Part I: Animal-sourced food consumption and Canada's emissions targets

Report Prepared for World Animal Protection Canada

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SUBMITTED BY

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About Us

Navius Research Inc. ("Navius") is an independent and non-partisan consultancy based in Vancouver. We operate proprietary energy-economy modeling software designed to quantify the impacts of climate change mitigation policy on greenhouse gas emissions and the economy. We have been active in this field since 2008 and have become one of Canada's leading experts in modeling the impacts of energy and climate policy. Our analytical framework is used by clients across the country to inform energy and greenhouse gas abatement strategy.

We are proud to have worked with:

- Most provincial and territorial governments, as well as the federal government.
- Utilities, industry associations and energy companies.
- Non-profit and research organizations with an interest in energy, climate change and economics.

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Executive Summary

World Animal Protection Canada is interested in examining the role of animal agriculture in achieving Canada's greenhouse gas (GHG) emissions targets of a 40-45% reduction in emissions by 2030 and net zero emissions in 2050. To support World Animal Protection, Navius developed a customized version of its energy-economy model, gTech. gTech simulates the effects of energy and climate policy on technology adoption, energy use, GHG emissions and the economy.

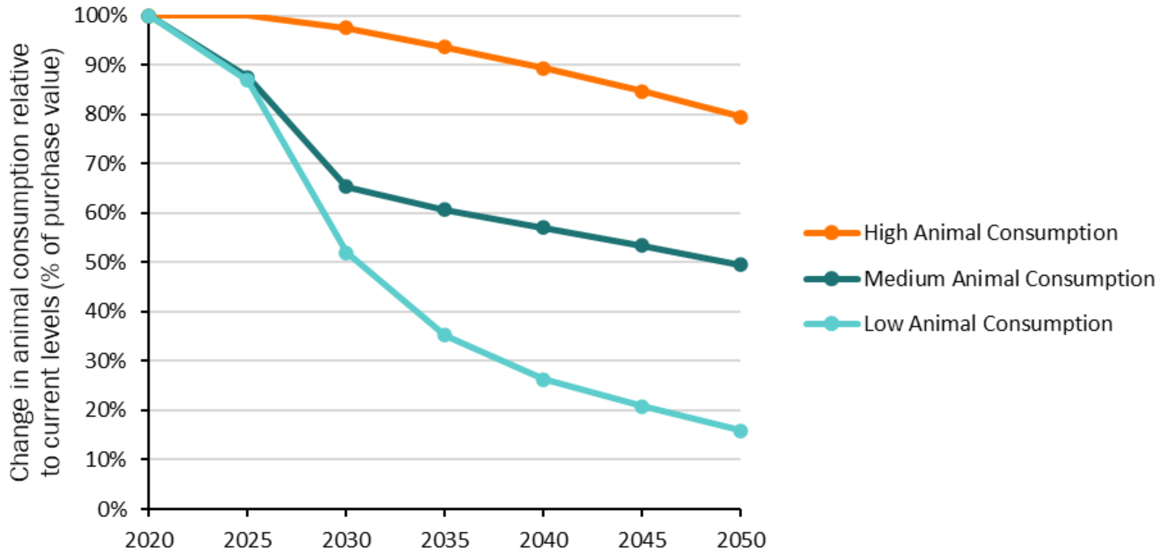
Using gTech, this analysis aims to answer the following questions:

- What is the impact of shifting consumer food consumption preferences on Canada's emissions?
- What is the impact of shifting consumer food consumption preferences on the cost of achieving Canada's emissions targets?

Three scenarios were examined in which Canada achieves its 2030 and 2050 emissions targets, each with different levels of future animal food consumption. To simulate changes in meat and dairy consumption over time, we vary three key dynamics in gTech: (1) what portion of meat and dairy consumption is substituted by plant-based alternatives over time, (2) how the cost of meat and dairy alternatives comes down over time, and (3) how willing consumers are to further substitute meat and dairy with plant-based alternatives (i.e., elasticity).

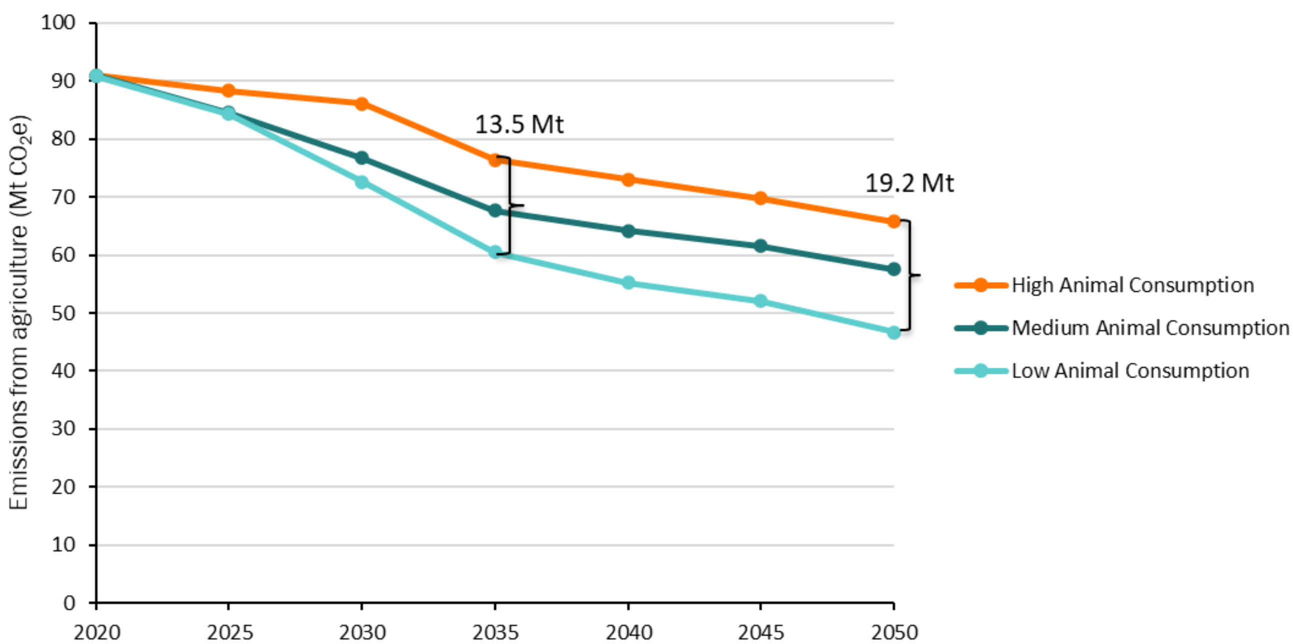
The resulting three scenarios are provided in Figure A, where the consumption of meat and dairy declines by 84% relative to current levels by 2050 in the low animal consumption scenario, and declines by 51% and 20% from current levels by 2050 in the medium and high animal consumption scenarios.

Figure A: Animal food consumption in three different scenarios in which Canada achieves its climate targets



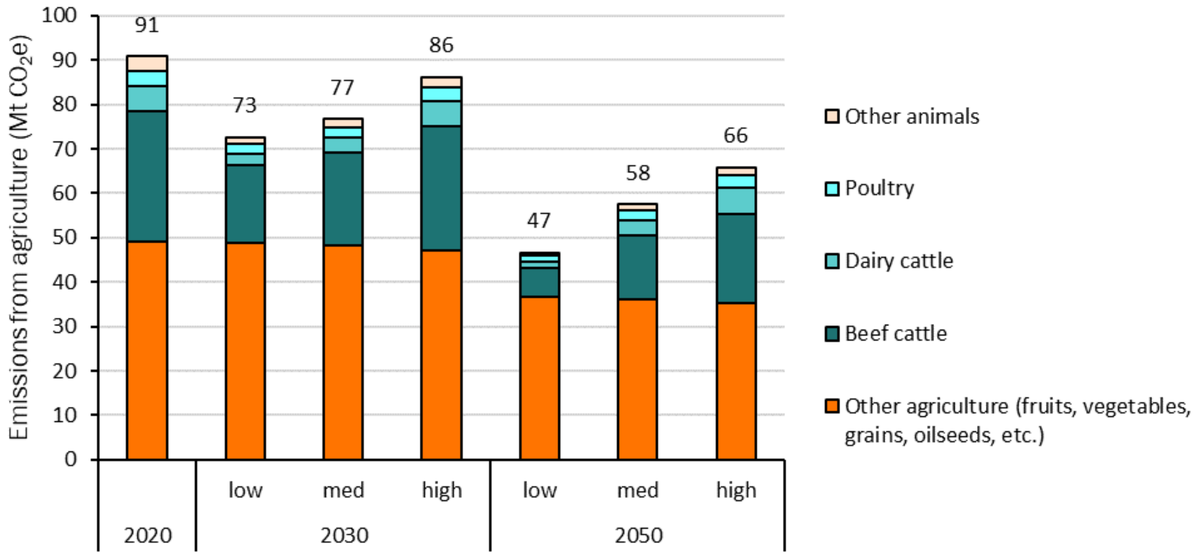
Results indicate that shifting demand from animal to plant-based foods can decrease the emissions impact of the agriculture sector. For example, agriculture emissions are 16% lower in 2030 and 29% lower in 2050 in the low animal consumption scenario relative to the high animal consumption scenario. This corresponds to a reduction in emissions of 13.5 Mt in 2030 and 19.2 Mt in 2050 (Figure B).

Figure B: Agricultural emissions in three different scenarios in which Canada achieves its climate targets



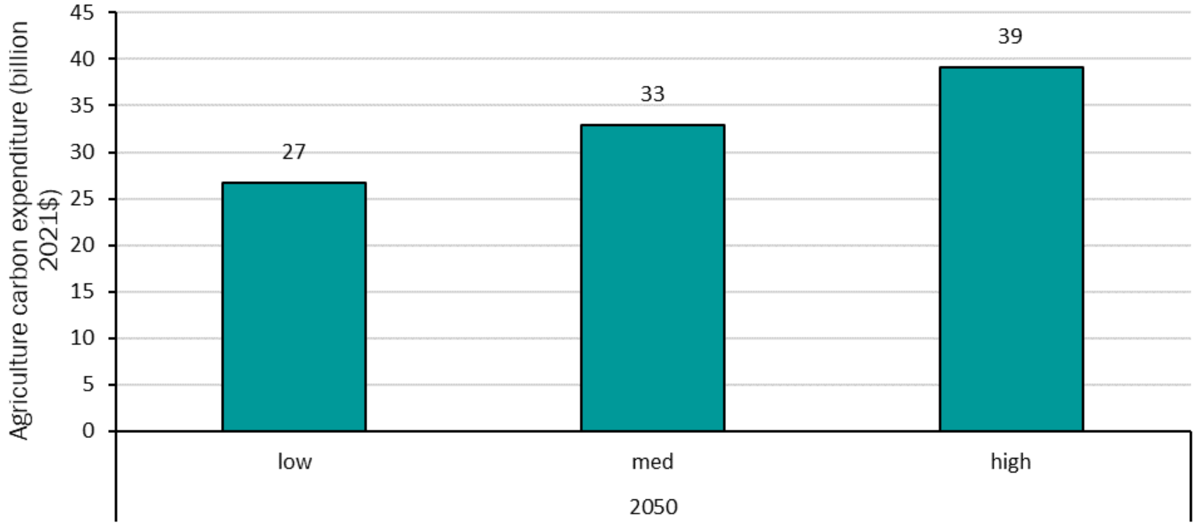
Agricultural emissions are lower in low animal consumption scenarios due to the high emissions intensity of animal agriculture and is primarily driven by a reduction in beef cattle production (Figure C).

