and pesticide runoff into the environment, CH_4 and N_2O emissions into the atmosphere, as well as ammonia and particulate matter emissions.

For some inputs such as nitrogen fertilizer, environmental damages are not spatially uniform but instead depend on a number of climatic, topographic, soil, and hydrological characteristics, as well as production systems and input use (Lichtenberg, 2004).[30] Policymakers thus face the decision of imposing uniform input tax rates which reflect the weighted average of expected environmental damages across all watersheds, or a series of differentiated tax rates that better reflect local environmental damages (e.g. differentiated by watershed). Differentiated tax rates capture the heterogeneity within the system, and are more efficient from an economic standpoint. However, differentiated tax rates would require extensive information on the farm practices, land quality, and seasonal conditions which would be costly to acquire and incorporate into taxation systems (Lichtenberg, 2004).

Policymakers thus face the decision of imposing uniform input tax rates which reflect the weighted average of expected environmental damages across all watersheds, or a series of differentiated tax rates that better reflect local environmental damages (e.g. differentiated by watershed).

Economic Aspects

Taxes are effective instruments when the avoided damages to the environment are greater than the costs of paying the tax or changing the practice that causes the pollution. In agriculture, the objective of taxes is to increase the price of a polluting input to incentivize farmers to decrease their level of input use, or to find alternatives (Wagner-Riddle & Weersink, 2011) For instance, applying input taxes to fertilizer has the potential to change farmers' crop mix toward less fertilizer-intensive crops (J. Wu et al., 2003).

The effectiveness of taxes in changing fertilizer and pesticide application rates largely depends on farmers' sensitivity to changes in input prices. A low-price elasticity implies that – at least in the short-run – a significant reduction in application rate is only attainable with very high tax rates. A meta-analysis of pesticide use in North America and Europe shows that the median pesticide demand elasticity is -0.28, which is relatively inelastic. However, these elasticities differ by the type of pesticide and farming system. For instance, the demand for pesticides for specialty crops is less elastic than for arable and grassland farming. In addition, the demand for herbicides is more elastic than for other pesticides (Böcker & Finger, 2017).

Previous research has found that the price elasticity of nitrogen fertilizer demand is inelastic in the short-run (Hansen, 2004); (Williamson, 2011), although estimates differ across studies based on: fertilizer and crop type, time series covered, and the methodology used.

These findings on price elasticity of demand for fertilizer and pesticides suggest that the environmental impacts of input taxes may depend substantially on how the proceeds are recycled. Schemes that reinvest tax revenues into agri-environment schemes – such as supporting the adoption of new on-farm technology, sustainable inputs, or improved training services – are more likely to produce significant environmental benefits (Finger et al., 2017). Indeed, there is an extensive emphasis on using input tax instruments in combination with other approaches such as command-and-control (e.g. input quotas) (Skevas et al., 2012) or conditional payments (Finger et al., 2017) for precisely this reason. However, depending on the stringency and durability of the input tax, producers may change their production practices and technologies which may allow the tax system to have a higher impact (irrespective of the effects of proceeds recycling).

Identifying the specific impact of input taxes is challenging as policymakers often implement several policies over a similar time frame. Austria's fertilizer taxation system was initially implemented in 1986 with the aim of raising funds to support grain producers and enable the export of their products. The tax rate increased from €0.25 /kg N in 1986 to €0.47/kg N in 1994 when it was abolished. Through the gradual increase in the taxes, demand for nitrogen fertilizer was reduced by 2.5% due to the price effect, and by 5.5% due to increased environmental awareness among farmers. The price effect made is so that taxes acted as a signal to producers that fertilizer is a cost factor (Rougoor et al., 2001).

In Canada, applying carbon pricing to certain aspects of on-farm fuel use is one example of how to directly tax CO_2 emissions from agriculture. To show the impact this pricing scheme would have on Canadian farmers, AAFC conducted an analysis of the change in net operating costs and income in light of carbon pricing and found that farms would see an average increase of $718 (+0.2%) to their operating costs as a result. Furthermore, net operating income was only expected to decline by about 1% for the average farm. These impacts vary by farm type and by province (AAFC, 2018).

Social Acceptability and Scalability

Uniform taxes on polluting inputs have low implementation costs and can be scaled reasonably quickly, as they can easily fit into an established taxation system. However, a regionally differentiated input tax system would translate into higher implementation and monitoring costs, making it more complex to scale.

Input taxes reduce producers' incomes, which makes them less attractive to the agricultural community. Moreover, with the exception of the dairy and poultry sectors, agriculture is primarily a trade-exposed sector and hence its products are often sold at international commodity prices. This limits producers' ability to pass on their costs to consumers. If these taxes are sufficiently high, they may affect domestic producers' ability to compete in both domestic and foreign markets [31] (Rivers & Schaufele, 2015). As such, well-designed recycling of tax revenues is crucial for the social acceptability of input taxes. Revenues could be recycled in several ways: by proportionally reducing farmers' overall tax burden; tax-refund schemes which recycle revenues back to farmers based on their output (Adamowicz & Olewiler, 2016); or additional financial support for BMP adoption to further reduce the use of polluting inputs (Finger et al., 2017). Trade competitiveness could be safeguarded by providing export-oriented producers with input tax rebates (although domestic producers may still be disadvantaged in domestic markets) (Rivers, 2010), or through the above-mentioned tax-refund scheme.

6.3 Voluntary Ecological Certification

Characteristics

Voluntary ecological certification schemes are a mechanism to differentiate products by communicating their environmental attributes. These certificates rely on criteria setting, metric development, performance measurement, and auditing processes at specific points along the supply chain. The most predominant conformity assessment across these standards is certification through third-party audits.

Certification can enhance product differentiation and lead to the creation of a market in which producers are able to command a price premium[32] from environmentally conscious consumers. Global supply for environmentally certified agricultural commodities has grown significantly over the past two decades. For many commodities, sustainable certification is increasingly becoming the 'price of entry' for producers to access food retailers and restaurant chains (Potts et al., 2014).

Although historically most agri-food certification schemes have focused on commodities grown in the tropics (e.g. coffee, cacao, and palm oil), there are important product niches operating in Canada and elsewhere for grains, fruits, vegetables, and meat. Various international and domestic sustainable sourcing forums and frameworks are active in Canada. Sustainable sourcing forums include the Sustainable Agriculture Initiative (SAI) Platform, the Sustainability Consortium, the Cool Farm Alliance, and Field-to-Market Alliance. The Roundtable on Responsible Soy standards developed by the Roundtable on Responsible Soy Association is an example of a global operation-level certification program. Other examples of operation-level programs in Canada include the Certified Sustainable Beef Framework developed by the Canadian Roundtable for Sustainable Beef, and the Canadian Organic Standards laid out by the Canadian Food Inspection Agency and audited through third-party certification bodies approved by Canadian Food Inspection Agency.

Certification can enhance product differentiation and lead to the creation of a market in which producers are able to command a price premium from environmentally conscious consumers.

Another prominent certification scheme is Fertilizer Canada's 4R[TM,33] Nutrient Stewardship Certification Program, which has developed province-specific standards for nutrient management planning, and offers specific certification programs for crop advisors and retailers to communicate the value of implementing 4R[TM] practices to farmers (Fertilizer Canada, 2019).

Certification schemes can be designed either as Business-to-Consumer or Business-to-Business schemes. Business-to-Consumer schemes attempt to ensure sustainable production through consumer demand, by using consumer-facing labels to communicate the product's environmental benefits. Rainforest Alliance is an example of Business-to-Consumer certification.

Business-to-Business standards shift the focus of demand from consumers to the private sector by setting "entry rules" emphasizing supply chain and risk management attributes. Business-to-Business designs can also be combined with consumer labeling. The Roundtable on Responsible Soy operates in 21 countries and is a leading example of a global Business-to-Business standard (Potts et al., 2014).

Provincial governments have also been active in this space. The governments of Alberta, Quebec, and Ontario have been working on benchmarking the EFP framework against the Farm Sustainability Assessment framework offered by the SAI Platform. This provides them with an opportunity to assess the EFP framework against international standards and help farmers satisfy consumers' preferences for sustainable food products (Alberta Wheat Commission, 2020) (Wilton Consulting Group, 2019).

Economic Aspects

Certification schemes attempt to incentivize certification through the use of price premiums or other economic benefits (e.g. improved market access) associated with certification. However, to be effective in spurring adoption, the price premium received by certified producers needs to be higher than the implementation and monitoring costs incurred by participating in the certification scheme (Weersink & Pannell, 2017).

Past experience has identified several challenges to realizing the economic benefits of certification schemes for producers. The first is oversupply: the supply of many certified sustainable products such as coffee, cocoa, and palm oil far outstrips demand, meaning that only a fraction of overall certified production is sold as such to consumers (and hence is able to command a premium) (Potts et al., 2014). However, vegetables certified under the Canadian Organic Standards are a notable exception to this trend, since supply has consistently kept up with demand. Second, consumers are not necessarily willing to pay higher prices for certain commodities, in which case the certified producers are not able to fully pass on their production costs. Third, in those cases where price premiums do in fact accrue to 'certified' products, they may end up in the hands of processors and retailers instead of producers (Berry & Weaver, 2018).

Evidence also suggests that there is little consumer pressure for producers of staple crops such as corn and soybeans to become certified. These commodities are often consumed indirectly as inputs to other products – for instance, intensive beef production requires a lot of corn, but consumers may be unaware of this and fail to make the connection between the beef that they are purchasing and the corn needed to feed it. In addition, the market for many staple crops is not vertically integrated, and producers have many avenues to sell their products. This creates opportunities for producers to focus on markets that don't impose certification requirements on them (Waldman & Kerr, 2014).

Social Acceptability and Scalability

Assessing the scalability of certification schemes partially depends on how one interprets their objectives. If one interprets their primary objective as communicating the environmental attributes of certified products to other firms or consumers, then these schemes are working effectively. If their objectives are understood more broadly as recognizing and rewarding certified farmers for their past and present stewardship measures – but not fostering widespread practice change – then these schemes are performing fairly well (although as noted above, there are some problems due to oversupply and the absence of price premiums). However, if one interprets their objective as transforming the sector by inducing large-scale behaviour change among producers (over and above business-as-usual), then the evidence is inconclusive – and in the case of some schemes, it may be too early to definitively answer this question.

There are at least two dimensions to assessing the potential for certification to catalyze broad-scale behaviour change and environmental improvement in the sector. The first concerns the environmental benefits of the BMPs prescribed by various certification schemes. The second concerns whether incentive schemes are fostering additional BMP adoption or behaviour change among producers relative to business-as-usual.

On the first point, although certification can provide incentives to increase the adoption of practices that are sustainable at the field-scale, in some cases the environmental benefits of these practices may be more questionable when applied to broader spatial scales – this is especially true for measures to reduce agricultural intensification (e.g. significant reductions in input use; creating more diverse landscapes to provide wildlife habitat on otherwise productive land, etc.). For instance, a meta-analysis of the environmental impacts of organic farming including cereals, milk, beef, and pork production in Europe suggests that organic farming has positive impacts on the environment per unit of cultivated land, but not per unit of output. This is because there is a persistent yield gap for most organic products compared to conventional products – although the gap varies considerably by commodity (Tuomisto et al., 2012).

All else being equal, large-scale adoption of organic agriculture will require bringing a larger area of land under cultivation in order to meet the projected yield gap.[34] If widespread adoption of organic farming leads to further expansion of cultivated land, this would lead to adverse environmental impacts such as higher GHG emissions, decreased habitat for wildlife, and increased potential for eutrophication[35] and acidification[36] per unit of product (due to lower yield in organic farming systems)[37] (Tuomisto et al., 2012). Achieving sustainable yield increases for organic farming is possible, but also challenging since the main reason for the low yield in on-field organic farming is soil nutrient deficiencies and problems with pests, diseases, and weeds.

On the second point concerning behaviour change, if certification schemes are to spur meaningful large-scale changes in behaviour, then their standards and monitoring mechanisms must be stringent enough to exclude poorly performing producers, and schemes will either need to overcome selection bias (where only the producers with the best environmental performance participate in the scheme) or induce significant spillover effects (where additional producers become certified after observing their peers' decision to become certified).

There is limited evidence to draw upon for answering these questions in the context of commonly grown crops in Canada or peer jurisdictions (e.g. the US, the UK, or the EU). One recent study assessed the potential additionality of certification under the Roundtable on Responsible Soy and the Roundtable on Sustainable Palm Oil (Garrett et al., 2016). It found that in some regions such as China, the adoption of certification is high despite the low potential for additionality. Estimated in terms of land cover change, adoption in these regions will likely have relatively low environmental impacts. This study also assessed Canada's performance under the Roundtable on Responsible Soy, concluding that adoption rates are low and that much of the adoption is likely to be non-additional (according to 2014 data).

Moreover, the requirement for third-party audits can also create additional barriers to entry, putting small producers at disadvantage. For these reasons, some initiatives have started to place more focus on self-assessment by producers, backstopped by the verification of a third-party auditor. Producer self-assessment enables access to certified sustainable markets at a lower cost, although they can be subject to higher risks of non-compliance. Other mechanisms such as allowance for group certification by small producers can also facilitate their participation.

Despite these challenges, there may be two moderating dynamics that increase the beneficial impacts of certification schemes and should be the topic of future policy research. The first is the previously mentioned potential for spillover effects from certification. These 'ripple effects' may be able to spur increased adoption over time. The second is the fact that many certification schemes – such as the Certified Sustainable Beef Framework – provide standards and requirements for continuous improvement among producers, which might also lead to further BMP adoption (relative to business as usual) over time.

In light of these challenges, there is a potential role for governments in addressing some of these barriers, and in assessing the performance of certification schemes. Governments have a central role in facilitating benchmarking and evaluating the environmental performance of certification schemes by providing data on indicators such as changes in soil organic carbon and water quality as a public good. They could also fund pilot studies using quasi-experimental research designs to better understand and test the theories of change embedded in certification schemes.

In cases where policymakers have determined that a given certification scheme (and their associated BMPs) have the potential to meet the sector's environmental and economic objectives, then policymakers may wish to consider using agri-environmental programs (e.g. cost-share) to support producers in adopting certification. This would simultaneously help address the fact that certification comes at a cost to producers with no guarantee of a corresponding economic return, and if the cost-share funding it used to target more marginal producers, it could also help address the issue of additionality.

6.4 Targeted Agri-environmental Subsidies

Characteristics

Some BMPs can impose high capital and maintenance costs and provide minimal private benefits to producers, but provide a significant environmental benefit to society (Rollins et al., 2018). In light of this fact, providing landowners with financial incentives can help increase BMP adoption rates, improving environmental quality and social welfare. This section focuses on three types of agri-environmental subsidies: traditional cost-share programs, spatial targeting, and reverse auctions. The latter two instruments have the potential to improve the cost-effectiveness of agri-environmental policy through improved targeting and will be the main focus of this section.

Currently, cost-share programs (like the kind discussed in section 5 of this report) are the most prevalent type of agri-environmental policy implemented by governments in Canada. Under cost-share programs, the government covers a fixed share of capital costs for adopting a set of eligible BMPs (Weersink & Pannell, 2017). Although these programs can be implemented fairly easily and have the potential to be adopted by a significant share of landowners, they are not always the most cost-effective means of promoting BMP adoption. This is because setting the appropriate payment level for BMP adoption can be challenging due to information asymmetries between governments and producers – producers know at what price point (or level of cost-sharing) they would be willing to implement a given BMP, but this information typically isn't known to policymakers. As such, subsidy programs risk overcompensating some landowners, or paying them to undertake BMPs that they would have implemented anyway. Revising cost-share programs to better reflect the private and public benefits provided by different BMPs – and prioritizing public funding for the BMPs providing public benefits that would otherwise go uncompensated – would improve the cost-effectiveness of these programs (Rollins et al., 2018).

Reverse auctions are one potential solution to the problem of information asymmetries. In a reverse auction, a centralized organization (e.g. government or an ENGO) identifies the specific BMPs or environmental benefits that they wish to procure through an auction, and farmers submit competitive bids to implement these BMPs. Bids are typically assessed and prioritized based on the environmental benefits per dollar spent – often by using an environmental benefits index (Boxall et al., 2017). Reverse auctions can be designed so that all farmers providing winning bids receive a uniform payment (known as a 'uniform price auction'), to reduce social tensions and reward farmers equally for the same BMP.[38]

An alternative approach to reverse auctions and cost-share programs is to implement a system of geographically targeted payment schemes.[39] In this method, participants are compensated through a system of uniform payments, but landowners are prioritized or identified based on some combination of geographic criteria (e.g. targeting land near sensitive watersheds; land on sloped sites; or areas with high conservation values) that are predicted to increase overall cost-effectiveness.

Economic Aspects

Targeted payment schemes can induce adoption of BMPs that have a high ratio of private costs to net public benefits, whereas properly designed reverse auctions can increase the cost-effectiveness of BMP adoption and improve the allocation of government funding. A growing literature suggests that conservation auctions usually outperform fixed-payment schemes (such as non-targeted cost-share), with cost savings ranging from 16% to 315%, depending upon the context and design of the program (Latacz-Lohmann & Schilizzi, 2005).

Although the economic theory behind instrument choice seems straightforward, the relative cost-effectiveness of these different programs in actual practice has varied in different contexts, with few hard and fast rules determining whether reverse auctions are to be preferred over a system of targeted payments.

For instance, experimental studies of reverse auctions have demonstrated that their cost-effectiveness is highly sensitive to farmer participation rates. Low participation rates have also been documented in field pilots and existing programs, which suggests that these concerns are not just limited to the laboratory (Rolfe et al., 2018). This introduces two problems. First, low participation rates increase the odds of funding projects that are relatively less cost-effective (i.e. with a higher ratio of costs to benefits), since there are fewer bids to construct bid supply curves and facilitate price discovery. Second, extremely low participation rates can lead to a situation whereby policymakers are unable to expend all of the funds earmarked for the auction (because there are not enough bidders), leading to missed opportunities for environmental improvement (Palm-Forster et al., 2015).

Some of the reasons behind low participation rates include the complexity of the auction structure and the transaction costs incurred by program participants – such as the time needed to submit complex bids, or the need for stable internet access – as well as the landowners' perceived likelihood of winning the auction (Palm-Forster et al., 2015). Research suggests that when reverse auction participation rates are low, targeted payments might be more cost-effective than reverse auctions. On the other hand, the same is also true of targeted payment schemes – unless the benefits of targeting exceed the transaction costs, policymakers are better off using a uniform payment scheme (Kelly et al., 2018).