Figure C: Agriculture emissions by type in three different scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)



In all target scenarios simulated, Canada's economy continues to grow at a similar rate out to 2050. At the same time, scenarios in which future animal consumption is lower lead to lower costs for Canada's economy to achieve its climate targets (11% less costly in 2030 in a low animal consumption scenario relative to high animal consumption). Scenarios in which future animal consumption is lower also lead to lower costs for Canada's agriculture sector to comply with climate policy. Results indicate that the compliance cost to achieve Canada's net zero emissions target could be $12.5 billion lower in 2050 in a low animal consumption scenario relative to a high animal consumption scenario (Figure D).

Figure D: Cost of policy compliance in 2050 for the agriculture sector in three scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)



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1. Introduction

Canada has committed to achieving a 40-45% reduction in greenhouse gas (GHG) emissions by 2030 and net zero emissions by 2050 in the *Canadian Net-Zero Emissions Accountability Act*.[1] To achieve this commitment, emissions from all sectors of Canada's economy will need to decline to net zero by 2050, including the agriculture sector.

The agriculture sector currently accounts for about 12% of Canada's emissions, with animal agriculture (not including feed and fertilizer for feed) accounting for 5% of total emissions. However, it is likely that the agriculture sector will account for an increasing portion of Canada's emissions in 2030 and 2050, as population and food consumption continue to grow, while emissions from the rest of Canada's economy decline in response to policy and adoption of available abatement technologies.

As the agriculture sector is faced with the challenge of decarbonization, there is increasing availability of meat- and dairy-alternative products on the market, as well as increasing awareness of the health and environmental benefits of shifting consumption away from animal foods. Canada's latest food guide, for example, emphasizes the importance of consuming plant-based foods.[2] Shifting agricultural production from animal- to plant-based foods can impact emissions in this sector due to the emissions intensive nature of animal agriculture.

It is within this context that World Animal Protection is interested in examining the role of animal agriculture in achieving Canada's emissions targets. Specifically, this analysis aims to answer the following questions:

- What is the impact of shifting consumer food consumption preferences on Canada's emissions in 2030 and 2050?
- What is the impact of shifting consumer food consumption preferences on the cost of achieving Canada's 2030 and 2050 emissions targets?

This report presents the findings of this analysis. It is structured as follows:

- Chapter 2 summarizes the analytical approach taken and key assumptions made.
- Chapter 3 presents results of the analysis.

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[1] Government of Canada. (2022). Canadian Net-Zero Emissions Accountability Act. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050/canadian-net-zero-emissions-accountability-act.html

[2] Government of Canada. (2022). Canada's Food Guide. Available from: https://food-guide.canada.ca/en/

- Chapter 4 presents important conclusions from the analysis.

2. Analytical approach

This section outlines the analytical approach taken for this analysis. First, a summary of assumptions is provided, followed by an introduction to the model used, a description of the policy scenarios simulated and key modelling assumptions.

2.1. Summary of assumptions

Modeling scenarios

To quantify the impact of shifting food consumption on Canada's emissions, we simulate two policy scenarios - current policy and target policy. The current policy scenario acts as a reference case in which no additional climate policy is implemented in Canada. It includes all existing policies, including the planned carbon price increase to $170/tCO$_{2e}$ by 2030 and the Clean Fuel Regulations. The target policy scenario simulates a cap on emissions at Canada's 2030 emissions target and net zero emissions in 2050. This report focuses on results of the target policy scenario.

For both policy scenarios, three different levels (low, medium and high) of meat and dairy consumption are simulated. This is known as a sensitivity analysis and addresses uncertainty in future levels of animal product consumption.

Key modeling assumptions

Navius' gTech model was used for this analysis. Multiple assumptions used to simulate Canada's agriculture sector and food consumption patterns are explained in the following sections. First, the agriculture sector is disaggregated into ten sub-sectors including beef cattle, dairy cattle, poultry, other animals, vegetables, fruits and nuts, other crops, greenhouses, grains, and oilseeds. Second, mitigation options available to reduce emissions from the agriculture sector are parameterized. This includes the cost and abatement potential of several low-carbon technologies available for use on farms, including energy efficiency measures, low carbon fuels, anaerobic digestion, feed additives and manure composting. Finally, the food manufacturing sector is disaggregated into five categories including meat, dairy, other foods, meat alternatives (such as Beyond Meat) and dairy alternatives (such as oat milk).

To simulate changes in meat and dairy consumption over time, we vary three key dynamics - what portion of meat and dairy consumption is substituted by plant-based alternatives over time (baseline share in the production function), how the cost of meat and dairy alternatives comes down over time (declining capital cost), and how willing consumers are to further substitute meat and dairy with plant-based alternatives (elasticity of substitution).

A more detailed explanation of the scenarios modeled and assumptions made is provided in the following sections.

2.2. Introduction to Navius' model

Canada's energy-economy is complex. Energy consumption, which is the main driver of anthropogenic greenhouse gas emissions, results from the decisions made by millions of Canadians. For example, households must choose what type of vehicles they will buy and how to heat their homes; industry must decide whether to install technologies that might cost more but consume less energy; municipalities must determine whether to expand transit service; and investors need to decide whether to invest their money in Canada or somewhere else. Currently, about 12% of Canada's GHG emissions come from the agriculture sector and its share is expected to increase in the future. Shifting agricultural production from animal-sources to plant-based foods can decrease the environmental impact of this sector due to the emissions intensive nature of animal agriculture.

All levels of government in Canada have implemented policies designed to encourage or require firms and consumers to take actions to reduce their emissions. Achieving Canada's net zero by mid-century target will require strengthening existing policies and/or implementing new policies that result in additional emission reduction activities.

Existing policies and those required to achieve Canada's net zero target will have effects throughout the economy and interact with each other. For example, the federal vehicle emission standard and carbon pricing efforts seek to reduce greenhouse gas emissions from passenger vehicles, as do a variety of provincial policies (such as BC's low carbon fuel standard, the proposed federal clean fuel standard and zero-emission vehicle mandates in Québec and proposed in BC). The interactive effects among such policies can be complex. The economic effects of all federal and provincial climate initiatives implemented together are even more complex.

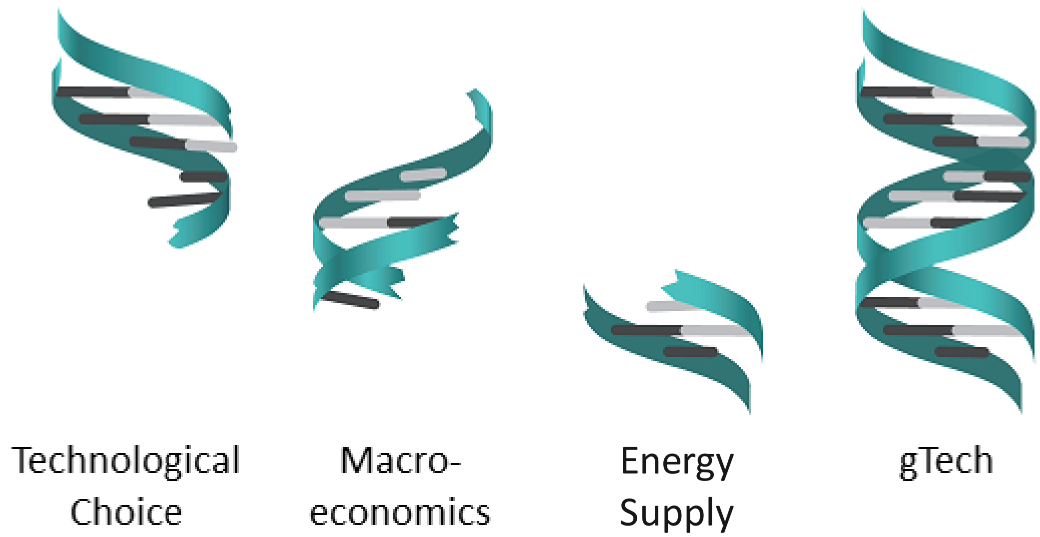
Estimating the regional, sectoral, technological and economic impacts of achieving Canada's net zero emissions target therefore requires a modeling framework that captures the complexity of the energy-economic system.

gTech is Navius in-house energy economy model used for this analysis. gTech provides a comprehensive representation of all economic activity, energy consumption and greenhouse gas emissions in Canada. gTech is unique among energy-economy models because it combines features that are typically only found in separate models:

- A realistic representation of how households and firms select technologies and processes that affect their energy consumption and greenhouse gas emissions;

- An exhaustive accounting of the economy at large, including how provinces and territories interact with each other and the rest of the world; and
- A detailed representation of energy supply, including liquid fuel (crude oil and biofuel), gaseous fuel (natural gas and renewable natural gas), hydrogen and electricity.

Figure 1: The gTech model



gTech builds on three of Navius' previous models (CIMS, GEEM and OILTRANS/IESD), combining their best elements into a comprehensive integrated framework.

Simulating technological choice

Technological choice is one of the most critical decisions that influence greenhouse gas emissions in Canada. For example, if a household chooses to purchase an electric vehicle over a gasoline car, that decision will reduce their emissions. Similarly, if a mining facility chooses to electrify its operations, that decision reduces its emissions.

gTech provides a detailed accounting of the types of energy-related technologies available to households and businesses. In total, gTech includes over 300 technologies across more than 50 end-uses (e.g., light-duty vehicle travel, residential space heating, industrial process heat, management of agricultural manure).

Naturally, technological choice is influenced by many factors. Table 1 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 1: Technological choice dynamics captured by gTech

Criteria	Description
Purchasing (capital) costs	Purchasing costs are simply the upfront cost of purchasing a technology. Every technology in gTech has a unique capital cost that is based on research conducted by Navius. Everything else being equal (which is rarely the case), households and firms prefer technologies with a lower purchasing cost.
Energy costs	Energy costs are a function of two factors: (1) the price for energy (e.g., cents per litre of gasoline) and (2) the energy requirements of an individual technology (e.g., a vehicle's fuel economy, measured in litres per 100 km). In gTech, the energy requirements for a given technology are fixed, but the price for energy is determined by the model. The method of "solving" for energy prices is discussed in more detail below.
Time preference of capital	Most technologies have both a purchasing cost as well as an energy cost. Households and businesses must generally incur a technology's purchasing cost before they incur the energy costs. In other words, a household will buy a vehicle before it needs to be fueled. As such, there is a tradeoff between near-term capital costs and long-term energy costs. gTech represents this tradeoff using a "discount rate". Discount rates are analogous to the interest rate used for a loan. The question then becomes: is a household willing to incur greater upfront costs to enable energy or emissions savings in the future? Many energy modelers use a "financial" discount rate (commonly between 5% and 10%). However, given the objective of forecasting how households and firms are likely to respond to climate policy, gTech employs behaviourally realistic discount rates of between 8% and 25% to simulate technological choice. Research consistently shows that households and firms do not make decisions using a financial discount rate, but rather use significantly higher rates.[3] The implication is that using a financial discount rate would overvalue future savings relative to revealed behaviour and provide a poor forecast of household and firm decisions.
Technology specific preferences	In addition to preferences around near-term and long-term costs, households (and even firms) exhibit "preferences" towards certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, buyers of passenger vehicles can be concerned about the driving range and available charging infrastructure of vehicles, some may worry about the risk of buying new technology, and some may see the vehicle as a "status symbol" that they value[4]. gTech quantifies these technology-specific preferences as "non-financial" costs, which are added to the technology choice algorithm.

[3] For example, see: Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047; Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. Resource and Energy Economics 31, 221-238.

[4] Kormos, C., Axsen, J., Long, Z., Goldberg, S., 2019. Latent demand for zero-emissions vehicles in Canada (Part 2): Insights from a stated choice experiment. Transportation Research Part D: Transport and Environment 67, 685-702.

Criteria	Description
The diverse nature of Canadians	Canadians are not a homogenous group. Individuals are unique and will weigh factors differently when choosing what type of technology to purchase. For example, one household may purchase a Toyota Prius while their neighbour purchases an SUV and another takes transit. gTech uses a "market share" equation in which technologies with the lowest net costs (including all the cost dynamics described above) achieve the greatest market share, but technologies with higher net costs may still capture some market share[5]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.
Changing costs over time	Costs for technologies are not fixed over time. For example, the cost of electric vehicles has come down significantly over the past few years, and costs are expected to continue declining in the future[6]. Similarly, costs for many other energy efficient devices and emissions-reducing technologies have declined and are expected to continue declining. gTech accounts for whether and how costs for technologies are projected to decline over time and/or in response to cumulative production of that technology.
Policy	One of the most important drivers of technological choice is government policy. Current federal, provincial and territorial initiatives in Canada are already altering the technological choices households and firms make through various policies: (1) incentive programs, which pay for a portion of the purchasing cost of a given technology; (2) regulations, which either require a group of technologies to be purchased or prevent another group of technologies from being purchased; (3) carbon pricing, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g., whether or not to charge GST on a given technology); and (5) flexible regulations, like the federal clean fuel standard which will create a market for compliance credits. gTech simulates the combined effects of all these policies implemented together.

Understanding the macroeconomic impacts of policy

As a full macroeconomic model (specifically, a "general equilibrium model"), gTech provides insight about how policies affect the economy at large. The key macroeconomic dynamics captured by gTech are summarised in Table 2.

[5] Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047.

[6] Nykvist, B., Sprei, F., & Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. *Energy Policy*, 124, 144-155.

Table 2: Macroeconomic dynamics captured by gTech

Dynamic	Description
Comprehensive coverage of economic activity	gTech accounts for all economic activity in Canada as measured by Statistics Canada national accounts[7]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and the transactions that occur between households, firms and government. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income and jobs.
Full equilibrium dynamics	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply for a good or service is equal to its demand). This means that a decision made in one sector is likely to have ripple effects throughout the entire economy. For example, greater demand for electricity requires greater electricity production. In turn, greater production necessitates greater investment and demand for goods and services from the electricity sector, increasing demand for labor in construction services and ultimately leading to higher wages. The model also accounts for price effects. For example, the electricity sector can pass policy compliance costs on to households, who may alter their demand for electricity and other goods and services (e.g., by switching to technologies that consume other fuels and/or reducing consumption of other goods and services).

[7] Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

Dynamic	Description
Sector detail	gTech provides a detailed accounting of sectors in Canada. In total, gTech simulates how policies affect over 80 sectors of the economy. Each of these sectors produces a unique good or service (e.g., the mining sector produces ore, while the trucking sector produces transport services) and requires specific inputs into production.
Labor and capital markets	Labour and capital markets must also achieve equilibrium in the model. The availability of labor can change with the "real" wage rate (i.e., the wage rate relative to the consumption level). If the real wage increases, the availability of labor increases. The model also accounts for "equilibrium unemployment".
Interactions between regions	Economic activity in Canada is highly influenced by interactions among provinces/territories, with the United States and with countries outside of North America. Each province in the model interacts with other regions via (1) the trade of goods and services, (2) capital movements, (3) government taxation and (4) various types of "transfers" between regions (e.g., the federal government provides transfers to provincial and territorial governments). The version of gTech used for this project accounts for the 10 Canadian provinces, the 3 territories in an aggregated region and the United States. The model simulates each of the interactions described above, and how interactions may change in response to policy.
Households	On one hand, households earn income from the economy at large. On the other, households use this income to consume different goods and services. gTech accounts for each of these dynamics, and how either changes with policy.

Understanding energy supply markets

gTech accounts for all major energy supply markets, such as electricity, refined petroleum products and natural gas. Each market is characterized by resource availability and production costs by province, as well as costs and constraints (e.g., pipeline capacity) of transporting energy between regions.

Low carbon energy sources can be introduced within each fuel stream in response to policy, including renewable electricity and bioenergy. The model accounts for the availability and cost of bioenergy feedstocks, allowing it to provide insight about the economic effects of emission reduction policy, biofuels policy and the approval of pipelines.

gTech: The benefits of merging macroeconomics with technological detail

By merging the three features described above (technological detail, macroeconomic dynamics, and energy supply dynamics), gTech can provide extensive insight into the effects of climate and energy policy.

First, gTech can provide insights related to technological change by answering questions such as:

- How do policies affect technological adoption (e.g., how many electric vehicles are likely to be on the road in 2030)?
- How does technological adoption affect greenhouse gas emissions and energy consumption?

Second, gTech can provide insights related to macroeconomics by answering questions such as:

- How do policies affect national and provincial gross domestic product?
- How do policies affect individual sectors of the economy?
- Are households affected by the policy?
- Does the policy affect energy prices or any other price in the model (e.g., food prices)?

Third, gTech answers questions related to its energy supply modules such as:

- Will a policy generate more supply of renewable fuels?
- Does policy affect the cost of transporting refined petroleum products, and therefore the price of gasoline in Canada?

Finally, gTech expands our insights into areas where there is overlap between its various features:

- What is the effect of investing carbon revenue into low- and zero-carbon technologies? This question can only be answered with a model like gTech.
- What are the macroeconomic impacts of technology-focused policies (e.g., how might a zero-emissions vehicle standard impact GDP)?
- Do biofuels-focused policies affect (1) technological choice and (2) the macroeconomy?

This modeling toolkit allows for a comprehensive examination of the impacts of Canada's net zero emission pathways.

Limits to forecasting

Despite using the best available forecasting methods and assumptions, the evolution of our energy economy is uncertain. In particular, forecasting greenhouse gas emissions is subject to two main types of uncertainty.

First, all models are simplified representations of reality. Navius' gTech model is, effectively, a series of mathematical equations that are intended to forecast the future. This raises key questions: "are the equations selected a good representation of reality?" and "do the equations selected overlook important factors that may influence the future?" The use of computable general equilibrium models (gTech) is well founded in the academic literature. In addition, Navius undertakes significant efforts to calibrate and back-cast the model to ensure that it captures key dynamics in the energy-economic system. However, Navius' tools do not account for every dynamic that will influence technological change. For example, household and firm decisions are influenced by many factors, which cannot be fully captured by even the most sophisticated model. The inherent limitation of energy-economy forecasting is that virtually all projections of the future will differ, to some extent, from what ultimately transpires.

Second, the assumptions used to parameterize the models are subject to uncertainty. These assumptions include, but are not limited to, oil prices, improvements in labour productivity and a stable climate. If any of the assumptions used prove incorrect, the resulting forecast could be affected. Sensitivity analysis is useful for determining the impact of different assumptions on model results

In sum, gTech is the most comprehensive model available for forecasting the techno-economic impacts of climate policy in Canada. Its representation of technological change, macroeconomic dynamics and fuels markets (as described above) mean that it is ideally positioned to forecast what the role of shifting food consumption on Canada's mid-century emissions is and how this will affect technological change, energy consumption, greenhouse gas emissions, the economy and a large array of other indicators.

2.3. Scenario design

Policy scenarios

Two policy scenarios were simulated in this analysis: a current policy scenario that includes currently implemented and announced policy, and a target scenario that implements a cap on emissions at Canada's 2030 emissions target and net zero in 2050. The focus of this report is the target scenario.

1. **Current policy scenario:** The current policy scenario simulated for this analysis includes all existing federal and provincial policies, as well as policies announced in Canada's *"A*

Healthy Environment and A Healthy Economy" plan.[8] This includes a federal carbon pricing backstop that increases to $170/tCO_{2e}$ in 2030[9] and the Clean Fuel Regulations.

2. **Target scenario:** This scenario includes a cap on emissions at Canada's 2030 emissions target (a 40-45% reduction in emissions from 2005 levels) and net zero emissions in 2050.[10] This scenario assumes that a certain number of offsets are available via land-use, land-use change and forestry (78 $MtCO_{2e}$ in 2030 and 103 $MtCO_{2e}$ in 2050) based on a recent report by Nature United.[11] This scenario assumes that all agricultural emissions are subject to the emissions cap. This scenario also assumes that the USA follows a reference case emissions trajectory and does not implement stringent climate policy.

Meat and dairy consumption scenarios

Different levels of meat and dairy consumption were modeled via uncertainty analysis to explore the effect on agricultural emissions and the cost of achieving Canada's net zero target. Three dynamics, including the share of meat and dairy consumption that is plant-based alternatives, the declining capital cost of meat and dairy alternatives, and the elasticity of substitution between animal and plant-based alternatives, were used to simulate different levels of meat and dairy consumption over time. Table 3 provides a summary of the three meat and dairy consumption scenarios simulated in this analysis. See the next section for a more detailed explanation of how these meat and dairy consumption forecasts were simulated.

Table 3: Uncertainty in animal product consumption examined in this analysis

Low Animal Consumption	Medium Animal Consumption	High Animal Consumption
• The share of meat consumption that is meat substitutes and the share of dairy consumption that is dairy substitutes increases significantly from 2020 to 2050	• The share of meat consumption that is meat substitutes and the share of dairy consumption that is dairy substitutes increases from 2020 to 2050	• The share of meat consumption that is meat substitutes and the share of dairy consumption that is dairy substitutes stays at current levels

8 https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

9 Note that currently, the agriculture sector is only partially covered under the carbon tax. Due to various exemptions for farmers, on-farm fuel usage for machinery is excluded from the tax. Since land-use emissions are not included under the tax, this effectively means that only grain and oilseed drying, and heating of barns and other farm buildings are taxed. Source: https://www.canada.ca/en/department-finance/news/2018/10/backgrounder-targeted-relief-for-farmers-and-fishers-and-residents-of-rural-and-remote-communities.html

10 Under net zero policy, a performance standard applies to all oil and gas facilities and includes 80% free allocations in 2020, 70% free allocations in 2025, 60% in 2030, 22% in 2040 and 0% in 2050.

11 https://www.science.org/doi/10.1126/sciadv.abd6034

• The cost of meat and dairy alternatives declines significantly over time • There is very high substitutability between plant-based products and animal products	• The cost of meat and dairy alternatives declines over time • There is high substitutability between plant-based products and animal products	• The cost of meat and dairy alternatives stays at current levels • There is low substitutability between plant-based products and animal products

2.4. Key modeling assumptions

This section summarizes key modeling assumptions related to the agriculture sector used in this analysis.

Agriculture sectors in gTech

Canada's agriculture sector is disaggregated into a number of sub-sectors in gTech which are outlined in Table 4. The disaggregation of these sectors is based on a variety of sources, including Statistics Canada's Supply-Use Tables and Environment and Climate Change Canada's National Inventory Report.[12] Note that seafood production is not included in the agriculture sector in gTech, but is captured in a separate sector in the model.

Table 4: Modeled agriculture sub-sectors

Category	Modeled sector
Animals	Dairy cattle
	Beef cattle
	Poultry
	Other animals
Fruits, Vegetables and Legumes	Vegetables
	Fruits and nuts
	Other (includes lentils, beans, chickpeas and miscellaneous crops)
	Greenhouse (includes greenhouses, nursery and floriculture products)
Grains and Oilseeds	Grains (wheat and other grains)
	Oilseeds (soy, canola, rapeseed)
Agriculture services	Agriculture services

[12] A more detailed description of how emissions from these sub-sectors are characterized in gTech can be found in this report: https://iafbc.ca/wp-content/uploads/2022/02/BC-Agriculture-GHG-Mitigation-2021.pdf

Mitigation options for agricultural emissions

Multiple mitigation options for the agriculture sector are available in gTech. In addition to reducing emissions from energy consumption, there are some mitigation options available for livestock that are relatively low-cost with high abatement potential. These options, including manure composting, feed additives and anaerobic digestion are explained below.