Social Acceptability and Scalability

Cost-share programs and targeted uniform payments are relatively easy to scale, since they have low transaction costs compared with reverse auctions, and their implementation is fairly straightforward (although targeted payments may have higher transaction costs than cost-sharing, due to the need to set up a system for prioritizing different geographies for payment). On the other hand, the complex mechanisms involved in setting up reverse auctions makes them challenging to scale.

In terms of social acceptability, farmers may not perceive reverse auctions as being fair, even if all winning bidders are provided with the same payment. Participants at several workshops convened by SPI expressed concerns that the requirements for reverse auction participants to compete with one another when submitting their bids could potentially undermine social cohesion and create tension within communities.

Reverse auction designs should be flexible enough to capture spatial differences in environmental variables, and flexible in terms of the admissible BMPs (where appropriate). For instance, the Conservation Reserve Program (CRP), which is the most extensive private-lands protection program in the United States, offers 10-15-year contracts for producers to retire highly erodible cropland and pastures. The eligible practices vary from grass, trees, wildlife cover, or other vegetation, which gives farmers more flexibility in terms of eligible participation criteria (Latacz-Lohmann & Schilizzi, 2005). Moreover, reverse auctions can potentially be combined with direct payments – as is the case with the CRP, which also offers a non-competitive sign-up process to target lands with very high environmental benefits.

6.5 Offsets (Water Quality, Carbon, Biodiversity)

Characteristics

Offsets are a form of tradeable credits that can be purchased by an organization (e.g. businesses, government departments, municipal water treatment facilities) to compensate for certain kinds of environmental harm. Land use offset markets have principally emerged to address three kinds of environmental problems – GHG emissions, water quality problems (e.g. excess nutrients or other pollutants entering into waterways), and biodiversity loss (e.g. habitat loss from mining, forestry, or residential and commercial property development, etc.).

Small offset markets for all three types of credits have emerged across the country – very few of them have enabled participation from the agriculture sector, which represents an untapped opportunity. Although many of these markets are voluntary (where polluters or developers are not legally required to purchase offsets), several regulatory markets exist (where regulated entities must purchase an offset for purposes of regulatory compliance) and others are in development. This report will briefly review the characteristics of each of these types of offset market before assessing some of their economic aspects, as well as their scalability and social acceptability.

Small offset markets for all three types of credits have emerged across the country – very few of them have enabled participation from the agriculture sector, which represents an untapped opportunity.

Carbon Offsets

A carbon offset is a tradable credit for a GHG emissions reduction that can be used to compensate for emissions created elsewhere. Under the right conditions, agriculture, forestry, and other land-use practices can reduce GHG emissions at a lower cost than other economic sectors (B. C. Murray, 2015). Agricultural practices covered in existing and proposed federal and provincial carbon offset protocols in Canada – and voluntary offset markets in Canada and other jurisdictions – include conservation cropping/conservation tillage and the Nitrous Oxide Emissions Reduction Protocol (NERP), and reducing GHG emissions from fed cattle (Government of Alberta, n.d.).

Alberta's conservation cropping protocol is one of the active compliance offset protocol for agricultural lands; however, it is expected to close at the end of 2021. The protocol creates offset credits based on soil carbon sequestration from conservation tillage and conservation cropping practices. This protocol quantifies annual emissions reductions based on the estimated yearly growth in SOC from adopting the practice. It is a compliance option under Alberta's Technology Innovation and Emissions Reduction (TIER) regulation – a GHG emissions intensity regulation for heavy industry – as well as the two intensity-based regulations that preceded it (the Specified Gas Emitters Regulation and the Carbon Competitiveness and Incentive Regulation).

The Climate Action Reserve in the United States is also developing a Soil Enrichment Protocol (SEP) to systematically quantify, monitor, report, and verify emissions reductions from on-farm soil carbon sequestration. This will reduce transaction costs and better enable farmers to connect to carbon markets. This protocol was released in mid-2020 with a primary focus on reductions from soil carbon sequestration, and future extensions to N_2O emissions from fertilizer use (Climate Action Reserve, 2020). The province of Ontario was also in the process of developing an NERP offset protocol as part of its cap and trade program, but it was discontinued with the wind-down of cap and trade in 2018.

However, there are impact limitations from the deployment of current soil carbon sequestration practices on agricultural lands. These practices have demonstrated the potential to offset emissions from the cultivation of certain crops, and soil carbon offsets - in tandem with other techniques - have the potential to cultivate wheat in a carbon-negative manner (Gan et al. , 2014). However, the potential for soil carbon on agricultural lands to sequester enough carbon to offset agricultural emissions and sell offsets to other sectors and industries is questionable with current practices. Current soil sequestration methods are not expected to deliver significant emissions reductions compared to other sectors here in Canada, with the current government plan only projecting agricultural-based offsets as reducing annual emissions by an additional 2 Mt, providing .25% of expected emissions cuts by 2030 (ECCC, 2020a). This isn't to say that there is no value in adopting current soil sequestration methods, as there is significant value in making agriculture a carbon sink rather than a carbon source. Overall, emissions sequestered by changes in soil cultivation are significant, as Canadian soils in 2018 were estimated to have kept 6.2 Mt of CO_2 out of the atmosphere, or .7% of the country's emissions total that year (Government of Canada, 2021).

Potential exists, to offset emissions of other industries from agricultural soil sequestration, but it will require novel soil sequestration methods that can increase the amount of carbon stored compared to contemporary practices by one or two orders of magnitude. Row and cover crops optimized to store greater carbon through their roots systems, such as those being explored at the Salk institute, could provide the magnitude of carbon sequestration potential required to see agricultural soil carbon play an offsetting role (Knotek et al., 2020).

A recent study by Nature United (Drever et al., 2021) provides a snapshot of the offsetting potential that Canadian producers might be able to offer to the carbon market. It is estimated that Canada could mitigate about 23 Mt of CO_2e from the various natural climate solution pathways by 2030 for abatement costs at or below $50 per tonne of CO_2e. Saskatchewan (6.6 Mt), Ontario (3.83 Mt), Quebec (3.41 Mt), and British Columbia (2.9 Mt) offer the lion's share of this mitigation potential via practices like: cover cropping (1.7 Mt) and nutrient management (1.3 Mt) in Saskatchewan, tree intercropping in Ontario (2.16 Mt) and Quebec (1.76 Mt), or avoided conversion of grasslands, forests, and wetlands across the country (Drever et al., 2021). If producers can adopt these practices, they may be able to access new revenue streams while also contributing to the environmental sustainability of Canada's food system.

Water Quality Trading

Water quality trading (WQT) was first initiated in the United States in 1981. Under WQT, regulated entities (typically point source polluters such as utilities) are provided with an emissions quota. If they exceed their emissions quota, they must either purchase credits from other regulated entities in the watershed, or purchase an offset from farmers implementing nutrient management BMPs within the watershed (such as cover cropping or riparian buffers). WQT enables significantly more cost-effective abatement for the regulated entity compared to upgrading existing water treatment infrastructure or building a new treatment plant (Puzyreva et al., 2019).

The South Nation Conservation Authority (SNCA)'s phosphorous trading program is a prominent Canadian example of WQT. In 1999, the Province of Ontario and the SNCA (a community-based watershed organization) developed Canada's first nutrient trading system for phosphorous. SNCA acted as a broker selling offset credits to new and expanding watershed treatment facilities that had a zero phosphorous discharge mandate. SNCA used the income from the sales to promote the adoption of phosphorous management BMPs among local farmers. Eligible BMPs included manure storage, septic systems, milk house wastewater management, livestock access restrictions, and barnyard runoff control. Between 2000 and 2009, 269 verifiable projects were completed and the SNCA estimates that the water quality trading system had reduced overall phosphorous abatement costs by about 40% (Puzyreva et al., 2019).

Conservation Offsets

Conservation offsets are markets that require proponents to compensate for the negative impacts of their project on some class of environmental assets (such as wetlands, native vegetation, biodiversity, or habitat for species at risk). Most conservation offset schemes adhere to a mitigation hierarchy to reflect the risks that development poses to vulnerable ecosystems. The first step in the hierarchy is prioritizing avoided impacts, followed by minimizing impacts, then by remediating impacts where necessary, with offsets emerging in the final stage of the mitigation hierarchy once all other options have been exhausted (Forest Trends., n.d.). Offset measures typically consist of ecosystem enhancement, restoration, creation, or conservation measures.

Several Australian states such as New South Wales and South Australia currently enable private agricultural landowners to supply biodiversity offset credits (Government of New South Wales, 2021; Government of South Australia, n.d.); similarly, private agricultural landowners in the US are able to supply wetland credits to mitigation banks at the federal level – and sometimes at the state level as well, such as in Florida (Vaissière & Levrel, 2015). Conservation offset programs that enable participation from agricultural landowners have not yet emerged in Canada, although they have been discussed among policymakers for some time. This primarily stems from the fact that most conservation offset policies in Canada have required the proponents to offset their impacts ('permittee responsible mitigation'), rather than purchase them from third parties ('habitat banking').

Economic Aspects

*T*he economic viability of offset programs primarily depends on the costs of the targeted conservation actions, the program's transaction costs (the costs of designing, administering, and enforcing the program), as well as the size of the potential offsets market. Offset programs are only viable if they provide credits that are less expensive than firms undertaking environmental abatement on their own.

The environmental integrity of the offset protocols depend on how they account for three critical variables, each of which has implications for transaction costs: **permanence** *(*ensuring the continued persistence of the environmental benefits generated by the offset); **additionality** (ensuring farmers wouldn't have implemented the credited environmental management actions anyways); and **leakage** *(*whereby the credit merely shifts environmental harms to other times and places, without actually reducing them in the aggregate). First, this report will discuss these three variables and then discuss their implications for program transaction costs.

First, if the environmental impacts of a development are permanent, then so should the compensatory environmental benefits secured by the offsets. **Permanence** can be undermined either by intentional reversals (e.g. when landowners decide to clear vegetation that was previously set aside for carbon or biodiversity credits) or due to natural disturbances, such as fires or severe weather events. Some carbon offset protocols, such as California's Compliance Offset Protocol for U.S. Forest Projects,[40] address the latter issue by requiring landowners to repay carbon credits from any intentional reversals (California Air Resources Board, 2014). By contrast, permanence risks due to natural hazards are typically either addressed by requiring offset providers to purchase an insurance product, or by creating a 'buffer pool' that discounts the number of credits issued to a landowner to account for these risks. Some protocols use buffer pools to address risks from both intentional reversals and natural hazards. For example, Alberta's Conservation Cropping protocol does not require farmers to maintain the practice over a specific period of time but instead deducts the total carbon sequestered by 7.5% for the dry prairie region and 12.5% for the Parkland region (Government of Alberta, n.d.).

Additionality is another important challenge facing offset systems. For instance, (Murphy et al., 2018) estimate that when carbon prices are low, offset credits for farmland afforestation result in a very high share of credits going to projects that would have been undertaken anyway. Additionality is typically either measured financially (which assesses whether the revenues from the offset credit are required in order for the project to financially break-even) or through the common-practice method (where the additionality of the practice is determined in terms of baseline adoption rates within a given region). Each of the protocols has their associated strengths and weaknesses – financial additionality arguably tracks the variables affecting producers' adoption decisions more closely (but requires more resources to assess), whereas the common-practice method streamlines program administration (at least in the short term) by providing a simple additionality metric, but it does not provide genuine information on whether actions would have been undertaken by producers in the absence of the program (Thamo & Pannell, 2016).[41]

The environmental integrity of the offset protocols depend on how they account for three critical variables, permanence, additionality, and leakage.

Addressing **leakage** remains one of the more pressing issues facing offset markets, especially for carbon sequestration. If carbon emissions from one activity are merely shifted elsewhere (e.g. land used to grow oilseed crops is afforested to generate carbon credits), but other producers respond by increasing their production to meet consumer demand – then the offsets will not produce genuine environmental improvements. Leakage risks are typically addressed by using a discount rate to deduct a percentage of the total number of credits (e.g. a landowner only receives carbon credits for 90% of their proven emissions reductions); however, some of these discount rates remain *ad hoc* and are not necessarily supported by the most up-to-date empirical evidence. Devising better safeguards to address leakage risk is an important priority for future offset protocols.[42]

As discussed above, there are multiple program design approaches that can help address issues associated with permanence, additionality, and leakage – but they can lead to additional transaction costs. While some transaction costs are an inherent feature of program design, others arise from coordination problems or fixed costs of participating in offset

protocols. Several protocols have attempted to address this by using offset credit aggregators, which pool together many small-scale projects to reduce participants' transaction costs such as Alberta's Conservation Cropping Protocol (Government of Alberta, n.d.).

Nevertheless, if the price of offsets do not compensate for the actual transaction costs involved in landowner participation (among other costs), then participation would expectedly be low (B. C. Murray, 2015). For instance, one assessment of WQT programs in Ontario, New Zealand, and the United States[43] found that given the wide range of transaction costs in the watersheds, these programs are only economically viable if there is sufficient variation in abatement costs across emitters (Puzyreva et al., 2019). As such, the challenge lies in ensuring that the program's offset protocols are rigorous enough to safeguard environmental integrity but streamlined and flexible enough to encourage participation. This remains an important area for future piloting and research.

Social Acceptability and Scalability

The acceptability of offset programs among farmers partially depends on the practices that are eligible for generating offsets and farmers' perceptions of them, the expected price of offset credits, as well as farmers' preferences over contract structures. Farmers' trust in program administrators also impacts their assessment of the social acceptability of offset programs more broadly (Puzyreva et al., 2019).

Evidence from conservation offset programs suggests that farmers generally prefer offset contracts that are more flexible and shorter in duration, which can create difficulties for assuring offset permanence (Vaissière et al. 2018). On the other hand, experience from US wetland mitigation banking suggests that farmers are more likely to find permanent offsets acceptable if they are generated on otherwise marginal farmland – such as by restoring wetlands or other degraded ecosystems (Vaissière and Levrel, 2015).

The scalability of offset systems on both the supply side and demand side varies with the type of offset market. On the supply side, land-use carbon offsets are relatively easy to scale, since they can be incorporated into established carbon pricing and offset programs. By contrast, water quality offsets and conservation offsets are more likely to be geographically circumscribed either due to inherent geographic limitations (i.e. WQT is limited to a certain watersheds by definition), or due to policy objectives (e.g. good practice recommendations that conservation offsets be provided within a prescribed radius of the impacted habitat or ecosystem). But under the right conditions, a thriving group of markets for both types of offsets could emerge, meeting environmental targets at a lower overall cost.

The demand side influences on scalability are fairly similar for terrestrial carbon offsets and water quality offsets – stringent regulatory policy (e.g. carbon pricing, zero net nutrient exports, or no net loss/net gain objectives for biodiversity) needs to be enacted both to ensure demand for offsets, and to ensure that offsets can compete with other abatement options (e.g. change in practices, or purchasing a credit from another emitter). Demand for conservation offsets will also depend on the environmental permitting and approvals processes under the respective federal or provincial legislation (e.g. the Federal Impact Assessment Act), as well as the offset multipliers or compensation ratios deemed necessary by policymakers to compensate for ecosystem or habitat loss and risks of offset failure (e.g. five hectares of enhanced or restored habitat required to compensate for each hectare of habitat loss).

7. POTENTIAL CASE STUDIES

As was discussed earlier in this report, achieving Canada's clean growth ambitions and increasing access to export markets will require designing new policies to address emerging environmental and economic opportunities. SPI identified six possible case studies for future research and convening that presented a strong opportunity for realizing the sector's environmental and economic objectives. The six options are: (1) Enhancing the efficiency of nitrogen fertilizer management; (2) Measures to improve soil health; (3) Commercializing next generation crop production technologies; (4) The role of improved animal genomics in reducing GHG emissions from the beef and dairy livestock sectors; (5) The potential for enhanced efficiency feeds to reduce GHG emissions in the beef and dairy livestock sectors; and (6) Circular economy approaches for Canada's agriculture and agri-food sector.

Case studies were identified based on three key criteria: the scope of the environmental challenge; the potential economic opportunity; as well as the scalability of the policy and/or technological solution. The proposed case studies were presented at an SPI workshop in Ottawa in January 2020 that brought together experts from government, industry, ENGOs and academia. In addition to critiquing the proposed case studies, workshop participants also provided suggestions on additional promising case study areas.

By targeting efficient nitrogen fertilizer management, policymakers can address one of the main sources of GHG emissions in the agricultural sector.

This section synthesizes the results from SPI's background research and key messages from workshop participants. The following sections will provide an overview of the six proposed case studies, followed by a thumbnail sketch of some of the most promising additional case study areas suggested by stakeholders.

7.1 Improving the Efficiency of Nitrogen Fertilizer Management

Overview

By targeting efficient nitrogen fertilizer management, policymakers can address one of the main sources of GHG emissions in the agricultural sector. In cases where farmers are applying fertilizers above the profit-maximizing rate, optimizing nitrogen fertilizer application can enhance on-farm profits by reducing input costs (without significant losses in yield). Efficient management of nitrogen fertilizer also reduces nitrogen runoff into surface water and leaching into groundwater, thereby advancing the Government of Canada's shared mandate with the provinces and territories to ensure water quality and safety. Moreover, this case study has a scalable and transferable analytical framework that is applicable to Canada's major field crops including corn, soybeans, wheat, canola, barley, rye, and potatoes.

Agronomic research has shown that there is high variability in the optimal rate of nitrogen fertilizer application between different years. It is difficult for farmers to predict what the profit-maximizing rate of N application would be for their field in any given year. Fertilizers are also relatively inexpensive inputs. As a result, farmers have an incentive to overapply fertilizer since the cost of over-application is generally small in comparison to the potential opportunity cost (forgone income and yield) of applying too little (Sheriff, 2005; Rajsic et al., 2009). Well-designed policies can help address these uncertainties, by providing financial support for producers to adopt BMPs suited to local agronomic conditions.

Views from Workshop Participants

Participants provided insights on the importance of this study area and on possible areas of refinement. They were overwhelmingly in favour of this approach due to the clear economic and environmental benefits that could be realized from reducing nitrogen fertilizer overapplication, as well as the scalability of the approach to different production systems.

However, some participants suggested that undertaking a case study in this area might not add as much value compared to other possible case studies, since governments, industry, and ENGOs are already taking multiple actions in this area. On the other hand, policymakers are mostly considering a relatively narrow subset of policy options, namely cost-share payments to support nutrient management planning and 4R nutrient certification. As such, a case study examining a broader set of policy options such as behavioural interventions, risk-sharing tools, or reverse auctions could make a valuable contribution.

Participants also suggested further extensions to the scope of the research. The first suggested extension was to examine complementary sources of nutrient inputs (e.g. cover crops, intercropping with legumes, or manure amendments), while the second was to incorporate policies for targeting GHG emissions from upstream fertilizer manufacturing. It was proposed that incorporating these issues into the scope of the nitrogen fertilizer case study would highlight environmental improvement opportunities that are not synthesized within existing studies.

Given the importance of nitrogen fertilizer management in reducing GHG emissions and in improving on-farm profits, SPI has initiated an extensive study on potential policy options in this space, focusing on efficient nitrogen fertilizer management as well as complementary measures to enhance soil health (see section 7.2 for further discussion of soil health issues). As nutrient management practices are highly dependent on the agronomic condition of each region, the study has focused its first round of research and convening on corn/soybean/winter wheat systems in Ontario and potato systems in PEI. This analytical model can then be applied to production systems in other parts of the country, such as oilseed and cereal crops in western Canada.

SPI's forthcoming nitrogen fertilizer management case focuses on identifying the nutrient management and soil health BMPs that are suitable for each region and production system, the adoption barriers facing farmers, as well as new policies for improving economic and environmental outcomes. The policy recommendations have been informed by workshops held in Ontario and PEI with multiple stakeholders including academics, producers, industry, policy advisors, ENGOs, and government bodies to ensure a holistic understanding of the problem as well as the implications of the proposed policy options for different stakeholders.

7.2 Improved Soil Health

Overview

Soil health remains a common and pressing agenda item for many policymakers in Canada. For instance, Ontario is in the process of implementing its 2018 Soil Health Strategy, and SOM is a key indicator in the government of Saskatchewan's Prairie Resilience framework (Government of Saskatchewan, 2018). SOC sequestration has also emerged as a key strategy for mitigating carbon emissions from the agricultural sector. This can be seen from Alberta's long-standing carbon offset protocol for conservation cropping (Government of Alberta, n.d.) and from the renewed efforts to incorporate agricultural soil carbon and/or afforestation measures into the climate change strategies of provinces as diverse as Ontario, Manitoba, and PEI (Government of Ontario, 2016; Government of Prince Edward Island, 2018; Government of Manitoba, 2017).

The issue is a pressing one since there are some indications that Canada has lost some of the positive momentum on soil health seen in previous decades. As was mentioned in section 3.2.2 of this report, national soil carbon sequestration rates peaked at 12 Mt/year in 2006 and have leveled off ever since, decreasing by nearly 50% to reach 6.2 Mt/year in 2018. Recent years have also seen producers transitioning away from pastures and perennial cover, an increase in annual cropping, as well as the discontinuation of a number of soil conservation measures in Central Canada and Atlantic Canada such as conservation tillage (Clearwater et al., 2016).

This case study proposes to use SOM as its headline indicator for soil health – since this would provide the entry point for an analysis of multiple economic and environmental benefits. On the environmental side, residues, manure, and organic amendments enhance SOM (leading to more SOC stored in soils). This enhancement improves soil structure and infiltration resulting in reduced surface runoff and improved water quality. Residue retention and reduced tillage also provide improved habitat for small mammal communities, and enhanced water quality also improves habitat for water-dwelling invertebrates (Awada et al., 2014).

On the economic side, SOM is essential to the long-term viability of crop production, and SOM/SOC also contributes to yield stability in the face of adverse weather impacts (Cong et al., 2014)

On the economic side, SOM is essential to the long-term viability of crop production, and SOM/SOC also contributes to yield stability in the face of adverse weather impacts (Cong et al., 2014). Many measures to promote SOM also provide additional economic benefits. For instance, zero tillage agriculture requires landowners to make fewer passes over their fields, which reduces soil compaction and saves on both energy and labour costs (Awada et al., 2014). SOM also enhances the ability of soils to store plant-available nitrogen. Practices such as sustainable crop rotations, intercropping, or cover cropping with nitrogen fixing legumes can enhance yields (OMAFRA, 2019b) and crop quality,[44] and save on input costs (Pannell, 2017).

Given the important need to improve soil health in many parts of the country, and the potential economic and environmental benefits this would provide, a detailed, regionally grounded case study examining the benefits of various soil health BMPs, the barriers to adoption, as well as new policy interventions that can attract new adopters, would be a valuable contribution. SPI has begun to explore these themes and plans to continue work on these issues in subsequent reports. Although the specific soil health BMPs will vary by region or by cropping system, candidate BMPs for consideration in these case studies may include agroforestry, cover cropping, more diversified crop rotations, tighter integration between crop production and livestock systems, and increasing adoption of conservation till/no-till agriculture, where appropriate.

Views from Workshop Participants

This case study received tremendous support from participants based on the potential for large environmental and economic benefits for both farmers and broader society. In addition, participants highlighted additional co-benefits from improving soil health in the form of enhanced ecological services, such as reduced run-off and lower flooding risk, and for better enabling farmers to adapt to climate change. Participants were also very open to the use of economic instruments to incentivize soil health practices.

Although the workshop participants took a broad interest in soil health, they also noted that provinces are already undertaking measures to address this issue, so the case study will require careful consideration of existing policies, and will need to identify areas where new policy approaches can offer the greatest value-added. Participants also proposed expanding the soil health indicators to go beyond SOM (such as water holding capacity, potentially mineralizable nitrogen, soil pH, etc.(USDA, 2017)), and to formulate policies that capture broader environmental and economic benefits for the sector.

7.3 Commercializing Next-generation Crop Production Technologies: Gene-editing/CRISPR

Overview

Meeting future food demand as a result of world population growth is one of the most significant challenges facing global agriculture – a challenge exacerbated by climate change. Technological advances play an essential role in enhancing yield stability and resilience in the face of increasingly volatile temperature and precipitation patterns, as well as pest and disease infestations (Ng & Ker, 2019). Commercializing promising technologies such as gene editing in crop development could enable Canada to play a significant role in sustainably meeting the burgeoning growth in global food demand, while minimizing the use of polluting production inputs such as fertilizers and pesticides.

Gene-editing technologies, such as CRISPR (clustered regularly interspaced short palindromic repeats), have the potential to become the next major technology in agriculture production. This technology makes direct changes to the target species' intrinsic DNA, whereas traditional genetic modification technologies introduce foreign DNA from a different species (Shew et al., 2018). CRISPR makes use of a naturally occurring enzyme to introduce, replace, or remove specific sections of genetic material to create a more desirable version of the crop (Montenegro, 2016). This process can create modified crop varieties that are more resistant to drought, pests, or disease, or which yield larger sized fruits and vegetables, to name just a few possible applications. As such, these technologies have the potential to increase farm profitability (depending on the price and yields of the new variety relative to the global market price for the crop), while simultaneously reducing the environmental footprint of crop production. This presents a major opportunity to decouple economic growth in the agriculture sector from the environmental impacts of food production.

CRISPR provides the opportunity for more affordable and rapid deployment of gene-editing technology. While genetically modified organisms (GMOs) take an average of 13 years to get to the market – with a mean cost of discovery, development, and authorization of more than USD $135 million – products that are genetically edited via CRISPR can get to the market in less than five years at an average cost of USD $10 million (CIBUS, 2020).

In addition to lower costs and reduced time to get to market, CRISPR may also benefit from a more favourable consumer perception since it is not necessarily categorized as a GMO. A multi-country assessment of consumers' willingness to consume CRISPR versus GMO food products also showed that consumers strongly prefer CRISPR food products (Shew et al., 2018). Another study by An et al. (2019) compared the willingness to consume and pay for canola oil that was either produced through gene-editing or genetic modification technologies. The results were similar – consumers had a higher willingness to pay for canola oil produced using gene-editing methods, ranging from 27% to 47% more than the average genetically modified canola oil price.

Although gene-editing has seen many research applications, it remains expensive to commercialize and deploy. Additionally, firms might under-invest in more environmentally-friendly applications of the technology due to the perceived lack of monetary rewards – cleantech typically faces even greater hurdles to product development and commercialization, due to the conventional market failure in which firms under-invest in new technologies, as well as the environmental market failure in which market prices typically fail to reflect the value of environmental externalities (Brownlee, Elgie and Scott, 2018).

The potential for gene-edited crops to provide environmental improvements under the right circumstances – as well as the risks that these benefits may not be fully rewarded in the marketplace unless they translate into productivity measures – suggests that governments have a special role to play by steering public funding for these technologies in more environmentally friendly directions. The federal government currently offers a number of programs that incentivize scientists to engage in gene-editing research. In 2021, the Natural Sciences and Engineering Research Council of Canada (NSERC) awarded a $325 000 grant researchers at the University of British Columbia through the Discovery Accelerator Supplements program to explore gene-splicing in polyploid Brassica napus, more commonly known as rapeseed (University of British Columbia, 2021). In 2018, the Social Sciences and Humanities Research Council of Canada (SSHRCC), awarded just under $100 000 in funding to Dalhousie University for a project named "The GMO 2.0 Partnership." This project has a five-year timeline and aspires to foster new research and establish new partnerships and approaches to GMO products (Dalhousie University, 2018). There is a clear role for government in this space, but it would be advisable for future calls for CRISPR or GMO food-related proposals to prioritize environmentally beneficial applications.

Thus, although gene-editing technology shows promise in revolutionizing production in the agriculture sector, few commercialized products currently exist on the Canadian market. This case study would identify best practices in allocating public funds for environmentally beneficial food products and biotechnologies, in order to identify lessons to accelerate the development of environmentally beneficial CRISPR applications.

Views from Workshop Participants

Support for the CRISPR case study primarily focussed on the technology's novelty and growth potential. Supporters highlighted that this is a relatively new technology which provides Canada with the opportunity to become a leader in its commercialization and export. The excitement and attention dedicated to this technology across the globe was another reason why participants thought a study of CRISPR's potential in the Canadian context would be particularly timely.

Other supporting comments concerned the potential for the technology to reduce GHG emissions and food waste, and improve agronomic productivity (e.g. by reducing input use or increasing yields). Efforts are currently underway to use CRISPR technology to improve plant nutrient acquisition and reduce food loss and waste by increasing the life shelf of food and resistance to pathogens (Gallegos, 2019). This could potentially lead to reductions in GHG emissions from crop production and across the food system more generally. Additionally, there is research interest in using CRISPR technologies to optimize common agricultural crops themselves to take up more carbon in their tissues, increasing the abatement potential of agriculture, and opening greater opportunities for revenue streams from carbon offsets (Ogura et al., 2019) (Howes, 2020).

Other participants noted the huge opportunities that gene-editing technology offers to agricultural producers. With the potential to develop drought, pest, and disease-resistant crop varieties, this technology has the ability to entirely change the way that the farming sector operates, and many felt it was important for Canada to be 'ahead of the curve' in terms of understanding these potential changes.

Those less supportive of the CRISPR case study raised four main objections. First, some participants were hesitant to expend limited financial and political capital on this topic, in light of the recent decision passed down by the EU to heavily regulate CRISPR products. Second, several workshop participants also cautioned that CRISPR would still face significant lead times to commercialization and deployment, which limits its utility in meeting Canada's 2030 GHG emissions reduction targets (although it could potentially make a substantial contribution to Canada's commitment to reach net-zero GHG emissions by 2050). Third, participants noted that the rapidly changing nature of this industry could invalidate a detailed case study in a very short period of time.

Finally, participants highlighted that although CRISPR does have potential environmental benefits, in some cases the realization of these benefits depends on a number of additional assumptions about producers' behaviour and other factors. For instance, even though CRISPR may enhance crop yields (which would move the sector closer to its growth targets), this does not necessarily mean that farmers will reduce the total area under cultivation, which is one of the primary environmental benefits of 'land sparing'[45] practices and technologies. Participants suggested that the case study would be improved if the scope was broadened to encompass breeding plants for new, low-input crop varieties, whether through conventional breeding practices or through gene-editing technologies such as CRISPR.

7.4 GHG Emissions Reductions in the Beef Livestock and Dairy Sectors: Animal Genomics

Overview

There is significant pressure on the livestock sector to produce greater quantities food in a more sustainable fashion. These pressures come from estimates that the world population may increase to 9 billion by 2050 and the growing demand for meat from the global middle class. The beef and dairy sector generally have a relatively high carbon footprint compared to most other protein sources, so policy interventions will be essential to ensure that this sector can grow in a way that is compatible with Canadian emissions reductions objectives. The good news is that Canada is well-positioned to address this challenge. The emissions intensity of Canada's beef production is relatively low – at 12 kg CO2 equivalent per kilogram of live weight, this is approximately half the global average (Gerber et al., 2013); (Legesse et al., 2016).

In 2017, 60% of agricultural sector emissions came from livestock production. CH_4 is the primary GHG emitted by the sector, which is mainly attributable to enteric fermentation from beef and dairy cattle (ECCC, 2021b). Therefore, measures and practices that help to reduce CH_4 emissions in beef and dairy livestock show significant promise in reducing the overall carbon footprint of these industries.

One of the principal mechanisms through which genomics affects GHG emissions is through the digestion of feed. Scientific research indicates that feed intake and CH_4 emissions are correlated with one another. By precisely selecting for traits that increase feed efficiency and reduce CH_4 emissions from cattle, animal genomics offers a potential solution to mitigate livestock GHG emissions. CH_4 emissions from cattle rearing can be reduced by selecting for cattle that consume less dry matter, or selecting those with improved feed conversion ratios[46] or residual feed intake.[47] While it was previously both technically challenging and expensive to collect the necessary data for trait selection, it is now much more feasible in light of the latest genomic breakthroughs.

The beef and dairy sector generally have a relatively high carbon footprint compared to most other protein sources, so policy interventions will be essential to ensure that this sector can grow in a way that is compatible with Canadian emissions reductions objectives.

Improving feed efficiency can also enhance on-farm profits by reducing input costs, since feed is a substantial part of the variable cost of livestock production. For instance, feed costs are estimated to be roughly half of operating costs for beef cattle in Manitoba (Government of Manitoba, 2016). Other studies have also corroborated this. Boaitey et al. (2017) found that, at the end of the feeding period for beef cattle (with a start age of cattle ranging from 200-310 days and an additional 28-35 days of adaptation period depending on the type of cattle), a unit reduction in feed intake (kg fed/day) is associated with an average increase of $13.23 in net returns and a 33.46 tonne reduction in CH_4 emissions (Boaitey et al., 2017). Preliminary results from the University of Guelph's Efficient Dairy Genome Project (EDGP), an international research project funded by Genome Canada, have suggested that breeding animals for increased feed efficiency and reduced CH_4 emissions can lower feed costs by $108/cow/year and decrease overall CH_4 emissions by an estimated 11% to 26% (Schenkel et al., 2019).

Although improving feed efficiency through genomics shows a lot of promise in reducing sectoral CH4 emissions, and Canada has invested heavily in the field, the actual impact highly depends on the on-farm adoption rates for cattle with these new genomic indices. Factors such as farmer perceptions of the technology, the financial benefits from the technology, and the distribution of benefits along the supply chain (from cow-calf to feedlot producers) all affect adoption rates. In terms of financial benefits (besides savings from more efficient input use) sellers could potentially sell carbon credits in federal or provincial carbon offset markets once the appropriate protocols have been developed. However, the price of carbon credits on offset markets might not rise to a level that effectively incentivizes the inclusion of CH_4 emissions in breeding goals. This suggests that there is a role for public policy in incentivizing research, development, and

deployment of genomics for low GHG-emitting beef and dairy livestock. [48] On the other hand, consumer preferences for milk and meat with a low carbon footprint (as indicated by higher demand and higher willingness to pay) might be sufficient to place a non-market value on these attributes in the future (de Haas et al., 2017).

Boaitey (2017) assessed the various factors impacting the uptake of genomic selection in beef cattle in Canada and found that the benefits of increasing feed efficiency through genomic selection are more likely to be captured by feedlot operators, and not cow-calf extensive operations. In addition, technology adoption among cow-calf producers is highly variable and depends on their familiarity with the technology and its perceived risk (Boaitey, 2017).

In light of the diverse and often countervailing factors reviewed above, this case study will undertake a detailed review of barriers to farmers' adoption of the technology on the ground, such as the cost of the technology to farmers, farmers' perception of the technology, consumers' perceptions of beef and dairy livestock with these new genomic indices, and other policies tailored to address the heterogenous benefits of the technologies along the supply chain.

Views from Workshop Participants

Participants saw value in this case study as GHG emissions from livestock is a pressing problem in the sector. This case study also has implications for on-farm profit and for generating exportable intellectual property. However, they were somewhat reluctant to choose this case study area (at least as a short-run measure to reduce GHG emissions), for two main reasons. First, participants were concerned that animal genomics may not be the most effective abatement option for the beef and dairy industry, and argued that (allegedly) more promising alternatives should be explored, such as feed additives. Second, similar to the CRISPR case study, beef genomics was perceived as less effective in reaching the 2030 emissions reduction targets due to the longer lead time needed for widespread access and adoption of livestock with these improved genomic indexes (although again this may have the potential to contribute to the 2050 target). The perception was that the perceived profitability improvements and the sustainable sourcing pressures would not be sufficient to spur sufficient adoption to make a material contribution to the 2030 target.

In light of this, participants argued that any case study of the beef and livestock sector should encompass a more comprehensive and systems-based examination of sustainability options in these industries (e.g. genomics, improved feed efficiency, promotion of extensive livestock production systems in grasslands and pasturelands).

7.5 GHG Emissions Reductions in the Beef Livestock and Dairy Sectors: Improved Feed Practices

Overview

Improving feed practices and diet modification might offer a more near-term solution to the pressing problem of reducing CH_4 emissions from the beef and dairy sector. Reducing CH_4 emissions from ruminants can also improve animal performance by reducing the energy that is lost from the animal's digestive system. The ruminant can redirect the conserved energy to more economical uses such as weight gain and milk production that can potentially offset producers' costs of changing feeding practices. Several feeding practices demonstrate substantial potential to reduce emissions from beef and dairy production. These include improving forage quality, substituting corn or small grain silage for grass silage or hay silage, adding oil and oilseeds to diets, as well as incorporating feed additives.