Table 5 provides an overview of the mitigation actions included in this analysis. Options to reduce emissions from non-combustion sources are less well understood than those for combustion sources. As a result, combustion, enteric fermentation and manure management abatement options are included in this modeling, while abatement opportunities for agricultural soils and land-use and land-use change and forestry (LULUCF) are excluded due to a lack of available data to parameterize these opportunities in gTech. To characterize abatement practices for livestock, this analysis relies on a recent report from the University of British Columbia.[13]

Table 5: Overview of modeled greenhouse gas mitigation options for agriculture

Abatement action	Combustion		Non-combustion			
	Stationary	Transport	Enteric fermentation	Manure management	Agricultural soils	LULUCF
Energy						
Battery electric vehicles		X				
Fuel cell electric vehicles	X	X				
Bioenergy	X	X				
Electric heat	X					
Livestock						
Anaerobic digestion				X		
Cattle feed additive			X			
Manure composting				X		

Zero-emission vehicles

Plug-in electric and hydrogen fuel cell vehicles are available to reduce emissions from transportation in agriculture.

[13] Borden, K., Hamilton, M., Li, Carson, Norgaard, A., Smukler, S. 2021. Opportunity assessment of agricultural GHG reductions and carbon sinks. Report prepared for BC Ministry of Agriculture, Food and Fisheries. Provided to Navius Research by Anna Stemberger, BC Ministry of Agriculture, Food and Fisheries on August 4, 2021.

Plug-in electric and hydrogen fuel cell vehicles are characterized based on the costs summarized in Table 6. These alternative-fuel drivetrains are available as an option for off-road farming vehicles (as well as for light-duty, medium-duty and heavy-duty road vehicles). The potential adoption of these technologies is a function of their upfront costs (for vehicles and charging infrastructure where appropriate), energy costs, and a dynamic representation of the barriers to their adoption (i.e., the implied cost of limited charging/fueling infrastructure, range concerns, unfamiliarity with the technologies, lack of supply).

Table 6: Zero emission vehicle costs

Technology/fuel	Cost	Sources
Plug-in electric vehicles	Battery pack costs decline from $492/kWh in 2015 to a minimum of $82/kWh.	Bloomberg New Energy Finance. (2020). Electric vehicle outlook; ICCT. (2019). Update on electric vehicle costs in the United States through 2030; Nykvist, B., F. Sprei, et al. (2019). "Assessing the progress toward lower priced long range battery electric vehicles." Energy Policy 124: 144-155.
Hydrogen fuel cell electric vehicles	Fuel cell stack system costs decline from $300/kW in 2015 to a minimum of $73/kW.	SA Consultants. (2016). Final report: Hydrogen storage system cost analysis; SA Consultants. (2017). Mass production cost estimation of direct H2 PEM fuel cell systems for transportation applications;
	Fuel tanks decline from $30/kWh in 2015 to a minimum of $11/kWh.	IEA. (2020). Breakdown of cost-reduction potential for electrochemical devices by component category.

Bioenergy

Various forms of bioenergy can be introduced in the liquid or gaseous fuel streams as summarized in Table 7, which can reduce both stationary and transport combustion emissions in the agriculture sector. Please note that the abatement costs shown are illustrative and will change dynamically in the model as a function of various factors including fossil energy prices and renewable fuel feedstock costs.

Table 7: Summary of bioenergy abatement options

Technology/Fuel	Approximate abatement cost ($/tonne CO_2e)	Sources
Second generation renewable natural gas	248	G4 Insights Inc. (2018). Our Technology; International Energy Agency Energy Technology System Analysis Programme (IEA ETSAP). (2013). Biogas and bio-syngas production; International Renewable Energy Association (IRENA). (2013). Road transport: the cost of renewable solutions; (S&T) Consultants Inc. (2012). Update of Advanced Biofuel Pathways in GHGenius.
Ethanol	156	
Cellulosic ethanol	172	
Biodiesel	116	
Hydrogenated renewable diesel	149	
Second generation renewable gasoline/diesel	411	

Notes: Abatement costs are illustrative and will vary in the modeling as they respond to changes in energy prices, technology learning and fuel carbon intensities, all of which are endogenously determined in gTech. Values are in 2020 CAD/tCO_{2e} captured, based on a 15% discount rate and 30-year project life. Second generation renewable natural gas: feedstock at $70/dry tonne, approximate wholesale cost of $16/GJ. Ethanol: corn at $169/tonne, approximate wholesale cost of $23/GJ. Cellulosic ethanol: feedstock at $70/dry tonne, approximate wholesale cost of $31/GJ. Biodiesel: Canola seed at $414/tonne, approximate wholesale cost of $25/GJ. Hydrogenated renewable diesel: canola seed at $414/tonne, approximate wholesale cost of $26/GJ. Second generation renewable gasoline/diesel: feedstock at $70/dry tonne, approximate wholesale cost of $44/GJ.

Electric heating

Another source of emissions from agriculture is the heating of barns and other farm facilities, including livestock heating, crop drying, equipment warming and keeping greenhouse temperatures constant.[14] Currently, natural gas and propane are the main sources of heat on farms in Canada. However, replacing this with RNG (as noted above) or electric heating systems can help reduce emissions.

Anaerobic digestion

Organic residues such as manure and crop residue can be used to create renewable natural gas (RNG) through the process of anaerobic digestion. Anaerobic digestion captures manure emissions and therefore reduces livestock emissions. Captured methane is then turned into RNG and can displace natural gas elsewhere in the economy.

The assumed cost of producing renewable natural gas via anaerobic digestion is provided in Table 8.[15]

[14] Shipley Energy. The Benefits of Natural Gas in the Agriculture Industry. Available from: https://www.shipleyenergy.com/resources/commercial/the-benefits-of-natural-gas-in-the-agriculture-industry

[15] Note that despite it's potential, there are known challenges associated with the application of manure methane digesters that should be considered. These are explored in this report: https://www.iatp.org/meeting-methane-pledge-us-can-do-more-agriculture

Table 8: Characterization of anaerobic digestion

Technology	Archetype production (TJ/yr)	Upfront cost (million 2019$)	Operating cost (2019$/GJ)	Cost of RNG output (2019$/GJ)
Anerobic digestion	23	1.7	1.9	12.7

Source: International Energy Agency (IEA) Energy Technology System Analysis Program (ETSAP) (2013). Biogas and Bio-syngas Production. https://iea-etsap.org/E-TechDS/PDF/P11_BiogasProd_ML_Dec2013_GSOK.pdf.
Notes: (1) Production of RNG is constrained to agricultural output. (2) Excludes value of digestate. (3) Norgaard et al. (2021) assume that 62.5% (+/-20%) of agricultural residues could be used to create renewable natural gas, based on a recent study finding that 50-75% of feedstocks in BC were considered as "easily accessible".

Manure composting

Composting is an alternative manure storage method that can be used to reduce GHG emissions. Specifically, aerobic composting reduces the amount of CH_4 produced by anaerobic decomposition of organic matter.

The abatement potential and cost of manure composting is summarized in Table 9.

Table 9: Characterization of manure composting

Livestock type	Reduction factor (t CO_2e/1000 hd/yr)	Upfront cost	Operating cost	Abatement cost ($/t CO_2e)
Dairy cattle	751	21,429	0	6 (4-11)
Beef cattle	361	21,429	0	12 (8-23)
Total	**659**	**21,429**	**0**	**7 (5-13)**

Source: Norgaard et al. (2021).
Notes: (1) Upfront cost is that of building a composting facility suitable for 1000 heads of cattle, with a volume of 25 cubic yards and a lifespan of 15-25 years. (2) No operating costs specified. (3) We assume that the GHG reduction factor can be extended to 2050.

Feed additives

Feed additives can reduce methane associated with enteric fermentation. This abatement action is based on the additive 3-nitrooxypropanol (3NOP), a synthetic compound which inhibits methanogenic bacteria from performing the final step of methane production in livestock's rumen.

The abatement potential and cost of feed additives is summarized in Table 10.

Table 10: Characterization of feed additives

Livestock type	Reduction factor (t CO_2e/1000 hd/yr)	Upfront cost	Operating cost ($/head/yr)	Abatement cost ($/t CO_2e)
Dairy cattle	925	0	25 (10-50)	27 (9-70)
Beef cattle	1,522	0	25 (10-50)	16 (5-48)
Total	**1,066**	0	**25 (10-50)**	**12 (8-58)**

Source: Norgaard et al. (2021).
Notes: (1) Costs are preliminary because 3NOP feed additive is not yet approved for use in Canada. (2) Abatement cost range reflects uncertainty in cost and GHG reduction potential. (3) We assume that the GHG reduction factor can be extended to 2050.

Food manufacturing sectors in gTech

Canada's food manufacturing sector is disaggregated into five sub-sectors for this analysis, outlined in Table 11. Disaggregation of these sectors is based on Statistics Canada's Supply-Use Tables. The dairy alternatives (e.g., oat milk) and meat alternatives (e.g., Beyond Meat) sectors become available in 2020 and parameterization of these sectors is based on the "other food" sector from the Supply-Use Tables. This is a critical assumption because the inputs (including agricultural goods, manufacturing goods, labour, etc.) consumed by the meat and dairy alternatives sectors impacts several factors such as the emissions and GDP of these sectors.

Table 11: Modeled food manufacturing sub-sectors

Category	Modeled sector
Food manufacturing	Meat
	Dairy
	Other foods
	Meat alternatives
	Dairy alternatives

Simulating changes in meat and dairy consumption

Future consumption of animal products was varied in this analysis by simulating different levels of substitutability between meat/dairy foods and plant-based foods. This was done by modeling three key dynamics:

1. **What share of meat and dairy consumption is plant-based alternatives over time.**

Each sector in the economy is given a choice of the ratio in which they will meet meat/dairy demand through plant-based substitutes. This is determined in the model via a production function that is informed by a baseline market share of alternatives, elasticity of substitution between the products, as well as other factors such as prices of inputs and outputs. To inform the baseline share that enters the production function, we use an article from the Good Food Institute, which suggests that meat alternatives made up 1.4% of meat product demand and dairy alternatives made up 15% of dairy product demand in 2020.[16] This baseline share of meat and dairy alternatives that informs the production function changes over time and varies by scenario.[17] It increases most in the low animal consumption scenario and does not increase in the high animal consumption scenario.

2. How the cost of meat and dairy alternatives come down over time.

Because the cost of meat and dairy alternatives is expected to come down over time[18], we simulate a declining capital cost function for these sectors in gTech. Based on an assumption that dairy alternatives are 11% more expensive than dairy, and meat alternatives are 43% more expensive than meat in 2020[19], we vary the level to which the cost of plant-based alternatives decline over time. The cost declines most in the low animal consumption scenario and does not decline in the high animal consumption scenario.

3. How much consumers substitute meat and dairy for plant-based alternatives.

When shifting food consumption away from meat and dairy, consumers can consume more meat and dairy alternatives such as Beyond Meat or oat milk, or they can consume more of other foods, such as grains, vegetables and legumes. This is simulated in gTech using an elasticity of substitution, a measure of how easily consumers will substitute between animal products and plant-based alternatives. The elasticity of substitution describes how the ratio of output of two goods change relative to the ratio of their prices. To parameterize the elasticity of substitution between meat/dairy and plant-based alternatives we draw on several studies[20], and to parameterize the elasticity of substitution between meat/dairy and other foods we use a 2012 USDA study[21].