Improving forage quality is a priority area for GHG emissions reductions. Legesse et al. (2016) estimated that around 80% of enteric CH_4 in beef production stems from the cow-calf sector in Canada and forage-based diets produce more CH_4 than grain-based diets for cow-calf production (Beauchemin et al., 2010).

Improving forage quality can reduce the amount of GHG emissions produced from ruminants. Beauchemin et al. (2011) conducted a life cycle assessment of GHG mitigation strategies for beef production in Western Canada, by evaluating the impact of improving the nutritional value of the forage by harvesting the mixed hay at an early stage of physiological maturity. This mitigation strategy increased the digestibility of the forage by around 10% and reduced the dry matter (DM) intake of the cow-calf herd. As a result, the GHG intensity of the cow-calf herd was reduced by 5%. Although harvesting hay at an earlier stage slightly reduced crop yields, the amount of cropland needed to meet feed requirements decreased, since higher quality forage satisfied the animal's nutritional needs at a lower DM intake.

In addition, **substituting forage for grain** can be used as a GHG mitigation strategy, but the extent to which grain diets can reduce emissions depends on the type of grain. Substituting corn silage or small grain silage for grass silage or grass hay can potentially reduce CH_4 emissions by 5% to 10% (Beauchemin, 2019). Beauchemin and McGinn (2008) found that a diet consisting mainly of corn produces about 30% less CH_4 compared to diets consisting mainly of barley (Beauchemin & McGinn, 2008). However, it is important to balance the CH_4 mitigation potential of grain-based diets against the environmental benefits from forage-based beef production – including conversion of fibrous feeds that are unusable for human consumption to high-quality protein sources, provision of wildlife habitat, and enhanced soil carbon sequestration due to permanent soil cover (Yildirim, Bilyea, Buckingham, 2018). More generally, it is important to pay attention to lifecycle impacts of feed substitution, since grain crop production will have a different GHG emissions profile compared to fibrous feeds (Beauchemin, 2019).

Studies concerning the impact of feed on dairy systems have also yielded promising results. One study, comparing a more fibrous corn varietal to conventional corn feeds, found that using a brown midrib cultivar can reduce enteric CH_4 emissions. Additionally, the more fibrous feed could also reduce the manure volatilization potential, as the results show a decrease in manure N excretion (Hassanat, Gervais & Benchaar, 2017). A similar study examined corn or barley as the feed input and discovered that when feed contained approximately medium levels of digestible content, corn reduced total GHG emissions by 13% compared to barley. It is also important to note that as the digestibility level of the forage crop (hay or silage) increased, the emissions-intensity tended to decrease. For instance, despite the earlier finding that corn reduced GHG emissions, when evaluating the GHG intensity of low-digestibility corn-silage and high-digestibility barley-silage, barley outperformed the corn feed (Guyader et al., 2017). This underscores the importance of considering the impact of all inputs when designing a feed strategy that is intended to reduce GHG emissions.

Adding oil and oilseeds to beef and dairy livestock diets is another mitigation option, with the potential to reduce CH_4 emissions in the range of 5% to 20%. If energy supplementation in a ruminant's diet is changed from carbohydrate to fat, then less enteric fermentation and CH_4 production will occur (Haque, 2018). Different fat sources can be added to the diet such as crushed oilseeds (sunflower seed, canola seed or flaxseed) or dried distiller grains, as well as whole cottonseed, plant oils, and some ethanol by-products. The economic viability of increasing the share of oils and oilseeds in beef and dairy livestock diets is affected by feed costs, as well as possible negative impacts on the performance of ruminants due to a reduction in feed intake and digestion.

Feed additives such as yeast, enzymes, nitrate, and plant extracts can also impact CH_4 produced by ruminants. For instance, Lee and Beauchemin (2014) found in their meta-analysis that supplementary nitrate is a viable additive to reduce enteric CH_4 emissions without negatively impacting cattle's dry matter intake and live weight gain. Jayasundara et al. (2016) examined CH_4 and N_2O mitigation strategies for Canadian dairy farms and concluded that the addition of nitrate supplementation and 3-nitrooxypropanol (3NOP) to dairy cow diets has the potential to reduce enteric CH_4 by about 30%. However, further research is needed to identify the safety and adoption potential of this measure (Jayasundara et al., 2016). Micro-algae has also been identified as an additive to reduce CH_4 emissions from enteric fermentation. However, while the results of in vitro studies seem promising, live animal trials show potential negative impacts on animal productivity such as milk yield (Boeckaert et al., 2008); (Beauchemin et al., 2009).

Other additives, though, show even greater potential to offset enteric emissions in beef cattle. In one study, the introduction of a 0.5% addition of red macro-algae in high forage diets earlier in the life cycle reduced enteric emissions by 83% (Roque et al., 2021). Meanwhile, the introduction of the same level of red macro-algae in low forage diets such as those fed to beef cattle in their finishing stage, reduced enteric emissions by 64% (Roque et al., 2021). This study also found that the introduction of red macro-algae demonstrated no noticeable difference in average daily gain for beef steers (Roque et al., 2021)

There are many different variables affecting the economic and environmental benefits of these improved feeding practices, including the diversity of feeding practices, the efficiency levels of current feeding practices, and their heterogeneous costs and impacts on ruminant performance. This calls for a focused case study, grounded in a regional production system, that can further evaluate the current efficiency level of these feed practices, potential improvements, and producers' barriers to adoption. This comprehensive understanding can then pave the way for policy recommendations that facilitate the adoption of improved practices by producers.

Views from Workshop Participants

A case study on feed measures was broadly supported by workshop participants based on the fact that the most recent North American trade deal (Canada-United States-Mexico Agreement, or CUSMA) provided the US with higher market access to some supply-managed agricultural sectors, such as dairy. The federal government has announced transitional support to help Canada's supply-managed producers manage these disruptions (BNN Bloomberg, 2018). The government could potentially make transitional support payments conditional on the adoption of BMPs, such as improved feeds, thereby improving the environmental footprint of the sector through the use of existing fiscal resources.

In contrast, some stakeholders did not entirely support the modified feeds case study, citing potential unforeseen consequences. They noted that extensive livestock systems are one of the few economically viable means of conserving biodiversity in grasslands and pasturelands, and that substituting traditional forages for more GHG-efficient feeds would further exacerbate the loss of grasslands and pasturelands. As mentioned previously, participants also thought that expanding the research scope to encompass GHG mitigation across the beef and dairy livestock sector more broadly would strengthen the case study.

7.6. Circular Economy Approaches for Canada's Agri-food Sector

Overview

Food loss and waste (FLW) is a major challenge facing the agriculture and agri-food system in Canada. The term "food loss" is typically used to describe the loss of food that occurs from production through to processing, while the term "food waste" describes the discarding of food, either through retail or food services, or by consumers within the home. The total avoidable and unavoidable FLW along the Canadian food value chain is estimated to be 35.5 million metric tonnes annually – but only 11.2 million metric tonnes (32%) of this total FLW is avoidable and likely edible. However, this is still equivalent to nearly one-fifth (18%) of all commodities entering the Canadian food system. This is clearly a lost opportunity in light of the fact that four million Canadians still struggle to access healthy food, including 1.4 million children (Nikkel et al., 2019).

The majority (71%) of the total FLW – as well as 49% of avoidable FLW – occurs during primary production, processing, and manufacturing. Approximately 6% of avoidable FLW occurs at the production stage, whereas approximately 20% occurs during processing and another 23% occurs during manufacturing, respectively (Nikkel et al., 2019). However, the FLW across the value chain differs substantially by crop. For instance, an estimated 13% of fruits and vegetables grown in Canada go unharvested or are discarded following harvest (ECCC, 2019c).

> ***Food loss and waste across the value chain differs substantially by crop type. For instance, an estimated 13% of fruits and vegetables grown in Canada go unharvested or are discarded following harvest (ECCC, 2019c).***

Key reasons for food loss at the production level in Canada include: culling to meet quality and cosmetic standards for produce; seasonal fluctuations in supply and demand; inadequate demand forecasting; insufficient number of employees to harvest and handle produce; inadequate storage, handling, and transportation infrastructure; order cancellation; overproduction to ensure contractual obligations are met; and market prices that are insufficient to cover the cost of harvest (ECCC, 2019c).

FLW has a significant environmental impact and often imposes substantial economic costs on businesses and society. Food that ends up in a landfill leads to CH_4 emissions, and it is estimated that within Canada alone, FLW (both avoidable and unavoidable components) is responsible for 56.5 million tons of CO_2 equivalent emissions and has a blue (surface and ground water) water footprint of 4.5 billion tonnes. This accounts for close to 60% of the food industry's entire environmental footprint, a large part of which comes from avoidable FLW (and hence is entirely unnecessary from a technical standpoint) (ECCC, 2019c).

The total financial value of this avoidable FLW has been estimated to be $49.5 billion – and almost half of this value is generated during production, processing, and manufacturing (Nikkel et al., 2019).[49] While these are likely to be upper-bound estimates of economic costs (and perhaps environmental impacts as well), they do illustrate that both the environmental and social costs are substantial.

Much of this FLW is the product of a linear 'take-make-waste' economic model that could be mitigated by adopting a circular economy approach. A circular economy for food mimics natural systems of energy, material, and nutrient flows. Repurposing crop residues, manufacturing by-products, and transforming unwanted and spoiled foods into feedstocks can allow what was previously considered waste to have another productive cycle. This has the potential to generate tremendous social, environmental, and economic benefits. One study estimated that the global economic opportunity created from cities alone shifting from waste to value capture in a circular agri-food economy is up to USD $700 billion annually (Ellen MacArthur Foundation, 2019).

A circular economy approach focused on FLW from primary production, processing, and manufacturing can decrease the carbon footprint of the sector by avoiding food waste, mitigating un-economic food losses throughout the value chain, and potentially creating extra value-added opportunities by redirecting these losses to other channels. Examples could include redistributing surplus edible food, creating new products out of otherwise unwanted food (e.g. using blemished spinach for frozen spinach 'smoothie pucks'), and returning crop residues to soil (to enhance SOM) – or using it as a raw material to produce bioenergy, biofertilizer, or bioplastic.

To provide an example close to home, a distillery in Ontario has found a way to use unwanted milk permeate (leftover milk product after fats and proteins are taken out to make products) to create vodka. This milk permeate is otherwise both an environmental and financial problem as farmers have to pay to safely dispose of it (CPA, 2020). In Denmark, the Billund Biorefinery collects organic household waste from the local municipality and organic by-products from the local agriculture industry to create biogas. This biogas is then used for the production of heat and electricity that is sold to the public grid (State of Green, n.d.).

The Nutrient Stakeholder Platform established in Quebec provides another interesting example. This platform was created in response to Quebec's Policy on Residual Materials and focuses on changing waste collection, waste treatment, and product distribution practices. This program brings together stakeholders from all aspects of the supply chain – such as producers, industry, and government actors – to inform them of the benefits of implementing circular economy practices. Areas of focus for this program include: securely establishing local fertilizer supplies to reduce food insecurity, increasing the use of nutrient recovery and reuse (NRR) practices, and increasing agricultural yields through the use of more nutrient-efficient products that can help mitigate environmental risks (IISD, 2018).

The concept of a circular economy for agriculture and agri-food has been gaining traction of late. For instance, the city of Guelph has launched a circular food economy program that aims to identify all the waste streams in the region's food systems and to think creatively about how these waste streams can be eliminated or turned into something that generates economic opportunities (City of Guelph, 2019). The federal Agricultural Clean Technology Program is a $25 million, three year program which also funds similar efforts in this space, such as agricultural bioproducts (AAFC, 2020a). These first movers notwithstanding, overall action in this area has been fragmented. Despite the tremendous potential for triple-bottom-line benefits, there is as yet no system-wide vision for transformational change in Canada's agriculture and agri-food industry (Ellen MacArthur foundation, 2019).

Views from Workshop Participants

Workshop participants offered three reasons for their enthusiasm toward a circular economy approach to agriculture and agri-food. The first one stemmed from the belief that food waste is such a significant issue in society and that a circular economy approach has the potential to realize both economic and environmental benefits. Second, many participants also supported this case study due to its potential to engage the entire agri-food supply chain and the private sector more broadly in solutions. Finally, participants also believed that the results from the case study could have the potential to be scaled to different jurisdictions, production systems, as well as both urban and rural areas.

Despite the support, participants emphasized the importance of having a portfolio of policy approaches, tailored to different commodities. Properly scoping each case study based on the specific processes that create FLW for that specific commodity is necessary in order to formulate effective policy recommendations. Additionally, participants proposed that a whole-sector approach is necessary to properly assess which economic instruments (such as financial penalties and rewards) would be most effective for engaging different parts of the supply chain such as producers, manufacturers, and consumers. These two suggestions imply that a 'package' of different policy approaches will be required to maximize the effectiveness of circular economy interventions. To provide one example, this could include focusing on practices that offer cost savings or economic benefits to encourage food producers, processors, and manufacturers to change their behaviour, whereas consumers would instead be engaged in a public communications campaign on waste avoidance to foster changes in their behaviour.

7.7 Other Case Study Areas Proposed by Workshop Participants

Participants also provided insights and suggestions on other potential case study areas that could help the sector concurrently achieve its economic and environmental goals. Key case study ideas included: (7) Changes to BRM programs and cross-compliance; (8) Behavioural approaches to farmers' decision making; (9) Incentivizing an ecosystem services approach to agriculture; (10) Leveraging corporate sustainability goals; (11) Addressing data gaps within the agriculture sector.

7.8. Changes to BRM Programs and Cross-compliance

AAFC currently provides a suite of jointly funded FPT BRM programs to farmers, including AgriInsurance, AgriStability, and AgriInvest. Several workshop participants have noted that there is an untapped opportunity to leverage these programs to enhance environmental outcomes, whether through an enhancement of existing programs (e.g. making *additional* BRM matching funds or insurance premium discounts conditional on BMP adoption) or through cross-compliance (making one or more forms of *existing* BRM supports conditional on BMP adoption). Moreover, the Prime Minister's inclusion of a review to AgriStability in the Minister of Agriculture and Agri-food's 2019 mandate letter has provided an important opportunity to review these programs and determine whether they could be modified to enhance environmental outcomes.

Although cross-compliance and enhancing BRM supports to reward BMP adoption both have the potential to serve as cost-effective tools for encouraging environmental stewardship, their distributional consequences are very different. Given the significant hardships that farmers have already experienced in the face of the COVID-19 crisis and extreme weather conditions, enhancing BRM supports so that they reward BMP adoption is by far the more attractive option in the short-to-medium term.

Moreover, devising effective enhancements to BRM programs will require a careful understanding of some of the trade-offs and limitations inherent in their design. For instance, research suggests that the current 1% match offered by governments for total net allowable sales under AgriInvest, might not be sufficient to incentivize farmers to adopt additional BMPs (Rude & Weersink, 2018). Thus, this case study would thoroughly review options for reforming BRM programs, such as the proper level of payment, the type of eligible BMPs, and the role of complementary programs (e.g. cost-share). This case study would draw upon local experiences with cross-compliance programs (e.g. Quebec and PEI), as well as other jurisdictions such as the US and the UK.

7.9. Behavioural Approaches to Farmers' Decision Making

Workshop participants consistently identified gaps in the public's understanding of farmers' motivation for adopting BMPs as a barrier to improved program design. Behavioural economics research has consistently helped to highlight the explanatory limitations of models of human behaviour based on expected utility maximization or the concept of the 'rational economic man.'

Through research and convening, this case study would undertake a strategic review of behavioural economics issues in the agriculture and agri-food landscape, and identify which kinds of behavioural interventions would be most effective at solving particular agri-environmental problems in specific contexts. This could lay the groundwork for potential pilot projects that test behavioural interventions such as: administrative experiments (testing how changes in administrative aspects of programs such as enrolment forms affect participation), framing experiments, social-norm based messaging for program outreach, the role of fellow farmers or agronomists in acting as trusted messengers, leveraging social norms using collective bonus payments, or testing the role of defaults in agri-environmental contracts.

An ecosystem services approach to agriculture would also advance two additional priorities shared by federal and provincial governments, namely nature-based solutions to climate change mitigation and natural infrastructure for climate change adaptation and resilience.

7.10. Incentivizing an Ecosystem Services Approach to Agriculture

A number of workshop participants argued that systematically demonstrating, quantifying, and capturing (or rewarding) the provision of on-farm ecosystem services would provide a wide range of benefits for producers, for wildlife, and for broader society. Priority management practices and ecosystem services identified by workshop participants included the establishment of riparian vegetation buffers (for water purification and erosion control), conserving and restoring on-farm wetlands (for flood mitigation and water purification), as well as conserving wild pollinators and/or biological control agents (to augment or stabilize crop yields). An ecosystem services approach to agriculture would also advance two additional priorities shared by federal and provincial governments, namely nature-based solutions to climate change mitigation (through practices that restore natural systems and enhance biological carbon on farmland) and natural infrastructure (ecosystems whose functions and services act as a complement or substitute to traditional grey infrastructure) for climate change adaptation and resilience.

The Nature Based Climate Solutions Summit, held in 2020, also championed both of these approaches for climate change mitigation and adaptation in Canada. Recent studies, like Drever et al. (2021) have shown that agricultural BMPs such as riparian buffer zones, and natural infrastructure solutions such as agro-forestry and wetlands, offer some promising mitigation and adaption prospects.

Stakeholders identified four major policy options for incentivizing an ecosystem services approach to agriculture. The first would be a payment for ecological services scheme aimed at conserving and enhancing already existing on-farm ecosystems. The second was a program modeled on the US CRP and Canada's Greencover program which ran from 2003-2008, both of which aimed to retire marginal farmland from production – which was identified as a major gap in existing federal programs. The third was a set of rewards for 'stacking' multiple ecosystem services (e.g. carbon, water, and biodiversity) – either through a series of results-based payments for each of the services or through a set of separately tradeable environmental credits (e.g. carbon, water quality, and biodiversity credits). Finally, some stakeholders suggested that a program similar to AAFC's Living Labs Initiative would provide an excellent avenue to pilot ecosystem services-based interventions, especially those with high potential for providing economic and environmental benefits, but which may require a more robust evidence base prior to scaling up (such as enhancing pollinator abundance on fruit farms).