Note that change in animal product consumption was also varied in the USA in this analysis via the same three dynamics described above. This was done to capture the impacts of exports on

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16 Good Food Institute. (2020). 2020 US retail market data for the plant-based industry. Available from: https://gfi.org/marketresearch/

17 Future share of meat and dairy alternatives is based on this Bloomberg article: https://www.bloomberg.com/company/press/plant-based-foods-market-to-hit-162-billion-in-next-decade-projects-bloomberg-intelligence/

18 EY Food and Agriculture. (2021). Protein reimagined: Challenges and opportunities in the alternative meat industry. Available from: https://www.ey.com/en_us/food-system-reimagined/protein-reimagined-challenges-and-opportunities-in-the-alternative-meat-industry

19 Good Food Institute. (2022). Reducing the price of alternative proteins. Available from: https://gfi.org/wp-content/uploads/2021/12/Reducing-the-price-of-alternative-proteins_GFI_2022.pdf

20 Yang & Dharmasena. (2021). U.S. Consumer Demand for Plant-Based Milk Alternative Beverages: Hedonic Metric Augmented Barten's Synthetic Model. *Foods, 10(265);* Oosterwijk. (2020). *Price Elasticity of The Demand for Plant-Based Milk in the Middle Atlantic Division;* Zhao, Wang, Hu, Zheng. (2022). Meet the meatless: Demand for new generation plant-based meat alternatives. *Appl Econ Perspect Policy, 1-18;* Tonsor, Lusk & Schroeder. (2021). *Impacts of New Plant-Based Protein Alternatives on U.S. Beef Demand.*

21 USDA. (2012). *The Demand for Disaggregated Food-Away-From-Home and Food-at-Home Products in the United States.*

Canada’s agriculture emissions and economy, as demand for animal-sourced products in the USA may impact animal agriculture production in Canada.

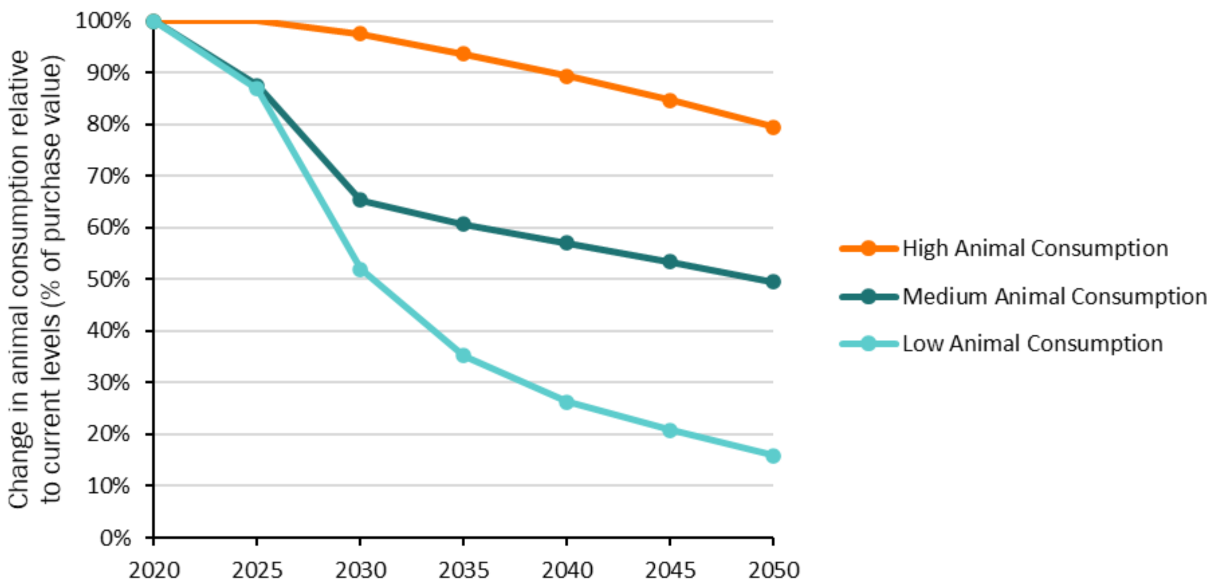
3. Results

This section presents the results of this analysis, including how animal food consumption could change over time in Canada, how this impacts agricultural emissions, and finally how this impacts the cost of achieving Canada's emissions targets.

3.1. Animal food consumption

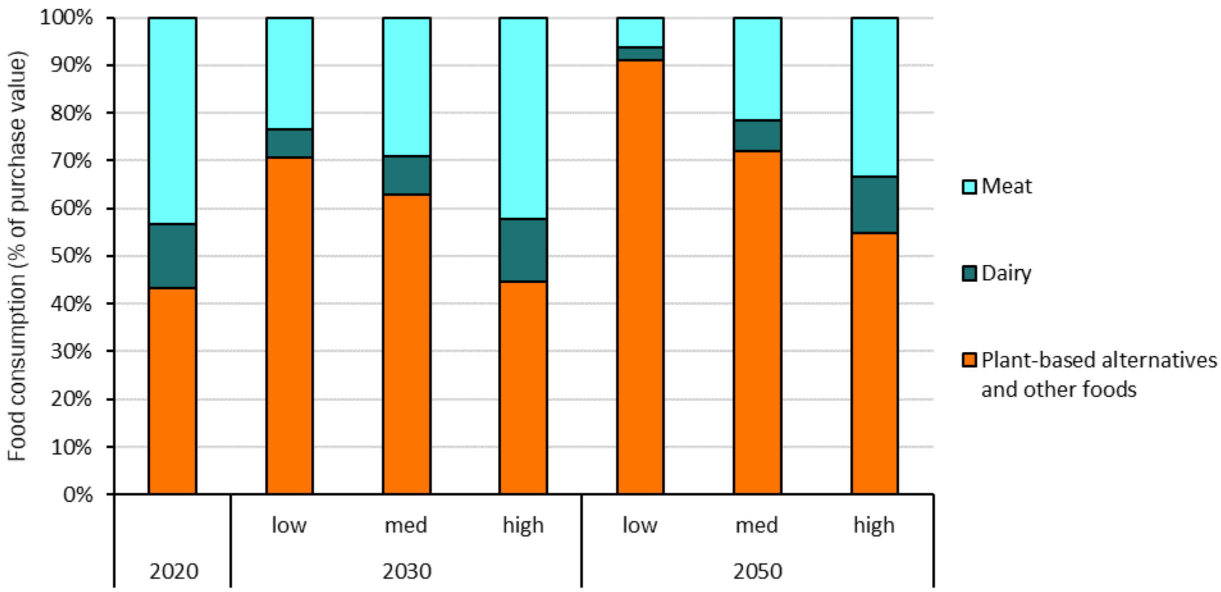
To capture uncertainty in how animal food consumption might change over time, we simulate three different levels of future animal consumption, as outlined in Section 2.4. The resulting three scenarios are provided in Figure 2. In the low animal consumption scenario, consumption of meat and dairy declines by 84% from current levels by 2050. In the medium and high animal consumption scenarios, meat and dairy consumption decline by 51% and 20% from current levels by 2050.

Figure 2: Animal food consumption in three different scenarios in which Canada achieves its climate targets



Declines in animal consumption are primarily driven by reductions in meat consumption, specifically beef which is the most emissions intensive form of animal agriculture (this is discussed more in the following section). Animal consumption is replaced by increased consumption of plant-based foods, including meat and dairy-alternatives, as well as fruits, vegetables, grains and legumes. This is demonstrated in Figure 3, which shows that current food consumption in Canada is made up of 57% animal foods. This portion declines to 45% in 2050 in the high animal consumption scenario, 28% in medium consumption and 9% in the low animal consumption scenario. Consumption of plant-based foods increases to replace animal foods, increasing from 43% of current food consumption to 55% in 2050 in the high animal consumption scenario, 72% in medium consumption and 91% in the low animal consumption scenario.

Figure 3: Portion of food consumption that is meat, dairy or plant-based in three different scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)



The next section discusses the impact of shifting food consumption on Canada's emissions.

3.2. Agricultural emissions

Impacts of food consumption on agricultural emissions

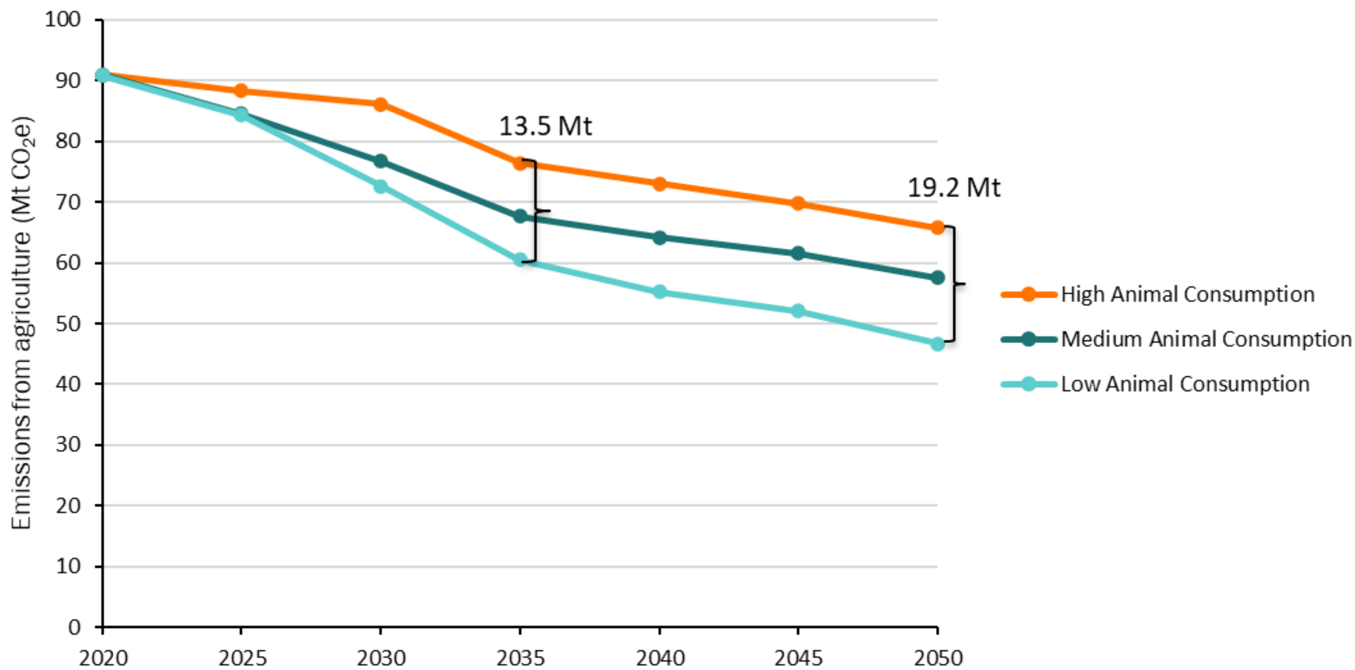
Agricultural emissions[22] decline in all target scenarios simulated in response to net zero climate policy. As the agriculture sector adopts low carbon fuels and emission abatement technologies to comply with policy, emissions from this sector decline from 91 Mt CO_2e in 2020 to 47–66 Mt CO_2e in 2050. Figure 4 presents emissions from agriculture in the three different animal consumption scenarios simulated. Emissions from agriculture decline by 28%, 37% and 49% relative to current levels in the high, medium and low animal consumption scenarios.

[22] Agricultural emissions refer to emissions occurring on farms within Canada. This includes emissions from the production of food in Canada that is then exported but does not include emissions from the production of food that is produced outside of Canada and imported into Canada for consumption.

The range in remaining emissions reflects the impact of animal food consumption. As food consumption shifts away from animal-based foods towards plant-based products, agricultural emissions are lower. For example, agriculture emissions are 16% lower in 2030 and 29% lower in 2050 in the low animal consumption relative to the high animal consumption scenario. This corresponds to 13.5 $MtCO_{2e}$ in 2030 and 19.2 $MtCO_{2e}$ in 2050.