7.11. Leveraging Corporate Sustainability Goals

Workshop participants noted the increasingly important role that corporate commitments to climate change mitigation, biodiversity conservation, and sustainable supply chains are playing in the agriculture and agri-food sector. As was mentioned previously, leading companies such as McDonald's, Maple Leaf, and Unilever are committing to reduce their GHG emissions and to enhancing the overall sustainability of their supply chains (CRSB, 2019; Maple Leaf Foods, 2019; Unilever, n.d.). Multisectoral initiatives that advocate for sustainable production through collaboration between stakeholders are also playing a role in setting sustainability standards along the supply chain. Some international examples of these initiatives include: The Science-Based Targets Network, a group of corporate and environmental leaders catalyzing GHG emissions reduction targets that are in line with targets for stabilizing global emissions proposed by climate scientist; and the One Planet Business for Biodiversity initiative, which focuses on systematic change to foster biodiversity conservation (particularly in the agriculture and agri-food sector) (OP2B, n.d.).

Closer to home, the Circular Economy Leadership Coalition is one of the more prominent Canadian multisectoral initiatives. Co-founded by the National Zero Waste Coalition and involving a number of private sector and ENGO players from Canada and abroad, the coalition provides technical expertise and a collaborative platform to accelerate the transition to a regenerative, zero-waste economy in Canada and around the world.

This case study would also build upon work that is already underway, since provincial governments have been working toward benchmarking their respective EFP frameworks against the Farm Sustainability Assessment framework offered by the SAI Platform. This benchmarking exercise provides them with an opportunity to assess the EFP framework against international standards. This case study would focus on a set of specific commodities, and assess the following issues: potential opportunities and pitfalls in anchoring policy around corporate sustainability initiatives; highlighting opportunities for collaboration and sustainability improvements along the supply chain; and identifying policy gaps and providing policy suggestions that further enhance multi-stakeholder collaboration in Canada's agriculture and agri-food system.

7.12. Addressing Data Gaps within the Agriculture Sector

Nearly all of the workshop participants identified data gaps as a major problem within Canada's agricultural sector. Stakeholder discussions and subsequent research have identified three major opportunities for improving data collection, analysis, and dissemination within the sector: (1) providing key information concerning environmental performance 'on the ground'; (2) indicators for benchmarking the environmental performance of Canada's agriculture and agri-food sector in a global context; and (3) data needs for assessing the effectiveness of agri-environmental programs.

There are currently several important data gaps for tracking environmental performance 'on the ground'. For instance, the available data on SOC from AAFC's agri-environmental indicators series are at a very high level of aggregation, but SOC levels at lower spatial scales are much more heterogeneous, which matters for policy targeting. To help evaluate the effectiveness of its nutrient management measures, the Ontario government decided to undertake systematic soil sampling, as well as analysis of historical data in the province to better track this key environmental indicator. There are also some important gaps in terms of reporting on essential data for agricultural decision making. For instance, there is very little data on the average fertilizer use by type of fertilizer as well as fertilizer use intensity (kg per acre), both of which are important for setting baselines against which nutrient management programs can be evaluated.

New approaches to data analysis and reporting are also required to benchmark the environmental sustainability of Canada's agricultural sector compared to peer countries. Currently, the available data is either highly aggregated (such as data presented from the National Inventory Report or AAFC's agri-environmental indicators series), or particular to specific commodities, such as GHG emissions from beef livestock (e.g. as estimated by FAOSTAT). Moreover, data on environmental performance is typically reported either in absolute terms (e.g. total GHG emissions), or in terms of an index. While indexes such as AAFC's Agri-Environmental indicators are useful, the information they provide is not necessarily internationally comparable.

As such, there are two important data needs that are still not being fully addressed. First, there is a need to provide information at an intermediate level of resolution, in which commodities are aggregated into broad groups (such as oilseeds or pulses) to facilitate international comparisons and avoid 'information overload', while keeping enough granularity to make the information relevant for domestic industry and policymakers. Second, there is a need for improved reporting of environmental performance on a per-unit basis to facilitate international benchmarking (e.g. per acre of land; per tonne of product; or perhaps per dollar of product). Although there are instances where the GHG emission intensity of certain crops or products is reported for the agricultural sector as a whole, greater disaggregation and ensuring that the methodology used is consistent would provide an opportunity to better track progress across peer countries and time periods.

Finally, although participants agreed that agri-environmental programs play an important role in promoting BMP adoption to producers, there is a critical need for rigorous program evaluations to better understand what's working, what aspects of program design need to be refined, and how to increase their cost-effectiveness and environmental impact. Virtually all agri-environment schemes in Canada conduct program reporting and evaluations on the basis of outcomes (e.g. number of landowners enrolled) rather than environmental impacts. Similarly, few if any programs have been evaluated using a control group or a counterfactual scenario to determine what would have happened in the absence of the program.

While acknowledging that federal departments sometimes face legal and confidentiality constraints in terms of what sorts of data they can share, this case study would convene a series of workshops to outline and test good practices for sharing program administrative data while respecting privacy constraints, as well as leading edge-principles for 'quasi-experimental' program design (i.e. implementing programs with treatment and control groups, or statistically matching participants with non-participants) to improve program design and environmental outcomes.

8. OVERVIEW OF STAKEHOLDER ASSESSMENT OF CASE STUDIES

Table 3 synthesizes the stakeholder's assessments of each case study, and categorizes future case studies in terms of priority (very high, high, moderate, low). This is followed by a discussion of next steps for SPI's work stream in this space.

Canada is facing an unprecedented opportunity to foster strong growth in the agriculture and agri-food sector while contributing to Canada's environmental objectives.

Table 3. Stakeholder Assessment of Case Studies

Case Study	Supporting Points	Drawbacks/ Suggestions for improvement	Ranking
1.Nitrogen Fertilizer Management	Generate both economic and environmental benefits Enhanced co-benefits such as water quality improvement and soil health Scalability to different production systems Contributing to Canada's international GHG emission reduction commitments	Actions already being taken, so need to clearly identify areas where new policy approaches can add value (e.g. behavioural economics approach, de-risking approach) Narrow framing – consider including fertilizer alternatives (e.g. manure, legumes) or upstream fertilizer production	**Very High**
2. CRISPR	Potential for Canada to become a leader in CRISPR development and patenting Global attention to new gene-editing technologies Large potential to alter the farming sector and farm practices The ease of setting regulatory and policy systems without the need to change an already established system	EU decision to regulate CRISPR as a GMO Regulatory bottlenecks Case study might become obsolete in a short period of time Doesn't necessarily encourage environmentally friendly practices Narrow framing – consider including selective plant breeding for low input use	**Low**
3. Animal Genomics	Potential to reduce GHG emissions in the livestock sector Potential to create exportable IP	More promising near-term option for improving the environmental performance of the beef industry Narrow framing – include more holistic, system-based approach, or multiple practices/ technologies Regulatory bottlenecks	**Moderate**
4. Feed Measures	Near-term potential to reduce GHG emissions in the livestock sector Opportunity to improve environmental outcomes by tying federal trade adjustment payments to BMP adoption by dairy industry	Pasture-based ruminant production helps maintain biodiversity in grasslands/pastures Narrow framing – include more holistic, system-based approach, or multiple practices/ technologies	**Moderate**
5. Soil Health	Generate significant environmental and economic benefits Enhanced co-benefits such as ecological services, e.g. reduced risk from run-off and flooding	Identifying areas where new policy approaches can add value to the actions provinces are already undertaking Broadening the scope beyond SOC and SOM	**Very High**
6. Circular Economy	Addressing FLW provides both economic and environmental benefits Engaging broader supply chains/ private sector in solutions	Circular economy solutions might be very different for each commodity Effective solutions need to identify and target appropriate points of supply chains	**High**

Participants' case study recommendations			
7. Changes to business risk management programs, and cross-compliance	Opportunity to leverage existing business risk management programs toward environmental stewardship Lower administrative costs (builds off existing programs)	Changes in BRM programs need to be made in collaboration with PT governments	**Moderate**
8. Behavioural approaches to farmers' decision making	Addresses knowledge gaps in factors influencing farmers' adoption decisions Novel approach to implementing cost-effective agri-environmental policy	Very context-specific (may be difficult to scale up) Social acceptability to manage (e.g. can be seen as social manipulation)	**High**
9. Incentivizing an ecosystem services approach to agriculture	Co-benefits for the environment and farmers Strong alignment with other federal and provincial government priorities (e.g. nature-based solutions; natural infrastructure)	Very site-specific Difficult to accurately assess environmental benefit and adequacy of ecosystem service payments	**High**
10. Leveraging corporate sustainability goals	Accelerating the adoption of sustainable farming practices through downstream pressures	Coordinated actions need to be take in collaboration with the value chain actors as a whole	**Moderate**
11. Addressing data gaps in the agriculture sector	Provides more granular data to inform decision making (e.g. by commodity group) Current data on environmental performance not necessarily internationally comparable (e.g. GHG intensity by commodity/activity group) Lack of rigorous baselines and/or control groups for program evaluation	Multiple legal and confidentiality implications	**High**

8.1 Next Steps

As this discussion has made clear, Canada is facing an unprecedented opportunity to foster strong growth in the agriculture and agri-food sector while contributing to Canada's environmental objectives. But current approaches are not enough to get us there. Through innovative policy approaches, policymakers can help increase technology deployment and BMP adoption to the benefit of farmers, industry, the environment, and Canadians at large.

This report has outlined some policy instruments and actionable opportunities help achieve Canada's ambitious targets. It also identified future case studies for research and convening to realize shared environment-economic objectives. Future work from SPI aims advance these case study topics along the spectrum from initial scoping research (as was done with this report), to regionally focused case studies (as is the case with the SPI's forthcoming report on efficient nitrogen fertilizer management in Ontario and PEI), and culminating in a series of pilot projects, co-designed with local partners, to test these policy interventions in different geographies across the country.

9. CONCLUSION

Canada has set ambitious targets to reduce GHG emissions by 40-45% below 2005 levels, reduce fertilizer emissions by 30% from 2020 levels by 2030, protect 25% of its terrestrial area and its ocean and shorelines by 2025, and reach net-zero emissions by 2050 (ECCC, 2020a; ECCC, 2021a). Canada also has aggressive economic growth targets in the agriculture and agri-food sector – namely growing agriculture, agri-food, and seafood exports).

Reconciling the economic opportunity with the environmental challenge will be no small feat. To give just one example, 10% of Canada's emissions originate from the agriculture sector. These emissions are complex in nature, encompassing fertilizer use, land management, livestock rearing, manure management, on-farm energy use, and food loss and waste – no single instrument or practice will be sufficient to do the job. Decoupling economic growth from environmental harm thus requires a well-targeted and comprehensive package of policies for the agriculture sector.

Federal, provincial, and territorial governments have already enacted numerous policies and programs that encourage environmental stewardship from producers and industry, such as the Environmental Farm Plan and voluntary cost-share programs. These programs have rolled out innovative designs such as social and spatial targeting in recent years, as well as tools for assessing the environmental benefits of proposed BMPs. Although these policies and programs show promise in reducing the sector's environmental footprint, there is still much room for improvement, and novel policy approaches will be needed to accelerate the development and adoption of improved technologies and BMPs.

Harnessing innovative policy instruments such as behavioral interventions, environmental taxes, voluntary ecological certification, targeted payment schemes (spatial targeting and reverse auctions), and offset programs (for water quality, GHGs, and biodiversity) can offer new avenues for clean growth in Canada's agriculture and agri-food sector. To address the sector's most important environmental challenges in an actionable way, these tools need to be grounded in solid analysis and piloted (and then scaled up) in key production systems.

Based on the stakeholder assessments from SPI's January 2020 workshop in Ottawa and the literature review of potential case studies for future research, stakeholders saw the nitrogen fertilizer management, soil health, and circular economy focus areas as having the greatest potential for reducing environmental impacts over the short and medium term, while providing economic benefits for producers. In the case of circular economy, economic and environmental benefits extend to the broader supply chain. There was also significant enthusiasm for an integrated case study assessing decarbonization opportunities across the beef and dairy livestock sectors (e.g. improved livestock feeds, carbon sequestration in prairie grasslands, etc.).

Experts also identified improvements to the current business risk management (BRM) programs and ecosystem services approaches to agriculture as focus areas with high potential. Adjustments to the BRM programs present an important window of opportunity to improve environmental outcomes using existing program frameworks. By contrast, focusing on the ecosystem services approach in agriculture would provide an integrated set of benefits for the sector, advancing climate mitigation targets as well as increasing the resilience of local communities.

By providing an integrated approach that moves from scoping research, to local convening, to the co-design of pilot projects for a host of priority agri-environmental issues, SPI will ensure that the policy recommendations are not only grounded in cutting-edge research, but also account for the social, economic and agronomic constraints in the local production systems and supply chains covered in the identified focus areas. This approach will enhance the adoption of new technologies and practices for the benefit of producers, industry, the environment, and society.

This report has made clear that a major clean growth opportunity in agriculture and agri-food awaits us – but only if Canada acts. And the time to act is now.

ENDNOTE CITATIONS

1 Authors' own calculations.
2 *Source: Trends shaping education, OECD (2019b, p.21)*
3 Although not the focus of this report, analyzing and forecasting the skills that the agriculture sector will need in the future, and developing a careful plan for effective skills and training programs, will be critical to the sustainability and resilience of the sector value chain in the coming years.
4 See Canada's Official Greenhouse Gas Inventory- Table A-10-2: GHG Emissions for Canada by Canadian Economic Sector (excluding on-farm fuel use) (ECCC, 2021b) for more information.
5 The 'With Measures' scenario considers programs or policies which are already largely implemented. This iteration of the Biennial Report includes emissions reductions factors for programs such as: carbon pollution pricing, accelerated coal-phase out, and the Low Carbon Economy Fund. This is not an exhaustive list.
6 The 'With Additional Measures' scenario considers program or policies that have been announced (i.e. in the Pan-Canadian Framework) but not yet implemented. This iteration of the Biennial Report considers emissions reduction factors for programs such as: the Clean Fuel Standard, net-zero building codes, and transport sector measures targeting light duty and off-road vehicles. This is not an exhaustive list.
7 Personal communication with Hugues Morand, AAFC, 20 April 2020.
8 *Adapted from Canada's Official Greenhouse Gas Inventory- Table A-10-2: GHG Emissions for Canada by the Canadian Economic Sector (excluding on-farm fuel use). Gross domestic product (GDP) at basic prices, by industry, annual average, industry detail, Table: 36-10-0434-06*
9 The numbers are based on averaging water withdrawal and consumption by sector over 2005-2013 period released by ECCC (2017), the data set can be accessed at: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/water-withdrawal-consumption-sector.html
10 *Source: Agri-Environmental Indicators, Report 4. (Clearwater et al., 2016, p.4)*
11 *Source: Agri-Environmental Indicators, Report 4. (Clearwater et al., 2016, p.2).*
12 The study valued all food loss using the average of food retail prices; and hotel, restaurant and institution prices. However, it should be noted that this methodology will almost certainly overestimate the value of FLW. For discussion, see Bellemare et al. (2017).
13 *Source: Skolrud, T. et al. (2020, p.11). Measuring Externalities in Canadian Agriculture: Understanding the Impact of Agricultural Production on the Environment*
14 These values were estimated using what are known as value transfer methods. Value-transfer methods use ecosystem service values from previous studies to estimate values for a novel policy context or study site. The CAPI report uses biophysical values for environmental services and then uses per-unit values from peer reviewed studies to convert these physical units to monetary values (unit value transfer).
15 *Calculated using 2011 constant GDP of crop and animal production in these provinces from Statistics Canada. The combined GDP of primary agriculture in these provinces in 2011 was $21.3 billion.*
16 Calculated using 2011 private household data from Statistics Canada.
17 As a % of the comparative added value contribution of the domestic agricultural economy.
18 *Source: Aqueduct Country and River Basin Rankings, World Resources Institute (Gassert et al., 2013)*
19 Data for eggs, chicken and dairy based on FAO STAT emissions intensity data (FAO, 2019).
20 As suggested by the Canada Food Brand project, this could also be used to foster alignment with the Sustainable Development Goal (SDGs) (Canada 2020, 2019).
21 *Source: World Development Report 2010 (World Bank, 2010, p. 5). This map represents the percent change in yield of 11 major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soybean, groundnut, sunflower, and rapeseed) from 2046 to 2055, compared with 1996–2005*
22 To be clear, this is not to argue that global average temperature increases of e.g. 3 degrees Celsius are in Canada's interest (to say nothing of obligations to people across the world who will be most impacted by the effects of future climate change, or to future generations). It is instead meant to illustrate that Canada's agricultural sector is better positioned to weather future climate change than peer countries.
23 Increasing emphasis on local food production and sales may provide GHG benefits in some instances, but this depends on context-specific comparative advantages in crop production and overall lifecycle GHG emissions (Rausser, Sexton & Zilberman, 2019).
24 The Ontario Soil and Crop Improvement Association was subcontracted to administer the development of EFPs by the Ontario Farm Environmental Coalition.
25 Some of these data are provided to the federal government via the AgriShare data system (e.g. numbers of BMPs funded by type, numbers of EFPs developed or updated), however, inconsistency in the level of detail varies by PT, making comparability challenging.
26 Nudges are measures that seek to change behaviour by modifying decision-making contexts in ways that are non-coercive and that do not affect monetary payoff (Sunstein & Thaler, 2008). Boosting is the other major paradigm for behavioural interventions. In contrast to nudges which attempt to benignly change peoples' decision-making environments, boosts attempt to empower people by enhancing their decision-making capabilities. Boosting interventions are also well worth considering in a number of policy contexts, although they will not be investigated in this report. For a discussion of the policy-relevance of boosting, see (Hertwig, 2017).
27 Positive Punishment refers to presenting something undesirable to the participant in order to decrease the likelihood that they will perform the same behaviour again. For example, adding disapproving messaging when undesirable choices are made.
28 Affectual Nudging refers to attempts to change behaviour by drawing on or influencing the target's emotions. For example, asking someone to exhibit empathy through the consideration of the other party's position.
29 This is in keeping with Sunstein and Thaler's commitment to nudges being transparent and publicly defensible ('publicity'), and to making the people being 'nudged' better off by their own standards (Sunstein & Thaler, 2008).
30 By contrast, pesticide damages are more closely associated with the specific pesticide formulation, the quantities of active ingredients applied, as well as the location in the field where the pesticides are applied.
31 However, previous research from Rivers and Schaufele (2015) found that the BC carbon tax (which was set at CAD $30/tonne at the time of publication) had little discernable effect on agricultural trade from 2008 (the period when the tax came into effect) to 2011 (when the government introduced carbon tax exemptions for several agricultural subsectors).
32 Strictly speaking, a price premium does not refer to the additional costs of certification – instead it refers to the price increase commanded by certified products after accounting for the increased costs of producing and certifying the product.
33 4R™ refers to right source, right rate, right time, and right place (Fertilizer Canada, 2019).
34 However, it is not clear if these results would be the same in Canada, since in reality it may be possible for organic agriculture to maintain current levels of food production through strategies that mitigate or compensate for yield penalties – such as only transitioning crops to organic production when yield gaps are small, aggressive prevention of avoidable food loss and food waste, or by further substituting plant protein for animal protein in human diets (see e.g. Muller et al. 2017).
35 Eutrophication refers to enrichment of aquatic and terrestrial habitat with nutrients which induces excessive growth of algae. The main agricultural sources of eutrophication are nitrate, phosphate and ammonia.