To put this emissions impact into context, a recent analysis of Canada's Emissions Reduction Plan (ERP)[23] found that there is a 9 Mt gap between announced policies and Canada's 2030 emissions target. These results suggest that if future animal consumption is lower, this could be enough to fill this gap and, in combination with the implementation of ERP policies, would allow Canada to achieve it's 2030 emissions target.

Figure 4: Agricultural emissions in three different scenarios in which Canada achieves its climate targets



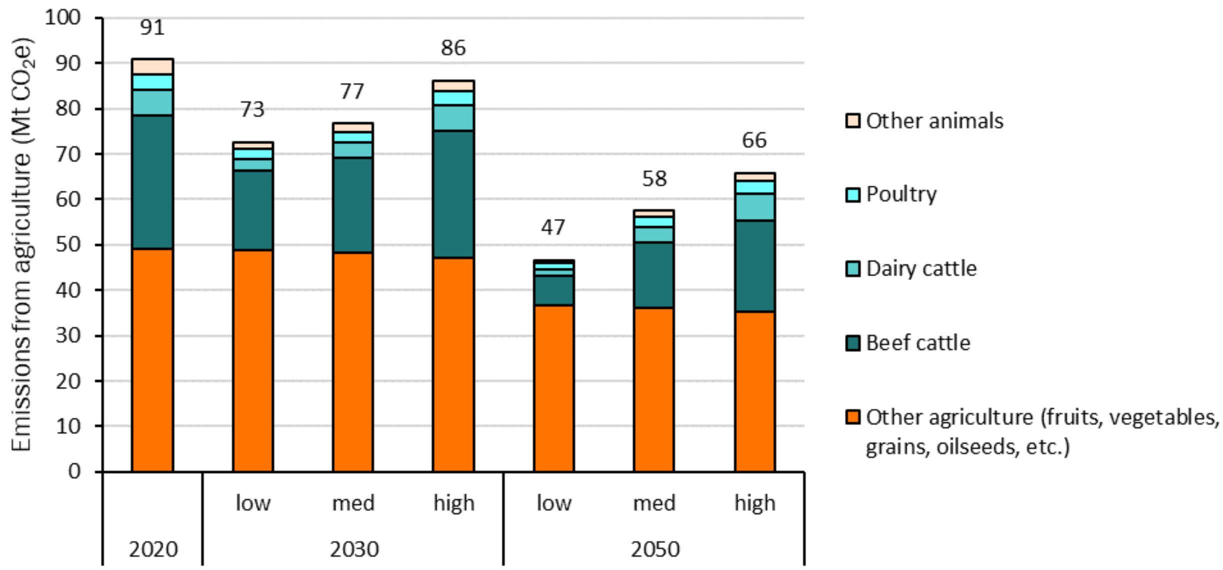
Composition of agricultural emissions in Canada

Agricultural emissions by type of agriculture are presented in Figure 5. This indicates that a significant contributor to emissions reductions between the low and high animal consumption scenarios is a reduction in emissions from beef cattle, as a result of lower demand for beef in

[23] Canadian Climate Institute. (2022). Independent Assessment: 2030 Emissions Reduction Plan. Available from: https://climateinstitute.ca/wp-content/uploads/2022/04/ERP-Volume-2-FINAL.pdf

the low animal consumption scenario. Beef production has a significant impact on agricultural emissions because beef production is the most emissions intensive form of agriculture.[24]

Figure 5: Total agriculture emissions by type in three different scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)



Shifting away from animal to plant-based agriculture reduces emissions for two main reasons. First, there is a reduction in emissions from animals themselves as fewer animals are farmed. Second, there is a reduction in emissions from input requirements to produce animals, including the growing of feed and use of fertilizer on that feed. Figure 6 presents emissions associated with animal agriculture in each scenario, including the indirect emissions associated with feed and fertilizer. It indicates that feed and fertilizer for animal agriculture add an additional 16% of emissions attributed to animal agriculture in 2020.

[24] Food and Agriculture Organization of the United Nations. *GLEAM 2.0 – Assessment of greenhouse gas emissions and mitigation potential.* Available from: https://www.fao.org/gleam/results/en/

Figure 6: Emissions from animal agriculture (including emissions from the production of animal feed and fertilizer for animal feed) in three different scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)

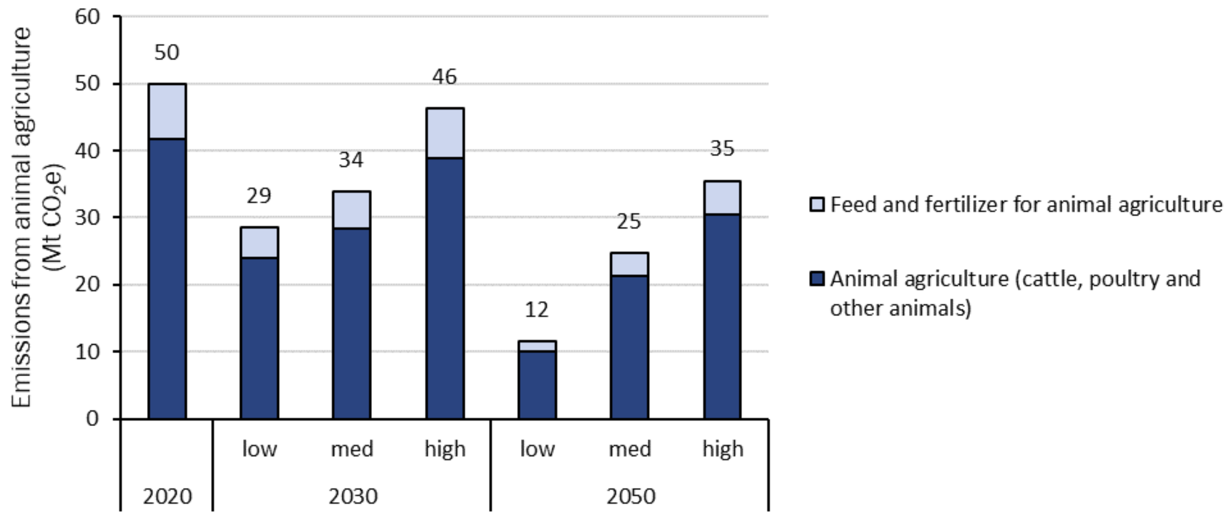
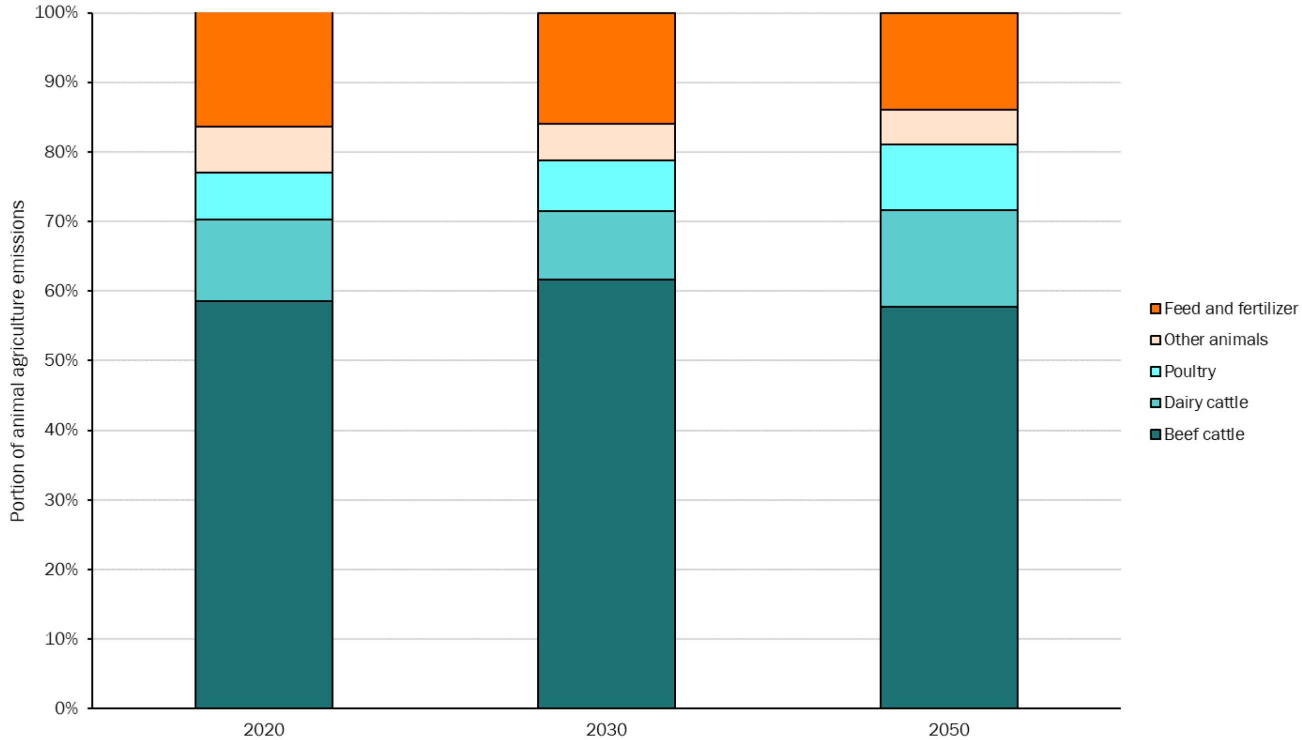


Figure 7 presents the share of animal agriculture emissions by type of agriculture, including the contribution of feed and fertilizer. This indicates that beef cattle are the largest contributor to animal agriculture emissions, followed by emissions from the production of animal feed and fertilizer for animal feed. Accounting for emissions from feed and fertilizer is therefore important when accounting for emissions from animal agriculture in Canada.

Figure 7: Portion of animal agriculture emissions by type of agriculture in a scenario in which Canada achieves its climate targets (assumes medium animal consumption)