36 The main agricultural sources of acidification are ammonia (NH_3) and sulphur dioxide ($_{SO2}$).
37 The eutrophication and acidification potential in organic farming per unit of land is generally lower in organic farming per area unit due to the reduced use of nutrient inputs. However, due to the lower productivity of organic farming, this does not hold true for eutrophication and acidification potential per unit of output.
38 Usually, this payment is either the value of the highest accepted bid, or the lowest rejected bid. Alternatively, they can each be paid for the value of their winning bid (this is known as a discriminative price auction).
39 In principle, it may be possible to target farmers based on demographic variables that are associated with higher levels of environmental risks, but this might be resource-intensive and there is currently no known program that has attempted this approach.
40 Although this is a forestry offsets program, it provides an instructive model for how to deal with carbon offsets in the land use sector more broadly.
41 There are other issues with the common practice approach to determining additionality as well – see (Thamo & Pannell, 2016)
42 However, it is important to recognize that some actions have negligible leakage risks, such as retiring marginal cropland, or conserving or restoring ecosystems such as pastures, or wetlands.
43 The programs included in the study are Lake Simcoe Phosphorus Offsetting Program (Ontario, Canada); South Nation Conservation water quality trading program (Ontario, Canada); The Lake Taupō nitrogen trading program (Waikato, New Zealand); Clean Water Services' Tualatin River program (Oregon, USA); Erie P Market (Western Lake Erie Basin, USA) ; and Electric Power Research Institute Ohio River Basin Trading Project (Ohio, USA).
44 For instance, integrating legumes into cereal cropping systems helps increase the latter's protein content, thus enabling producers to command a higher price for their cereal crop (Government of Alberta, 2008).
45 For example, intensifying agricultural production so to arrest or slow down the increase in cultivated area, and increase the overall area of land devoted to nature conservation (e.g. by retiring marginal cropland).
46 Amount of dry matter needed to gain one unit of weight.
47 The difference between the animals' actual feed intake and its expected feed intake based on its size and growth.
48 Assuming that the marginal abatement cost does not exceed the social cost of carbon.
49 The study valued all food loss using the average of food retail prices; and hotel, restaurant and institution prices. However, it should be noted that this methodology will almost certainly overestimate the value of FLW. For discussion, see Bellemare et al. (2017).

REFERENCES

AAFC. (2017a). Commodity Innovation Series: Snapshot of Opportunities in Spain's Pulse Sector. Government of Canada. Retrieved from https://publications.gc.ca/collections/collection_2017/aac-aafc/A74-4-11-2017-eng.pdf

AAFC. (2017b). Commodity Innovation Series: Snapshot of Opportunities in Italie's Lentil Sector. Government of Canada. Retrieved from https://www.agr.gc.ca/resources/prod/Internet-Internet/MISB-DGSIM/ATS-SEA/PDF/snapshot_lentils_italy_apercu_lentilles_italie1-eng.pdf

AAFC. (2018). Financial Impacts of Carbon Pricing on Canadian Farms. Government of Canada. Retrieved from https://multimedia.agr.gc.ca/pack/pdf/carbon_price_presentation-eng.pdf

AAFC. (2019). Canadian Agricultural Partnership. Government of Canada. Retrieved from http://www.agr.gc.ca/eng/about-our-department/key-departmental-initiatives/canadian-agricultural-partnership/?id=1461767369849

AAFC. (2020a). Agricultural Clean Technology Program. Government of Canada. Retrieved from https://www.agr.gc.ca/eng/agricultural-programs-and-services/agricultural-clean-technology-program/?id=1521202868490

AAFC. (2020b). Canadian Agricultural Strategic Priorities Program. Government of Canada. Retrieved from https://www.agr.gc.ca/eng/agricultural-programs-and-services/canadian-agricultural-strategic-priorities-program/?id=1549325740130

AAFC. (2020c). Boosting Canada's reputation as a global leader in plant proteins. Government of Canada. Retrieved from https://www.canada.ca/en/agriculture-agri-food/news/2020/06/boosting-canadas-reputation-as-a-global-leader-in-plant-proteins.html

AAFC. (2021a). Agricultural Climate Solutions. Government of Canada. Retrieved from https://www.agr.gc.ca/eng/agriculture-and-the-environment/agricultural-climate-solutions/?id=1615985409730

AAFC (2021b). Local Food Infrastructure Fund. Government of Canada. Retrieved from https://agriculture.canada.ca/en/agricultural-programs-and-services/local-food-infrastructure-fund

AAFC. (2021c). 2020-2023 Departmental Sustainable Development Strategy. Government of Canada. Retrieved from https://agriculture.canada.ca/en/about-our-department/key-departmental-initiatives/federal-sustainable-development-strategy/2020-2023-departmental-sustainable-development-strategy

AAFC. (2021d). 2021-22 Departmental Plan. Government of Canada. Retrieved from https://agriculture.canada.ca/sites/default/files/legacy/pack/pdf/dp-pm_2021-22-eng.pdf

AAFC. (2021e). On-Farm Climate Action Fund. Government of Canada. Retrieved from https://agriculture.canada.ca/en/agricultural-programs-and-services/agricultural-climate-solutions-farm-climate-action-fund-0

ACEG. (2017). Unleashing the Growth Potential of Key Sectors. Ottawa, ON: Advisory Council on Economic Growth.

Adamowicz, W. L., & Olewiler, N. (2016). Helping markets get prices right: Natural capital, ecosystem services, and sustainability. In Canadian Public Policy (Vol. 42, Issue 1, pp. S32–S38). University of Toronto Press Inc. doi: https://doi.org/10.3138/cpp.2015-021

Agriculture and Resource Development. (n.d.) What is GROW? Government of Manitoba. Retrieved from https://www.gov.mb.ca/water/watershed/grow/

AIC. (2017). An Overview of the Canadian Agricultural Innovation System. Agricultural Institute of Canada. Retrieved from https://www.aic.ca/wp-content/uploads/2021/04/AIC-An-Overview-of-the-Canadian-Agricultural-Innovation-System-2017.pdf

Alberta Wheat Commission. (2020). Sustainability at the Provincial Level. Alberta Wheat Commission. Retrieved from https://albertawheat.com/our-programs/government-relations-and-policy/sustainability

An, H., Adamowicz, W. L., & Lloyd-Smith, P. (2019). Strategic behaviour in stated preferences and the demand for gene-edited canola oil. Agriculture and Applied Economics Association Annual meeting. Atlanta: GA.

Awada, L., Lindwall, C. W., & Sonntag, B. (2014). The development and adoption of conservation tillage systems on the Canadian Prairies. International Soil and Water Conservation Research, 2(1), 47–65. Doi: https://doi.org/10.1016/S2095-6339(15)30013-7

Banerjee, S. (2018). Improving Spatial Coordination Rates under the Agglomeration Bonus Scheme: A Laboratory Experiment with a Pecuniary and a Non-Pecuniary Mechanism (NUDGE). American Journal of Agricultural Economics, 100(1), 172–197. Doi: https://doi.org/10.1093/ajae/aax066

Beauchemin, K. A. (2019). Reducing methane emissions from livestock. Agriculture and Agri-Food Canada. Retrieved from http://www.agr.gc.ca/eng/news-from-agriculture-and-agri-food-canada/scientific-achievements-in-agriculture/reducing-methane-emissions-from-livestock/?id=1548267761377

Beauchemin, K. A., Henry Janzen, H., Little, S. M., McAllister, T. A., & McGinn, S. M. (2010). Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. Agricultural Systems, 103(6), 371–379. Doi: https://doi.org/10.1016/J.AGSY.2010.03.008

Beauchemin, K. A., McAllister, T. A., & McGinn, S. M. (2009). Dietary mitigation of enteric methane from cattle. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 4. Doi: https://doi.org/10.1079/PAVSNNR20094035

Beauchemin, K. A., & McGinn, S. M. (2008). Reducing methane in dairy and beef cattle operations: What is feasible. *Prairie Soil Crop*, *1*, 17-21.

Beauchemin, Karen. A., Janzen, H. H., Little, S. M., McAllister, T. A., & McGinn, S. M. (2011). Mitigation of greenhouse gas emissions from beef production in western Canada—Evaluation using farm-based life cycle assessment. Animal Feed Science and Technology, 166–167, 663–677. Doi: https://doi.org/10.1016/j.anifeedsci.2011.04.047

Beaulieu, M., Fric, C. & Soulard, F. (2007). Estimation of Water Use in Canadian Agriculture in 2001. Statistics Canada. Retrieved from https://www.manitoba.ca/sd/waterstewardship/licensing/wlb/pdf/sc_estimation_of_water_use_in_canadian_agriculture_2001.pdf

Berry, R., & Weaver, M. (2018). Exporting Ecolabels: Is Demand for Certified Sustainable Products Affecting International Trade. *US International Trade Commission, Washington DC, USA*.

Bellemare, M. F., Çakir, M., Peterson, H. H., Novak, L., & Rudi, J. (2017). On the measurement of food waste. *American journal of agricultural economics*, *99*(5), 1148-1158.

Bernedo, M., Ferraro, P. J., & Price, M. (2014). The persistent impacts of norm-based messaging and their implications for water conservation. *Journal of Consumer Policy*, *37*(3), 437-452.

BEUC. (2020). One Bite at a Time: Consumers and the Transition to Sustainable Food. The European Consumer Organization. Retrieved from https://www.beuc.eu/publications/beuc-x-2020-042_consumers_and_the_transition_to_sustainable_food.pdf

BNN Bloomberg. (2018). Trudeau meets with Quebec dairy farmers post USMCA, promises compensation. BNN Bloomberg. Retrieved from https://www.bnnbloomberg.ca/trudeau-meets-with-quebec-dairy-farmers-post-usmca-promises-compensation-1.1147661

Boaitey, A. (2017). Three Essays on Beef Genomics: Economic and Environmental Impacts. University of Alberta. Doi: https://doi.org/10.7939/R32B8VR9H

Boaitey, A., Goddard, E., Mohapatra, S., & Crowley, J. (2017). Feed Efficiency Estimates in Cattle: The Economic and Environmental Impacts of Reranking. Sustainable Agriculture Research, 6(2), 35. Doi: https://doi.org/10.5539/sar.v6n2p35

Böcker, T. G., & Finger, R. (2017). A Meta-Analysis on the Elasticity of Demand for Pesticides. Journal of Agricultural Economics, 68(2), 518–533. Doi: https://doi.org/10.1111/1477-9552.12198

Boeckaert, C., Vlaeminck, B., Dijkstra, J., Issa-Zacharia, A., Van Nespen, T., Van Straalen, W., & Fievez, V. (2008). Effect of dietary starch or micro algae supplementation on rumen fermentation and milk fatty acid composition of dairy cows. Journal of Dairy Science, 91(12), 4714–4727. Doi: https://doi.org/10.3168/jds.2008-1178

Boxall, P. C. (2017). Evaluation of Agri-Environmental Programs: Can We Determine If We Grew Forward in an Environmentally Friendly Way?. In *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* (Vol. 66, No. 2, pp. 171-186).

Boxall, P. C., Perger, O., Packman, K., & Weber, M. (2017). An experimental examination of target based conservation auctions. Land Use Policy, 63, 592–600. Doi: https://doi.org/10.1016/J.LANDUSEPOL.2015.03.016

Boxall, P. C., Weber, M., Perger, O., Cutlac, M., & Samarawickrema, A. (2008). Results from the Farm Behaviour Component of the Integrated Economic-Hydrologic Model for the Watershed Evaluation of Beneficial Management Practices Program. Doi: https://doi.org/10.22004/AG.ECON.116268

Brandon, A., Ferraro, P. J., List, J. A., Metcalfe, R. D., Price, M. K., & Rundhammer, F. (2017). *Do the effects of social nudges persist? Theory and evidence from 38 natural field experiments* (No. w23277). National Bureau of Economic Research.

Brownlee, M., Elgie, S., and Scott, W. (2018) Canada's Next Edge: Why Clean Innovation is Critical to Canada's Economy and How We Get it Right. Smart Prosperity Institute.

Buchholz, M., Peth, D., & Mußhoff, O. (2018). Tax or green nudge? An experimental analysis of pesticide policies in Germany. DARE Discussion Papers.

Byerly, H., Balmford, A., Ferraro, P. J., Hammond Wagner, C., Palchak, E., Polasky, S., Ricketts, T. H., Schwartz, A. J., & Fisher, B. (2018). Nudging pro-environmental behaviour: Evidence and opportunities. Frontiers in Ecology and the Environment, 16(3), 159–168. Doi: https://doi.org/10.1002/fee.1777

CAFTA. (n.d.). Canada and India Comprehensive Economic Partnership Agreement. CAFTA. Retrieved from https://cafta.org/trade-agreements/canada-india-cepa/

California Air Resources Board. (2014). Compliance Offset Program. Government of California. Retrieved from https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program

Campbell, I.D., Durant D.G., Hunter, K.L. and Hyatt, K.D. (2014): Food Production in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.

Canada2020. (2019). Final Report from the Canada Food Brand Project. Canada2020. Retrieved from https://canada2020.ca/final-report-from-the-canada-food-brand-project/

Cason, T. N., Gangadharan, L., & Duke, C. (2003). A laboratory study of auctions for reducing non-point source pollution. Journal of Environmental Economics and Management, 46(3), 446–471. Doi: https://doi.org/10.1016/S0095-0696(03)00026-3

Chabé-Ferret, S., Le Coent, P., Reynaud, A., Subervie, J., & Lepercq, D. (2019). Can we nudge farmers into saving water? Evidence from a randomised experiment. European Review of Agricultural Economics, 46(3), 393–416. Doi: https://doi.org/10.1093/erae/jbz022

Christensen, T., Pedersen, A. B., Nielsen, H. O., Mørkbak, M. R., Hasler, B., & Denver, S. (2011). Determinants of farmers' willingness to participate in subsidy schemes for pesticide-free buffer zones—A choice experiment study. Ecological Economics, 70(8), 1558–1564. Doi: https://doi.org/10.1016/j.ecolecon.2011.03.021

CIBUS. (2020). Cibus—Innovating precision plant breeding. CIBUS. Retrieved from https://www.cibus.com/our-technology.php

City of Guelph. (2019). 50x50x50 by 2025: Creating Canada's first circular food economy. City of Guelph. Retrieved from https://guelph.ca/wp-content/uploads/SmartCities_Booklet.pdf

Clearwater, L., Martin, T. & Hoppe, T. (2016). Agri-Environmnetal Indicators Report Series; Report #4. Agriculture and Agri-Food Canada. Retrieved from http://www.agr.gc.ca/eng/agriculture-and-climate/agricultural-practices/climate-change-and-agriculture/agricultural-greenhouse-gas-indicator/?id=1461014704763

Climate Action Reserve. (2020). Soil Enrichment Protocol. Climate Action Reserve. Retrieved from http://www.climateactionreserve.org/how/protocols/soil-enrichment/

Clot, S., Grolleau, G., & Méral, P. (2017). Payment Vs. Compensation for Ecosystem Services: Do Words Have A Voice In The Design of Environmental Conservation Programs? Ecological Economics, 135(May 2017), 299–303. Doi: https://doi.org/10.1016/j.ecolecon.2016.12.028

Colen, L., Gomez y Paloma, S., Latacz-Lohmann, U., Lefebvre, M., Préget, R., & Thoyer, S. (2016). Economic Experiments as a Tool for Agricultural Policy Evaluation: Insights from the European CAP. Canadian Journal of Agricultural Economics, 64(4), 667–694. Doi: https://doi.org/10.1111/cjag.12107

Cong, R.-G., Hedlund, K., Andersson, H., & Brady, M. (2014). Managing soil natural capital: An effective strategy for mitigating future agricultural risks? Agricultural Systems, 129, 30–39. Doi: https://doi.org/10.1016/J.AGSY.2014.05.003

CPA. (2020). This Ontario distillery turns milk by-products into vodka. Chartered Professional Accountants of Canada. Retrieved from https://www.cpacanada.ca/en/news/pivot-magazine/2020-03-17-dairy-distillery-vodkow

CRSB. (2020). McDonalds Canada now with sustainable sourcing in its Quarter Pounders. Canadian RoundTable for Sustainable Beef. Retrieved from https://www.crsbcertified.ca/blog/mcdonalds-canada-now-with-sustainable-sourcing-in-its-quarter-pounders/

Czap, H. J., Czap, N. V., Khachaturyan, M., Burbach, M. E., & Lynne, G. D. (2011). Smiley or Frowney: The effect of emotions and framing in a downstream water pollution game. Doi: https://doi.org/10.22004/AG.ECON.102696

Czap, N. V., Czap, H. J., Lynne, G. D., & Burbach, M. E. (2015). Walk in my shoes: Nudging for empathy conservation. Ecological Economics, 118, 147–158. Doi: https://doi.org/10.1016/J.ECOLECON.2015.07.010

Czap, N. V., Czap, H. J., Banerjee, S., & Burbach, M. E. (2019). Encouraging farmers' participation in the Conservation Stewardship Program: A field experiment. *Ecological Economics*, *161*, 130-143.

Dalhousie University. (2018). DAL Researchers Receive $2.4 million in funding from SSHRC. Dalhousie University. Retrieved from https://www.dal.ca/news/2018/06/04/dal-researchers-receive--2-4-million-in-funding-from-sshrc.html

de Haas, Y., Pszczola, M., Soyeurt, H., Wall, E., & Lassen, J. (2017). Invited review: Phenotypes to genetically reduce greenhouse gas emissions in dairying. Journal of Dairy Science, 100(2), 855–870. Doi: https://doi.org/10.3168/jds.2016-11246

Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., ... & Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances*, *7*(23), eabd6034.

Duncan, A., Dunn, H., Vella, M. & Stratton, L. (2012). Functional Foods for Healthy Aging: A Toolkit for Registered Dietitians. University of Guelph. Retrieved from https://www.cfdr.ca/Downloads/Presentations/Functional-Foods-For-Healthy-Aging-TOOLKIT-January.aspx

Eagle, A. J., Rude, J., & Boxall, P. C. (2015). Agricultural support policy in Canada: What are the environmental consequences? NRC Research Press, 24, 13–24. Doi: https://doi.org/10.1139/er-2015-0050

ECCC. (2017). Water Withdrawal and Consumption by Sector. Government of Canada. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/water-withdrawal-consumption-sector.html

ECCC. (2018). Wildlife Habitat Capacity on Agricultural Land. Government of Canada. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/wildlife-habitat-capacity-agricultural-land.html

ECCC. (2019a). Canada's Fourth Biennial Report on Climate Change. Government of Canada. Retrieved from https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/fourth-biennial-report-climate-change.html

ECCC. (2019b). National inventory report 1990 –2017: Greenhouse Gas sources and sinks in Canada, Part 1 & 3. Government of Canada. Retrieved from https://unfccc.int/documents/194925

ECCC. (2019c). Taking Stock: Reducing Food Loss and Waste in Canada. Government of Canada. Retrieved from https://www.canada.ca/content/dam/eccc/food-loss-and-waste/Taking%20Stock%20Report%20EN%20Final.pdf

ECCC. (2020a). A HEALTHY ENVIRONMENT AND A HEALTHY ECONOMY. Government of Canada. Retrieved from https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

ECCC. (2020b). MODELLING AND ANALYSIS OF A HEALTHY ENVIRONMENT AND A HEALTHY ECONOMY. Government of Canada. Retrieved from https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/annex_modelling_analysis_healthy_environment_healthy_economy.pdf

ECCC. (2021a). Government of Canada confirms ambitious new greenhouse gas emissions reduction target. Government of Canada. Retrieved from https://www.canada.ca/en/environment-climate-change/news/2021/07/government-of-canada-confirms-ambitious-new-greenhouse-gas-emissions-reduction-target.html

ECCC. (2021b). National inventory report 1990 –2019: Greenhouse Gas sources and sinks in Canada, Part 1. Government of Canada. Retrieved from https://unfccc.int/documents/271493

Ellen Mcarthur Foundation. (2019). Cities and circular economy for food-Executive Summary. Ellen Macarthur Foundation. Retrieved from: https://ellenmacarthurfoundation.org/cities-and-circular-economy-for-food

FAO. (2019). Emissions Intensities. United Nations. Retrieved from http://www.fao.org/faostat/en/#data/EI/visualize

FAOSTAT. (2016). Land use, area of arable land. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/faostat/en/#data/RL/visualize

Farm Credit Canada. (2019). Diversifying Canada's Agricultural Exports: Opportunities and challenges in wheat, canola, soy, and pulses. Farm Credit Canada. Retrieved from https://www.fcc-fac.ca/fcc/resources/trade-rankings-report-2019-e.pdf

Farm Credit Canada. (2020). Trade Rankings 2020: Opportunities and challenges to diversify Canada's food exports. Farm Credit Canada. Retrieved from https://www.fcc-fac.ca/fcc/resources/trade-rankings-report-2020-e.pdf

Fertilizer Canada. (2019). What's In It 4R Me? Fertilizer Canada. Retrieved from https://fertilizercanada.ca/our-focus/advocacy/whats-in-it-4r-me/

Finger, R., Möhring, N., Dalhaus, T., & Böcker, T. (2017). Revisiting Pesticide Taxation Schemes. Ecological Economics, 134, 263–266. Doi: https://doi.org/10.1016/J.ECOLECON.2016.12.001

Fooks, J. R., Higgins, N., Messer, K., Duke, J., Hellerstein, D., & Lynch, L. (2016). Conserving Spatially Explicit Benefits in Ecosystem Service Markets: Experimental Tests of Network Bonuses and Spatial Targeting. American Journal of Agricultural Economics, 98(2), 468–488.

Forest Trends. (n.d.). The Mitigation Hierarchy. Forest Trends. Retrieved from https://www.forest-trends.org/bbop/bbop-key-concepts/mitigation-hierarchy/

GAC. (2017a). Text of the Comprehensive Economic and Trade Agreement – Chapter 24: Trade and the Environment. Government of Canada. Retrieved from https://www.international.gc.ca/trade-commerce/trade-agreements-accords-commerciaux/agr-acc/ceta-aecg/text-texte/24.aspx?lang=eng

GAC. (2017b). Invest in Canada – Canada's Competitive Advantage: Agri-Food Processing Sector. Government of Canada. Retrieved from https://www.international.gc.ca/investors-investisseurs/assets/pdfs/download/vp-agri_food.pdf

Gallegos, J. (2019). Five ways CRISPR plants can combat climate change. Alliance for Science. Retrieved from https://allianceforscience.cornell.edu/blog/2019/12/five-ways-crispr-plants-can-combat-climate-change/

Gan, Y., Liang, C., Chai, Q., Lemke, R. L., Campbell, C. A., & Zentner, R. P. (2014). Improving farming practices reduces the carbon footprint of spring wheat production. Nature Communications, 5(1), 5012. Doi: https://doi.org/10.1038/ncomms6012

Garrett, R. D., Carlson, K. M., & Rueda, X. (2016). Assessing the potential additionality of certification by the round table on responsible soybeans and the roundtable on sustainable palm oil (Environmental Research Letters (2016) 11 (045003) DOI: 10.1088/1748-9326/11/4/045003). In Environmental Research Letters (Vol. 11, Issue 7). Doi: https://doi.org/10.1088/1748-9326/11/7/079502

Gassert, F., Reig, P., Luo, T., & Maddocks, A. (2013). A weighted aggregation of spatially distinct hydrological indicators. *World Resources Institute: Washington, DC*.

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., ... & Tempio, G. (2013). *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*. Food and Agriculture Organization of the United Nations.

Glauber, J. (2020). The Current State of Agricultural Trade and the World Trade Organization. International Food Policy Research Institute. Retrieved from https://www.ifpri.org/news-release/current-state-agricultural-trade-and-world-trade-organization

Government of Alberta. (n.d.) Agricultural Carbon Offsets – Overview. Government of Alberta. Retrieved from https://www.alberta.ca/agricultural-carbon-offsets-overview.aspx

Government of Alberta. (2008). Crop Rotations in Direct Seeding. Government of Alberta. Retrieved from https://open.alberta.ca/dataset/3decfc22-edbc-4c04-8cd4-39240500eaf2/resource/148f9e8a-40c9-4b6d-9136-405f460e8135/download/2008-519-28.pdf

Government of British Columbia. (2018). Canadian Agricultural Partnership: Beneficial Management Practices 2018/19. ARDCorp.

Government of Canada. (2020). Canada – Indonesia Relations. Government of Canada. Retrieved from https://www.canadainternational.gc.ca/indonesia-indonesie/bilateral_relations_bilaterales/canada-indonesia-indonesie.aspx?lang=eng

Government of Canada. (2021). Greenhouse gas emissions by province and territory. Government of Canada. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

Government of Manitoba. (n.d.). Environmental Farm Plan. Government of Manitoba. Retrieved from https://www.gov.mb.ca/agriculture/environment/environmental-farm-plan/

Government of Manitoba. (2016). Beef Cattle Budget and Tools | Manitoba Agriculture | Province of Manitoba. Government of Manitoba. https://www.gov.mb.ca/agriculture/business-and-economics/financial-management/beef-cattle-budget-and-tools.html

Government of Manitoba. (2017). A Made-in-Manitoba Climate and Green Plan. Government of Manitoba. Retrieved from https://www.gov.mb.ca/asset_library/en/climatechange/climategreenplandiscussionpaper.pdf

Government of New South Wales. (2021). About the Biodiversity Offsets Scheme. Government of New South Wales. Retrieved from https://www.environment.nsw.gov.au/topics/animals-and-plants/biodiversity-offsets-scheme/about-the-biodiversity-offsets-scheme

Government of Ontario. (2016). Ontario's five year climate change action plan 2016-2020. Government of Ontario. Retrieved from https://doi.org/PIBS 9942e

Government of Ontario. (2019). Canada-Ontario Environmental Farm Plan: Overview. Government of Ontario. Retrieved from http://www.omafra.gov.on.ca/english/environment/efp/efp.htm

Government of Prince Edward Island. (n.d.). Alternative Land Use Services (ALUS) Program. Government of Prince Edward Island. Retrieved from https://www.princeedwardisland.ca/en/service/alternative-land-use-services-alus-program

Government of Prince Edward Island. (2018). A Climate Change Action Plan for Prince Edward Island; 2018-2023. Government of Prince Edward Island. Retrieved from https://www.princeedwardisland.ca/fr/information/environnement-eau-et-changement-climatique/climate-change-action-plan-2018-2023

Government of Saskatchewan. (n.d.). Farm Stewardship Program. Government of Saskatchewan. Retrieved from https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/canadian-agricultural-partnership-cap/environmental-sustainability-and-climate-change/farm-stewardship-program-fsp

Government of Saskatchewan. (2018). Saskatchewan's Climate Resilience Measurement Framework. Government of Saskatchewan. Retrieved from https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/a-made-in-saskatchewan-climate-change-strategy/climate-resilience-framework-and-reports

Government of South Australia. (n.d.) Turn your native vegetation into income. Government of South Australia. Retrieved from https://www.environment.sa.gov.au/topics/native-vegetation/offsetting/turn-your-native-vegetation-into-income

Griesinger, M. R., Palm-Forster, L. H., Messer, K. D., Butler, J., & Fooks, J. (2017). Stewardship signaling and the power of using social pressures to reduce nonpoint source pollution (2017 Annual Meeting, July 30-August 1, Chicago, Illinois, Issue 259153). Agricultural and Applied Economics Association.

Guyader, J., Little, S., Kröbel, R., Benchaar, C., & Beauchemin, K. A. (2017). Comparison of greenhouse gas emissions from corn-and barley-based dairy production systems in Eastern Canada. *Agricultural systems*, *152*, 38-46.

Hanna, R., Mullainathan, S., & Schwartzstein, J. (2012). Learning Through Noticing: Theory and Experimental Evidence in Farming. Doi: https://doi.org/10.3386/w18401

Hansen, L. G. (2004). Nitrogen Fertilizer Demand from Danish Crop Farms: Regulatory Implications of Heterogeneity. In Canadian Journal of Agricultural Economics (Vol. 52).

Hassanat, F., Gervais, R., & Benchaar, C. (2017). Methane production, ruminal fermentation characteristics, nutrient digestibility, nitrogen excretion, and milk production of dairy cows fed conventional or brown midrib corn silage. *Journal of Dairy Science*, *100*(4), 2625-2636.

Haque, M. N. (2018). Dietary manipulation: A sustainable way to mitigate methane emissions from ruminants. Journal of Animal Science and Technology, 60(1), 15. Doi: https://doi.org/10.1186/s40781-018-0175-7

Hellerstein, D., Higgins, N., & Roberts, M. J. (2015). Options for Improving Conservation Programs: Insights from Auction Theory and Economic Experiments. Doi: https://doi.org/10.22004/AG.ECON.262210

Hertwig, R. (2017). When to consider boosting: some rules for policy-makers. *Behavioural Public Policy*, *1*(2), 143-161.

Holmes, E., Bradshaw, B., Yang, W., & Smithers, J. (2011). AGRI-ENVIRONMENTAL STEWARDSHIP ADOPTION IN CANADA: A STATE OF KNOWLEDGE REVIEW AND ANNOTATED BIBLIOGRAPHY. Linking Environment and Agriculture Research Network. Retrieved from https://learnnetwork.ualberta.ca/wp-content/uploads/sites/70/2018/07/PR032011Holmesetal.pdf

Howes, L. (2020). How we'll reengineer crops for a changing climate. C&EN, 98(6). Retrieved from https://cen.acs.org/food/agriculture/ll-reengineer-crops-changing-climate/98/i6

IISD. (2018). Nutrient Recovery and Reuse in Canada: Foundations for a national framework. International Institute for Sustainable Development. Retrieved from https://www.iisd.org/sites/default/files/meterial/nutrient-recovery-reuse-canada.pdf

Innovation Hub. (2017). Increasing Response Rates to a Statistics Canada Survey. Government of Canada. Retrieved from: https://www.canada.ca/content/dam/pco-bcp/documents/pdfs/Stats-Can-eng.PDF

IPCC. (2017). IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. Research Handbook on Climate Change and Agricultural Law, 7,13-15. Doi: https://doi.org/10.4337/9781784710644

ISED. (2018). Canada's Economic Strategy Tables: Agri-food. Government of Canada. Retrieved from https://www.ic.gc.ca/eic/site/098.nsf/eng/00022.html

ITC. (2019). The European Union Market for Sustainable Products. European Commission. Retrieved from https://www.intracen.org/uploadedFiles/intracenorg/Content/Publications/EU%20Market%20for%20Sustainable%20Products_Report_final_low_res.pdf

Jayasundara, S., Ranga Niroshan Appuhamy, J. A. D., Kebreab, E., & Wagner-Riddle, C. (2016). Methane and nitrous oxide emissions from Canadian dairy farms and mitigation options: An updated review. In Canadian Journal of Animal Science (Vol. 96, Issue 3, pp. 306–331). Doi: https://doi.org/10.1139/cjas-2015-0111

Kelly, K. E., Belcher, K., & Khakbazan, M. (2018). Economic Targeting of Agricultural Beneficial Management Practices to Address Phosphorus Runoff in Manitoba. Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 66(1), 143–166. Doi: https://doi.org/10.1111/cjag.12143

Kitchen, A. (2012). Social, Economic and Environmental evalution of agri-environmental beneficial practices. Simon Fraser University. Retrieved from https://summit.sfu.ca/item/12479

Knotek, M., Bushman, T., Savitz, S., Canavati, A., Kizer, A., Volk, N., & Butler, J. (2020). From the Ground Up Cutting-Edge Apporches for Land-Based Carbon Dioxide Removal. Energy Futures Initiative. Retrieved from https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5fd25dad0435fb34f51d095a/1607622070340/From+the+Ground+Up+12.10.20+Final.pdf

Latacz-Lohmann, U., & Schilizzi, S. (2005). AUCTIONS FOR CONSERVATION CONTRACTS: A REVIEW OF THE THEORETICAL & EMPIRICAL LITERATURE. Scottish Executive Environment and Rural Affairs Department. Retrieved from https://digital.nls.uk/pubs/scotgov/2006/0022574.pdf

Lee, C., & Beauchemin, K. A. (2014). A review of feeding supplementary nitrate to ruminant animals: nitrate toxicity, methane emissions, and production performance. *Canadian Journal of Animal Science*, *94*(4), 557-570.

Legesse, G., Beauchemin, K. A., Ominski, K. H., McGeough, E. J., Kroebel, R., MacDonald, D., Little, S. M., & McAllister, T. A. (2016). Greenhouse gas emissions of Canadian beef production in 1981 as compared with 2011. Animal Production Science, 56(3), 153–168. Doi: https://doi.org/10.1071/AN15386

Li, W., & Just, D. R. (2019). Behavioural economics in food and agriculture. In The Routledge Handbook of Agricultural Economics (pp. 84–95). Routledge. Doi: https://doi.org/10.4324/9781315623351-6

Lichtenberg, E. (2004). Some hard truths about agriculture and the environment. *Agricultural and Resource Economics Review*, *33*(1), 24-33.

MacWilliam, S., Parker, D., Marinangeli, C. P., & Trémorin, D. (2018). A meta-analysis approach to examining the greenhouse gas implications of including dry peas (Pisum sativum L.) and lentils (Lens culinaris M.) in crop rotations in western Canada. *Agricultural Systems*, *166*, 101-110.

Maple Leaf Foods. (2019). Maple Leaf is now carbon neutral. Maple Leaf Foods. Retrieved from https://www.mapleleaf.ca/carbonneutral/

Marr, E. J., & Howley, P. (2019). The accidental environmentalists: Factors affecting farmers' adoption of pro-environmental activities in England and Ontario. Journal of Rural Studies, 68, 100–111. Doi: https://doi.org/10.1016/j.jrurstud.2019.01.013

McCarron, B., Cfa, S. T., & Giunti, A. (2018). Charting Asia's Protein Journey. ADM Capital Foundation. Retrieved from https://www.admcf.org/research-reports/charting-asias-protein-journey/

McCune, J. L., Colla, S. R., Coristine, L. E., Davy, C. M., Flockhart, D. T., Schuster, R., & Orihel, D. M. (2019). Are we accurately estimating the potential role of pollution in the decline of species at risk in Canada?. *Facets*, *4*(1), 598-614.

McInnes, D. (2021). The Business Case for Establishing the National Index on Agri-Food Performance | Affirming Canada's Agri-Food Sustainability Leadership. DMci Strategies.

Messer, K. D., Ferraro, P., & Allen, W. (2015). Behavioural nudges in competitive environments: a field experiment examining defaults and social comparisons in a conservation contract auction. *Bioecon Network*.

Montenegro, M. (2016). CRISPR is coming to agriculture—With big implications for food. Ensia. Retrieved from https://ensia.com/voices/crispr-is-coming-to-agriculture-with-big-implications-for-food-farmers-consumers-and-nature/

Muller, A., Schader, C., Scialabba, N. E. H., Brüggemann, J., Isensee, A., Erb, K. H., ... & Niggli, U. (2017). Strategies for feeding the world more sustainably with organic agriculture. *Nature communications*, *8*(1), 1-13.

Murphy, R., Gross, D. M., & Jaccard, M. (2018). Use of revealed preference data to estimate the costs of forest carbon sequestration in Canada. Forest Policy and Economics, 97, 41–50. Doi: https://doi.org/10.1016/j.forpol.2018.06.008

Murray, A. (2016). Partial versus Total Factor Productivity: Assessing Resource Use in Natural Resource Industries in Canada. CSLS Research Reports.

Murray, B. C. (2015). Why Have Carbon Markets Not Delivered Agricultural Emission Reductions in the United States? 30(2), 1–5.