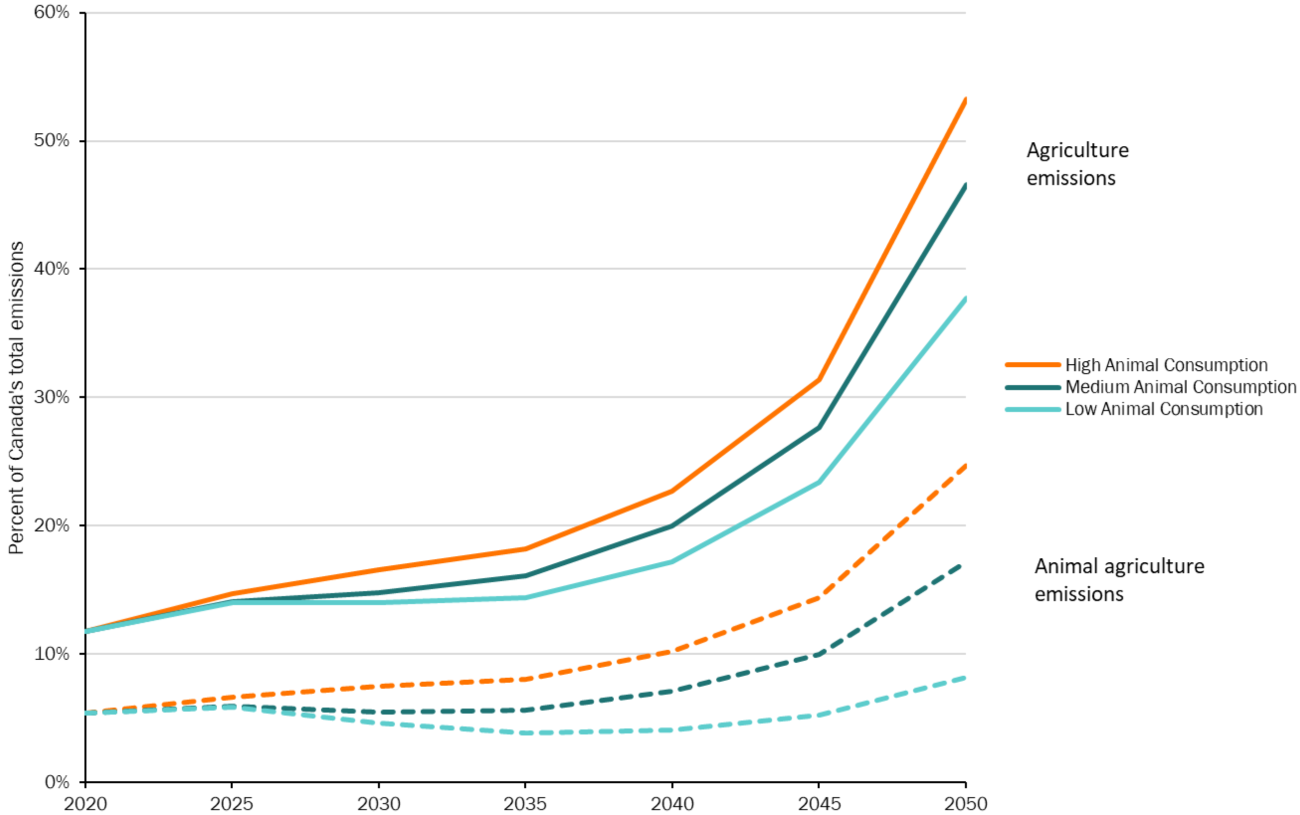


Role of agricultural emissions in Canada's net zero future

It is interesting to note that although absolute emissions from agriculture decline in all net zero scenarios simulated in this analysis, the agriculture sector makes up a significantly larger portion of Canada's total emissions by 2050 in all scenarios compared to today. This is due to a greater relative reduction in emissions in other sectors, many of which have more readily available, lower-cost abatement options to comply with net zero.

Figure 8 shows the share of Canada's total emissions from agriculture and animal agriculture in a net zero scenario with low, medium, and high animal food consumption. It indicates that the agriculture sector's contribution to emissions increases from 12% today to 53% in 2050, if meat consumption remains high. Similarly, emissions from animal agriculture increase from 5% of total emissions today to 17% in 2050, if Canadians reduce consumption as per the medium scenario. The contribution of agriculture to Canada's emissions increases less under a low animal consumption scenario, from 12% today to 38% in 2050 (8% for animal agriculture).

Figure 8: Agriculture emissions (total and animal agriculture) as a percent of Canada's total emissions in three different scenarios in which Canada achieves its climate targets



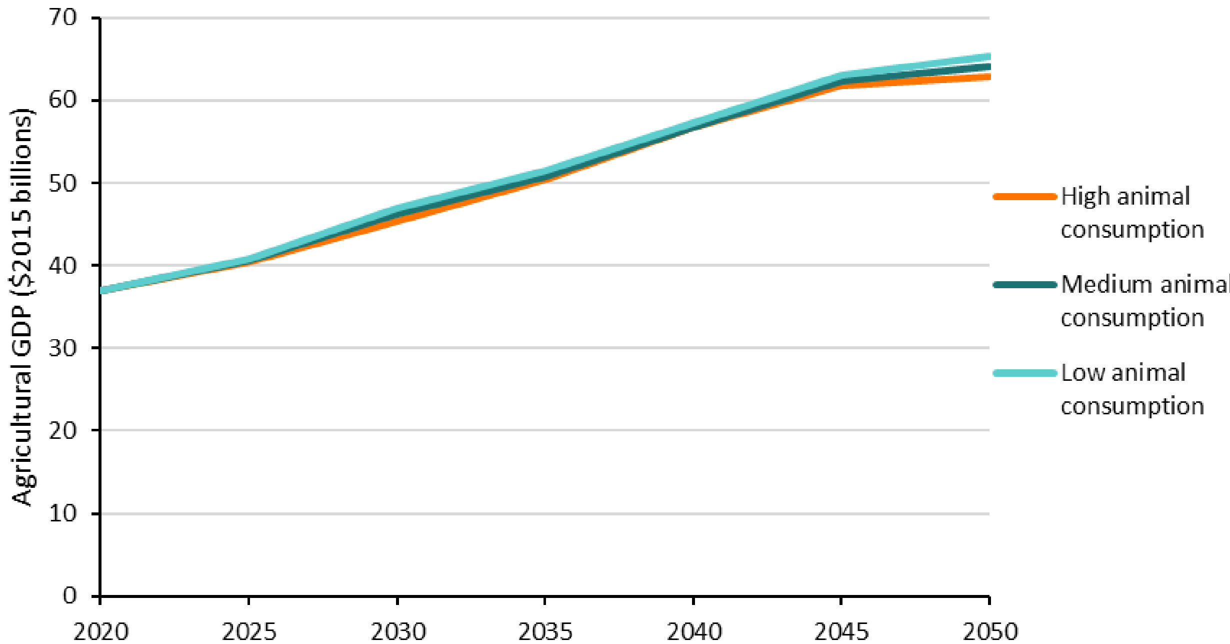
3.3. Cost of achieving Canada's emissions targets

GDP impacts

In all target scenarios simulated in this analysis, Canada's economy-wide GDP continues to grow out to 2050. Scenarios in which future animal consumption is lower lead to similar levels of economic growth as scenarios in which future animal consumption is higher (cumulative annual GDP growth rate from 2020-2050 is 1.4% under target policy for all three animal consumption scenarios).

While economy-wide GDP is similar across animal consumption scenarios, there are differences in GDP within the agricultural sector. GDP from plant-based agriculture (including fruits, vegetables, oilseeds, etc.) increases in the low animal consumption scenarios, while GDP from animal agriculture (including cattle, poultry, etc.) and from grains (used in part for animal feed) decreases in the low animal consumption scenario. In balance, Canada's agricultural GDP remains similar between all three animal consumption scenarios out to 2050 (Figure 9). This suggests that this sector is resilient to changes in demand – if Canada shifts to less animal and more plant-based consumption in the future, this sector can maintain the same level of economic growth by shifting production to more plant-based products.

Figure 9: Agricultural sector GDP in three scenarios in which Canada achieves its climate targets



This result is driven by two key dynamics. First, in a future in which demand for plant-based products increases, the value of these products rises, having a positive effect on agricultural GDP in the low animal consumption scenarios. Second, there is an increased cost to the production of animal agriculture in a net zero emission future because of the costs associated with reducing emissions to comply with Canada's targets (see next section). As such, shifting to less emissions-intensive agriculture reduces costs and has a positive effect on agricultural GDP in the low animal consumption scenarios. Together these dynamics offset the negative impacts to GDP from reduced demand for animal agriculture, suggesting that Canada's agriculture sector could shift towards plant-based production without negatively impacting earnings.

Policy compliance costs

There is a cost to comply with climate policy, either through the adoption of abatement technologies, payment of a carbon tax, or purchase of offsets for any emissions remaining by 2050. As such, the more the agriculture sector reduces its emissions through other means (such as shifting away from animal agriculture towards plant-based agricultural production), the lower the cost of policy compliance as the stringency of emissions reduction requirements increases. In addition, the more the agriculture sector reduces its emissions, the fewer emissions reductions are required in other sectors of the economy, leading to lower overall costs for Canada's economy to achieve its emissions targets.

The cost of policy compliance is determined using a shadow carbon price. The shadow carbon price is a measurement of the level of policy stringency required to achieve Canada's 2030 and 2050 emissions targets. It can be thought of as the cost per tonne of CO_2e emitted that is required to comply with Canada's targets. Results indicate variation in the shadow carbon price under different levels of future animal consumption and suggest that a future with less animal and more plant-based food consumption could reduce the cost of Canada achieving its climate targets. Under a low animal consumption scenario, the shadow carbon price is 11% lower in 2030 compared to a high animal consumption scenario, and 4% lower in 2050. This suggests that if Canada's future animal consumption is lower, it will cost 11% less for the economy to comply with the 2030 emissions target compared to a future in which animal consumption remains at current levels.

Looking at the agriculture sector specifically, scenarios in which future animal consumption is lower lead to lower costs for this sector to comply with climate policy. Figure 10 quantifies the cost to the agriculture sector of complying with Canada's 2050 net zero target under each animal consumption scenario. Costs are calculated based on the shadow carbon price and total agricultural emissions in each year. Results indicate that the compliance cost to achieve Canada's net zero emissions target could be $12.5 billion lower in 2050 in a low animal consumption scenario relative to high animal consumption scenario. Similarly, the cost of policy compliance could be $6.5 billion lower in 2030 and $8 billion lower in 2040 in a low animal consumption scenario relative to high animal consumption scenario. This reduced policy compliance cost is due to the lower emissions intensity of this sector under low animal consumption scenarios relative to high animal consumption, as indicated in Figure 11.

Figure 10: Cost of policy compliance in 2050 for the agriculture sector in three scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)

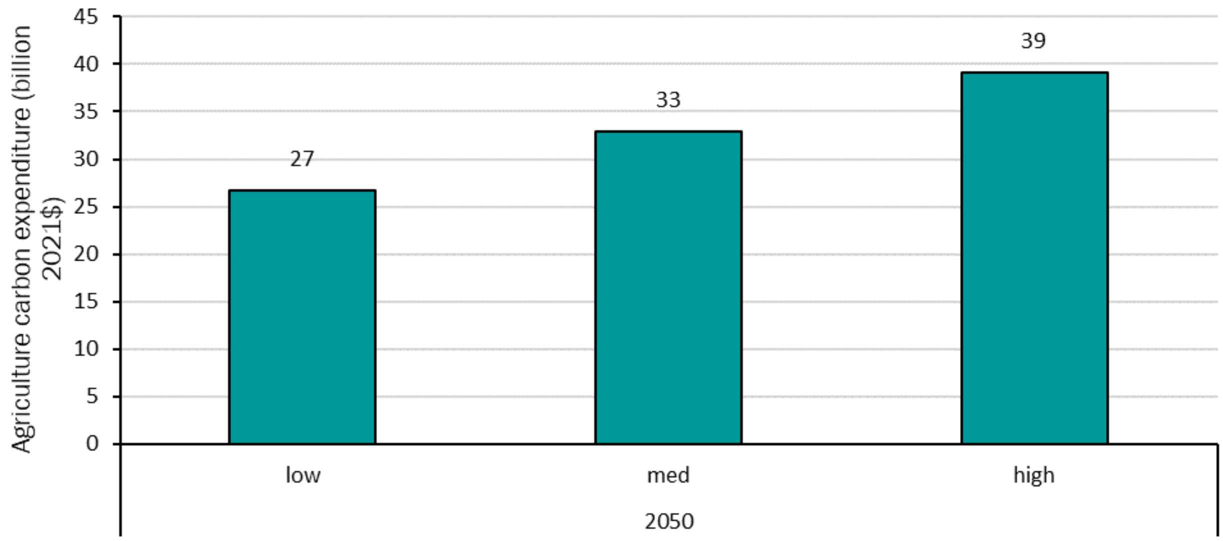
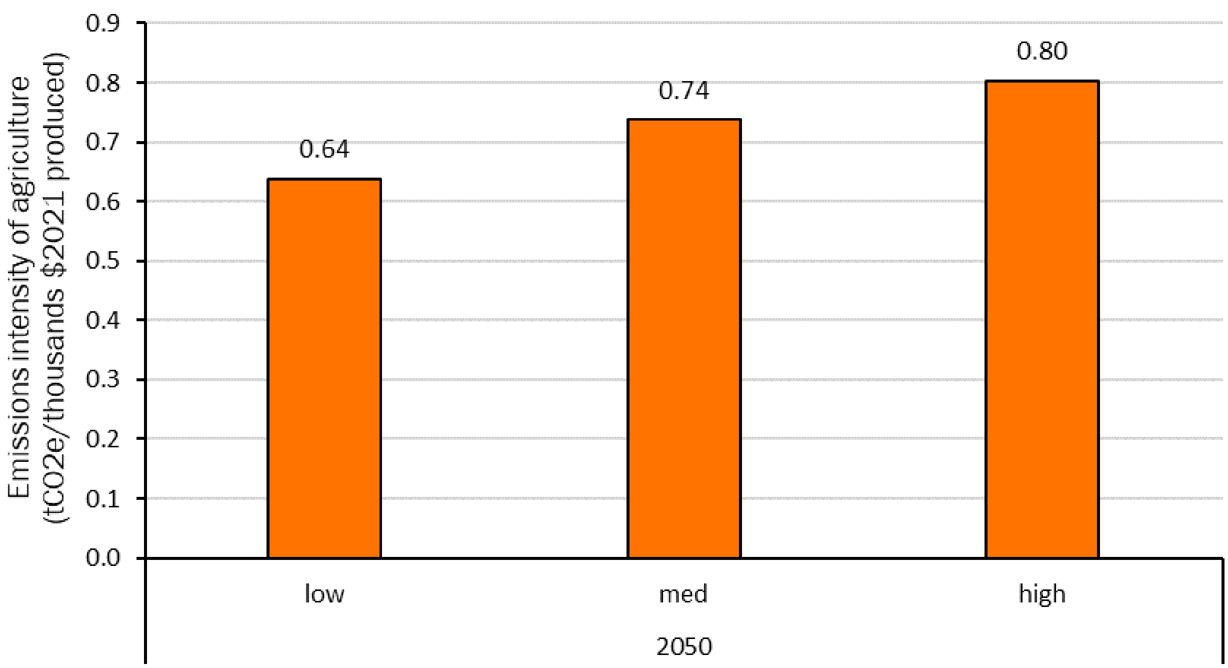