Naidoo, R., Boxall, P., & Adamowicz, W. L. (2012). *Impact evaluation in Canadian agricultural landscapes: scoping the science*. Linking Environment and Agriculture Research Network.

Ng, H., & Ker, A. P. (2019). On Technological Change and Yield Resiliency in Canadian Crop Yields. Doi: https://doi.org/10.22004/AG.ECON.288896

Nikkel, L., Maguire, M., Gooch, M., Bucknell, D., LaPlain, D., Dent, B., Whitehead, P., & Felfel, A. (2019). The Avoidable Crisis of Food Waste: Technical Report. 1–122. Retrieved from https://secondharvest.ca/wp-content/uploads/2019/01/Avoidable-Crisis-of-Food-Waste-Technical-Report-January-17-2019.pdf

NRCan. (2017). Water. Natural Resources Canada-Government of Canada. Retrieved from https://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/selected-thematic-maps/16888#distributionofwater

OECD. (2012). Water quality and agriculture: Meeting the policy challenge. Key Messages and Executive Summary. OECD Studies on Water, 155. Doi: https://doi.org/10.1787/9789264168060-en

OECD. (2018). Real GDP long-term forecast (indicator). In Real GDP long-term forecast (indicator) (Issue 103). Doi: https://doi.org/10.1787/d927bc18-en

OECD. (2019). Chapter 5. Innovation policy and the agricultural innovation system. In Innovation, Productivity and Sustainability in Food and Agriculture: Main Findings from Country Reviews and Policy Lessons.

OECD (2019a), "Research and Development", OECD Statistics (database). Retrieved from https://stats.oecd.org/

OECD. (2019b). Trends Shaping Education – 2019. OECD. Retrieved from https://www.oecd.org/education/trends-shaping-education-22187049.htm

OECD (2021), Agricultural support (indicator). OECD. Doi: 10.1787/6ea85c58-en

Office of the Auditor General of Canada. (2008). Chapter 3—Managing Environmental Programming—Agriculture and Agri-Food Canada. Government of Canada.

Ogura, T., Goeschl, C., Filiault, D., Mirea, M., Slovak, R., Wolhrab, B., Satbhai, S. B., & Busch, W. (2019). Root System Depth in Arabidopsis Is Shaped by EXOCYST70A3 via the Dynamic Modulation of Auxin Transport. Cell, 178(2), 400-412.e16. Doi: https://doi.org/10.1016/j.cell.2019.06.021

OMAFRA. (2019a). Water Requirements of Livestock. Government of Ontario. Retrieved from http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm

OMAFRA. (2019b). Cover Crops. Government of Ontario. Retrieved from http://www.omafra.gov.on.ca/english/crops/facts/cover_crops01/covercrops.htm

OP2B. (n.d.). One Planet Business for Biodiversity. OP2B. Retrieved from https://op2b.org/

OSICA. (n.d.). Lake Erie Agriculture Demonstrating Sustainability (LEADS). OSCIA. Retrieved from https://www.ontariosoilcrop.org/canadian-agricultural-partnership/lake-erie-agriculture-demonstrating-sustainability-leads/

OSCIA. (2014). Alternative Funding Models for Agricultural Stewardship Programs in Ontario. OSCIA. Retrieved from https://www.ontariosoilcrop.org/wp-content/uploads/2015/08/final_oscia_funding_model.pdf

Palm-Forster, L. H., Ferraro, P. J., Janusch, N., Vossler, C. A., & Messer, K. D. (2019). Behavioural and Experimental Agri-Environmental Research: Methodological Challenges, Literature Gaps, and Recommendations. Environmental and Resource Economics, 73(3), 719–742. https://doi.org/10.1007/s10640-019-00342-x

Palm-Forster, L. H., Swinton, S., Lupi, F., & Shupp, R. (2015). Too Burdensome to Bid: Transaction Costs and Pay-for-Performance Conservation (2016 Allied Social Sciences Association (ASSA) Annual Meeting, January 3-5, 2016, San Francisco, California, Issue 212816). Agricultural and Applied Economics Association.

Pannell, D. J. (2017). Economic perspectives on nitrogen in farming systems: Managing trade-offs between production, risk and the environment. Soil Research, v. 55(6), 473-478–2017 v.55 no.6. Doi: https://doi.org/10.1071/SR16284

Peth, D., Mußhoff, O., Funke, K., & Hirschauer, N. (2018). Nudging Farmers to Comply With Water Protection Rules – Experimental Evidence From Germany. Ecological Economics, 152, 310–321. Doi: https://doi.org/10.1016/J.ECOLECON.2018.06.007

Petsakos, A., & Jayet, P.-A. (2010). Evaluating the efficiency of a N-input tax under different policy scenarios at different scales (120th Seminar, September 2-4, 2010, Chania, Crete, Issue 109397). European Association of Agricultural Economists.

Potts, J., Lynch, M., Wilkings, A., Huppé, G., Cunningham, M., & Voora, V. (2014). The State of Sustainability Initiatives Review 2014.Standards and the Green Economy. International Institute for Environment and Development.

Puzyreva, M., Roy, D., & Stanley, M. (2019). Case Study Research on offsets for water quality management. IISD. Retrieved from https://www.iisd.org/publications/case-study-research-offsets-water-quality-management

PwC Canada. (2019). Consumer Insights Survey, 2019. PwC Canada. Retrieved from https://www.pwc.com/ca/en/industries/retail-consumer/environmental-sustainability-becoming-a-business-imperative.html

Rajsic, P., Weersink, A., & Gandorfer, M. (2009). Risk and Nitrogen Application Levels. Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 57(2), 223–239. Doi: https://doi.org/10.1111/j.1744-7976.2009.01149.x

Rausser, G., Sexton, S., & Zilberman, D. (2019). The economics of the naturalist food paradigm. *Annual Review of Resource Economics*, *11*, 217-236.

RBC. (2019). How the coming skills revolution can transform agriculture Farmer 4.0. RBC. Retrieved from http://www.rbc.com/economics/economic-reports/pdf/other-reports/Farmer4_aug2019.pdf?_ga=2.9869685.157452427.1632239829-1977154754.1632239829

Rivers, N. (2010). Impacts of climate policy on the competitiveness of Canadian industry: How big and how to mitigate? Energy Economics, 32(5), 1092–1104. Doi: https://doi.org/10.1016/j.eneco.2010.01.003

Rivers, N, & Schaufele, B. (2015). The Effect of Carbon Taxes on Agricultural Trade. Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 63(2), 235–257. Doi: https://doi.org/10.1111/cjag.12048

Robinson, G. M. (2006). Canada's Environmental Farm Plans: Transatlantic Perspectives on Agri-Environmental Schemes. The Geographical Journal, 172(3), 206–218.

Roe, B. E., & Just, D. R. (2009). Internal and external validity in economics research: Tradeoffs between experiments, field experiments, natural experiments, and field data. American Journal of Agricultural Economics, 91(5), 1266–1271. Doi: https://doi.org/10.1111/j.1467-8276.2009.01295.x

Rolfe, J., Schilizzi, S., Boxall, P., Latacz-Lohmann, U., Iftekhar, S., Star, M., & O'Connor, P. (2018). Identifying the causes of low participation rates in conservation tenders. International Review of Environmental and Resource Economics, 12(1), 1–45. Doi: https://doi.org/10.1561/101.00000098

Rollins, C., & Boxall, P. C. (2018). Environmental stewardship in the Canadian agricultural sector under Growing Forward 1 and 2 (No. 18–07; Clean Economy Working Paper Series). Smart Prosperity Institute. Retrieved from https://www.greengrowthknowledge.org/sites/default/files/downloads/resource/environmentalstewardshipinitiative_compressed.pdf

Rollins, C., Simpson, S., & Boxall, P. C. (2018). Evaluating an Agricultural Extension Program aimed at improving biodiversity in Alberta, Canada. In Linking Environment and Agriculture Research Network.

Roque, B. M., Venegas, M., Kinley, R. D., de Nys, R., Duarte, T. L., Yang, X., & Kebreab, E. (2021). Red seaweed (Asparagopsis taxiformis) supplementation reduces enteric methane by over 80 percent in beef steers. Plos one, 16(3), e0247820.

Rougoor, C. W., Van Zeijts, H., Hofreither, M. F., & Bäckman, S. (2001). Experiences with fertilizer taxes in Europe. Journal of Environmental Planning and Management, 44(6), 877–887. Doi: https://doi.org/10.1080/09640560120087615

Rude, J., & Weersink, A. (2018). The potential for cross-compliance in Canadian agricultural policy: linking environmental goals with business risk management programs. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *66*(3), 359-377.

Schenkel, F., Stothard, P., & De Pauw, M. (2019). The Efficient Dairy Genome Project. University of Guelph. Retrieved from https://genomedairy.ualberta.ca/

Schwarze, J., Sophie Holst, G., & MUßHOFF, O. (2014). Do farmers act like perfectly rational profit maximisers? Results of an extra-laboratory experiment. Doi: https://doi.org/10.5836/ijam/2014-01-03

Searchinger, T., Waite, R., Hanson, C., & Ranganathan, J. (2019). Creating a Sustainable Food Future. World Resources Institute. Retrieved from https://research.wri.org/wrr-food

Semmelink, A. L. (2015). Differences between farmer and government official views of best management practices: Cracks or crayons? University of British Columbia.

Sheeder, R. J., & Lynne, G. D. (2011). Empathy-conditioned conservation: "Walking in the shoes of others" as a conservation farmer. Land Economics, 87(3), 433–452. Doi: https://doi.org/10.3368/le.87.3.433

Sheriff, G. (2005). Efficient waste? Why farmers over-apply nutrients and the implications for policy design. *Applied Economic Perspectives and Policy*, *27*(4), 542-557.

Shew, A. M., Nalley, L. L., Snell, H. A., Nayga, R. M., & Dixon, B. L. (2018). CRISPR versus GMOs: Public acceptance and valuation. Global Food Security, 19, 71–80. Doi: https://doi.org/10.1016/J.GFS.2018.10.005

Skevas, T., Stefanou, S. E., & Lansink, A. O. (2012). Can economic incentives encourage actual reductions in pesticide use and environmental spillovers? Agricultural Economics, 43(3), 267–276. Doi: https://doi.org/10.1111/j.1574-0862.2012.00581.x

Skolrud, T., Belcher, K., Lloyd-Smith, P., Slade, P., Weersink, A., Abayateye, F., & Prescott, S. (2020). Measuring Externalities in Canadian Agriculture: Understanding the Impact of Agricultural Production on the Environment. *Ottawa, Canada: The Canadian Agri-Food Policy Institute*.

Smuckler, S. (2019). Managing Canadian Croplands to Maximize Carbon Sequestration and Minimize Other Ecosystem Service Trade-offs. Canadian Agri-food Policy Institute. Retrieved from https://capi-icpa.ca/wp-content/uploads/2019/04/2019-02-21-CAPI-land-use-dialogue_Smukler-Paper-WEB-4.pdf

Smyth, S. J., Gleim, S., & Lubieniechi, S. (2020). Regulatory barriers to innovative plant breeding in Canada. *Frontiers in Genome Editing*, 11.

Söderholm, P., & Christiernsson, A. (2008). Policy effectiveness and acceptance in the taxation of environmentally damaging chemical compounds. Environmental Science & Policy, 11(3), 240–252. Doi: https://doi.org/10.1016/J.ENVSCI.2007.10.003

Sparling, D., Cheney, E. & Cranfield, J. (2012). Not Enough GREEN in Canada's Bioproduct Industry. Richard Ivey School of Business. Retrieved from https://www.ivey.uwo.ca/media/3779209/sparling-cheney-cranfield-bioproduct-report.pdf

State of Green. (n.d.). Billund Biorefinery. State of Green. Retrieved from https://stateofgreen.com/en/partners/billund-biorefinery/

Statistics Canada. (2019). Agricultural Water Survey, 2018. Government of Canada. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/190912/dq190912d-eng.htm

Statistics Canada. (2020). Federal Government Spending on Science and Technology, 2020/2021. Government of Canada. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/200611/dq200611b-eng.htm

Statistics Canada. (2021a). Impacts of the drought on crop quality indicators. Government of Canada. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/210729/dq210729d-eng.htm

Statistics Canada. (2021b). Farm Debt Outstanding, classified by lender (x1,000). Government of Canada. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210005101

Sunstein, C. & Thaler, R. (2008). *Nudge: Improving Decisions about Health, Wealth, and Happiness.* New Haven, CT: Yale University Press.

Thamo, T., & Pannell, D. J. (2016). Challenges in developing effective policy for soil carbon sequestration: Perspectives on additionality, leakage, and permanence. Climate Policy, 16(8), 973–992. Doi: https://doi.org/10.1080/14693062.2015.1075372

Tuomisto, H. L., Hodge, I. D., Riordan, P., & Macdonald, D. W. (2012). Does organic farming reduce environmental impacts? – A meta-analysis of European research. Journal of Environmental Management, 112, 309–320. Doi: https://doi.org/10.1016/J.JENVMAN.2012.08.018

UN Department of Economic and Social Affairs. (2019). World Population Prospects 2019 Highlights. United Nations. Retrieved from https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

UNCTAD. (2016). Exploring New Trade Frontiers: The Political Economy of the Trans-Pacific Partnership. United Nations. Retrieved from https://unctad.org/system/files/official-document/webditc2016d3_en.pdf

Unilever. (n.d.). Sustainable and Regenerative Sourcing. Unilever. Retrieved from https://www.unilever.com/planet-and-society/protect-and-regenerate-nature/sustainable-and-regenerative-sourcing/

University of British Columbia. (2021). More than $20 million in NSERC Funding Awarded to New Projects Led by UBC Researchers. University of British Columbia. Retrieved from https://research.ubc.ca/more-20m-nserc-funding-awarded-new-projects-led-ubc-researchers

USDA. (2012). Conservation Reserve Program Sign-Up 43 Environmental Benefits Index (EBI). Government of the United States of America.

USDA. (2017). Soil Health Assessment. Government of the United States of America. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/assessment/

Vaissière, A. C., Tardieu, L., Quétier, F., & Roussel, S. (2018). Preferences for biodiversity offset contracts on arable land: a choice experiment study with farmers. *European Review of Agricultural Economics*, *45*(4), 553-582.

Vaissière, A. C., & Levrel, H. (2015). Biodiversity offset markets: What are they really? An empirical approach to wetland mitigation banking. *Ecological Economics*, *110*, 81-88.

Vercammen, J. (2018). Agri-Environmental Programs: Why Are They Slowing Down? FARE Share, National Food Policy Issue, 20.

Wagner-Riddle, C., & Weersink, A. (2011). Net Agricultural Greenhouse Gases. In Sustaining Soil Productivity in Response to Global Climate Change (pp. 169–182). Wiley-Blackwell. Doi: https://doi.org/10.1002/9780470960257.ch12

Waldman, K. B., & Kerr, J. M. (2014). Limitations of certification and supply chain standards for environmental protection in commodity crop production. *Annu. Rev. Resour. Econ.*, *6*(1), 429-449.

Wallander, S., Ferraro, P., & Higgins, N. (2017). Addressing Participant Inattention in Federal Programs: A Field Experiment with The Conservation Reserve Program. American Journal of Agricultural Economics, 99(4), 914–931. Doi: https://doi.org/10.1093/ajae/aax023

Weersink, A., & Pannell, D. (2017). Payments versus Direct Controls for Environmental Externalities in Agriculture. Oxford University Press. Doi: https://doi.org/10.1093/acrefore/9780199389414.013.520

Weersink, A., von Massow, M., & McDougall, B. (2020). Economic thoughts on the potential implications of COVID-19 on the Canadian dairy and poultry sectors. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 68(2), 195-200.

Weersink, A., von Massow, M., Bannon, N., Ifft, J., Maples, J., McEwan, K., & Wood, K. (2021). COVID-19 and the agri-food system in the United States and Canada. Agricultural Systems, 188, 103039.

Williamson, J. M. (2011). The role of information and prices in the nitrogen fertilizer management decision: New evidence from the agricultural resource management survey. Journal of Agricultural and Resource Economics, 36(3), 552–572.

Wilton Consulting Group. (2019). Benchmarking Canadian Agri-food Sustainability Standards. Wilton Consulting Group. Retrieved from https://www.wiltongroup.ca/wilton-blog/2019/4/11/benchmarking-cdn-agri-food-standards

World Bank. (2010). World Development Report 2010: Development and Climate Change. World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/4387

World Economic Forum. (2019). The Global Competitiveness Report, 2017-2018. World Economic Forum. Retrieved from http://www3.weforum.org/docs/GCR2017-2018/05FullReport/TheGlobalCompetitivenessReport2017%E2%80%932018.pdf

Wu, J., Adams, R. M., Kling, C. L., Tanaka, K., Wu, J., Adams, R. M., Kling, C., & Tanaka, K. (2003). Assessing the Costs and Environmental Consequences of Agricultural Land Use Changes: A Site-Specific, Policy-Scale Modeling Approach.

Wu, S., Palm-Forster, L., & Messer, K. D. (2017). Heterogeneous Agents and Information Nudges in Non-Point Source Water Pollution Management. Department of Applied Economics and Statistics, University of Delaware, Newark, DE.

Yildirim, T., Bilyea, T. & Buckingham, D. (2019). Clean Growth in Agriculture. The Canadian Agri-Food Policy Institute. Retrieved from https://capi-icpa.ca/wp-content/uploads/2019/03/2019-03-22-CAPICEF-Final-Report_WEB-1.pdf.

Smart Prosperity Institute

institute.smartprosperity.ca

ACKNOWLEDGEMENTS

The authors would like to thank Stewart Elgie and Mike Wilson of Smart Prosperity Institute for providing strategic direction on this project.

Smart Prosperity Institute also thanks the participants at our January 2020 workshop in Ottawa for their time and valuable insights. Thanks to Mike Wilson, Paige Olmsted, Katherine Monahan, Colleen Kaiser and all of the report authors for facilitating the workshop breakout discussions. Thank you to Mathias Schoemer for design, and Madeleine McGillivray for editing. Thanks as well to Laura Wohrizek, Beverley Hinterhoeller and Brydie Brown for their invaluable assistance with planning the workshop.

Finally, thanks to the staff at the Environment Policy Division of Agriculture and Agri-food Canada for their thoughtful and detailed comments on this report.

Review of this report does not imply endorsement, and all errors and omissions remain the responsibility