Figure 11: Emissions intensity of the agriculture sector in 2050 in three scenarios in which Canada achieves its climate targets (low, medium and high refer to animal food consumption levels)



4. Conclusions

Results of this analysis suggest two key conclusions.

First, if food consumption shifts away from animal-based foods towards plant-based alternatives, this reduces emissions from the agriculture sector and contributes towards achievement of Canada's emissions targets. Because animal agriculture is more emissions intensive than plant-based agriculture, shifting demand towards plant-based production leads to lower emissions in this sector. If future animal consumption is low, the resulting reduction in emissions could be enough, in combination with the implementation of ERP policies, to allow Canada to achieve it's 2030 emissions target. There are other environmental benefits of this shift, beyond the impact on GHG emissions, which are not explored in this analysis, including land-use[25,26,27,28], water[29,30,31,32], biodiversity[33,34,35], and pandemic risk[36],[37],[38].

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[25] Clark, M.; Tilman, D. (2017). Comparative Analysis of Environmental Impacts of Agricultural Production Systems, Agricultural Input Efficiency, and Food Choice. *Environ. Res. Lett., 12 (6), 064016.* Available from: https://doi.org/10.1088/1748-9326/aa6cd5.

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[29] Ibid.

[30] Springmann, M.; Wiebe, K.; Mason-D'Croz, D.; Sulser, T. B.; Rayner, M.; Scarborough, P. (2018). Health and Nutritional Aspects of Sustainable Diet Strategies and Their Association with Environmental Impacts: A Global Modelling Analysis with Country-Level Detail. *The Lancet Planetary Health, 2 (10), e451–e461*. Available from: https://doi.org/10.1016/S2542-5196(18)30206-7.

[31] Gerten, D.; Heck, V.; Jägermeyr, J.; Bodirsky, B. L.; Fetzer, I.; Jalava, M.; Kummu, M.; Lucht, W.; Rockström, J.; Schaphoff, S.; Schellnhuber, H. J. (2020). Feeding Ten Billion People Is Possible within Four Terrestrial Planetary Boundaries. *Nat Sustain, 3 (3), 200–208.* Available from: https://doi.org/10.1038/s41893-019- 0465-1

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[34] Coimbra, Z. H.; Gomes-Jr, L.; Fernandez, F. A. S. Human Carnivory as a Major Driver of Vertebrate Extinction. (2020). *Perspectives in Ecology and Conservation, 18 (4), 283–293.* Available from: https://doi.org/10.1016/j.pecon.2020.10.002.

[35] Gerten, D.; Heck, V.; Jägermeyr, J.; Bodirsky, B. L.; Fetzer, I.; Jalava, M.; Kummu, M.; Lucht, W.; Rockström, J.; Schaphoff, S.; Schellnhuber, H. J. (2020) Feeding Ten Billion People Is Possible within Four Terrestrial Planetary Boundaries. *Nat Sustain, 3 (3), 200–208.* Available from: https://doi.org/10.1038/s41893-019- 0465-1

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Second, scenarios in which future animal consumption is lower lead to similar levels of economic growth as those in which animal consumption is higher. Scenarios in which future animal consumption is lower also lead to lower costs to the agriculture sector to comply with future climate policy. This is because implementation of policy stringent enough to achieve Canada's climate targets will impose policy compliance costs on emitting sectors. The more the agriculture sector reduces its emissions, the fewer emissions reductions are required in other sectors of the economy as well, leading to lower overall costs for Canada's economy to achieve its emissions targets. If Canada's future animal consumption is in line with the low animal consumption scenario simulated, it will cost 11% less for the economy to comply with the 2030 emissions target compared to a future in which animal consumption remains at current levels. By shifting towards less emissions intensive forms of agriculture, production of more plant-based products can reduce policy compliance costs for this sector and reduce the cost of Canada achieving its climate targets, while maintaining economic growth.

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World Animal Protection Discussion of Results

What do results mean for policy makers?

A future with lower animal consumption can fill the gap between Canada's emissions trajectory under announced ERP policies and its 2030 emissions target.

Results of this analysis suggest that a future with lower animal food consumption can reduce agricultural emissions and contribute towards achievement of Canada's emissions targets at lower costs to both the Canadian economy *and* to the agricultural sector.

If Canada follows a low animal consumption path, emissions from agriculture could be reduced by 13.5 Mt in 2030 under current policy relative to a high animal consumption path (i.e., staying at current levels). A recent analysis of Canada's Emissions Reduction Plan (ERP)[39] found that there is a 9 Mt gap between announced policies and Canada's 2030 emissions target. This means that shifting to low animal consumption could be enough to fill this gap and, in combination with the implementation of ERP policies, would allow Canada to achieve it's 2030 emissions target.

Additionally, agriculture emissions are 29% lower in 2050 if Canada follows a low animal consumption path relative to current levels. This corresponds to a reduction in agricultural emissions of 19.2 Mt in 2050, thereby reducing emission reduction requirements in other sectors of the economy and making it easier and cheaper for Canada to meet its net zero by 2050 target.

Policy that encourages less animal food consumption by Canadians can help drive emission reductions in line with Canada's targets, while reducing policy compliance costs associated with decarbonization.

Potential policies that could drive a future with lower animal food consumption include extending the coverage of the carbon tax to include agriculture, an animal product

[39] Canadian Climate Institute. (2022). Independent Assessment: 2030 Emissions Reduction Plan. Available from: https://climateinstitute.ca/wp-content/uploads/2022/04/ERP-Volume-2-FINAL.pdf

("meat") tax, redirecting agricultural subsidies, or a moratorium on new industrial animal operations.

By leading to lower greenhouse gas emissions in the agriculture sector, scenarios in which future animal consumption is reduced result in lower costs for Canada's agriculture sector to comply with climate policy. This policy approach is consistent with the objectives of the latest Canada Food Guide, which promotes plant-based alternatives for health and environmental benefits.[40]

A first step to understanding the role of fewer animal agriculture emissions in Canada's net zero future is to improve tracking of emissions by directly reporting all emissions associated with animal agriculture. Emissions from the production of animal feed, including fertilizer, are a significant component of agricultural emissions but are typically reported elsewhere in Canada's inventory and not accounted for in animal agriculture.

Meat and dairy-alternatives present an economic opportunity for Canada.

Canada has already invested $153 million in plant-based protein development via the Protein Industries Canada Super Cluster[41], which is a group of businesses, institutions and non-profits working together to make Canada a world leader in the growing market for plant-based proteins. As demand for alternatives to animal products increases, there is potential for Canada to become a leader in the production of plant-based proteins[42] and capitalize on a large and growing market.[43]

What do results mean for the average Canadian?

In this analysis, a medium animal consumption scenario refers to a 51% reduction in animal consumption by 2050 from current levels, while a low animal consumption scenario refers to an 84% decline. This means that if every meal consumed today includes animal-sourced foods, by 2050, 50% of meals (in the medium animal consumption scenario) or 20% of meals (in the low animal consumption scenario) contain meat and/or dairy. In other words, if the average Canadian consumes seven dinners in a week, all of which currently contain meat and/or dairy, three of these

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[40] Government of Canada. *Canada's Food Guide.* Available from: https://food-guide.canada.ca/en/

[41] Protein Industries Canada. https://www.proteinindustriescanada.ca/

[42] Tiffany Stephenson. (2021). Plant-based proteins: A growth industry in Canada's backyard. Available from: https://www.edc.ca/en/blog/canada-plant-based-protein-growth.html

[43] Bloomberg. (2021). Plant-based Foods Market to Hit $162 Billion in Next Decade, Projects Bloomberg Intelligence. Available from: https://www.bloomberg.com/company/press/plant-based-foods-market-to-hit-162-billion-in-next-decade-projects-bloomberg-intelligence/ l

dinners would contain meat/dairy in 2050 in the medium animal consumption scenario and one would contain meat/dairy in the low scenario.

Although these resulting declines in consumption appear extreme, it is important to note that this level of change in our consumption patterns aligns with recommendations in other literature sources, which discuss the importance of eating fewer animal-sourced foods to achieve meaningful reductions in greenhouse gas emissions and meet the targets set out in the Paris Agreement. For example, the World Resources Institute found that reducing meat consumption in North America by 50% by 2050 is consistent with a "sustainable" diet, equivalent to consuming 1.5 hamburgers per week.[44] Experts agree and predict that without urgent and drastic shifts in global meat consumption, agriculture will consume the entire world's carbon budget necessary for keeping global temperature rises under 2°C by 2050.[45,46] Wealthy nations must reduce beef consumption by 90% by 2050, while global consumption must decline by 75%.[47,48] There are health benefits to this shift as well, as industrial animal agriculture is a primary contributor to what many scientists consider the three most serious human health threats: climate change, antibiotic resistance, and the rise of noncommunicable diseases.[49]

Limitations of analysis scope

It is important to note that there are other environmental implications of shifting food consumption to be more plant-based beyond impacts to greenhouse gas emissions, which are not explored in this analysis. Although these impacts are not accounted for in the modeling, they will increase the environmental benefits of reducing animal consumption and are therefore worth mentioning.

Currently, agriculture land accounts for around half of all habitable land on earth, where 83% is used for animal agriculture including feed crops.[50] Switching to a more plant-based diet would partially free up these land areas, which could become

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44 World Resources Institute. (2018). How to sustainably feed 10 billion people by 2050. Available from: https://www.wri.org/insights/how-sustainably-feed-10-billion-people-2050-21-charts

45 Nature. (2019). *Eat less meat: UN climate-change report calls for change to human diet.* Available from: https://www.nature.com/articles/d41586-019-02409-7

46 EAT. *Diets for a Better Future.* Available from: https://eatforum.org/knowledge/diets-for-a-better-future/

47 Carrington. (2018). Huge reduction in meat-eating 'essential' to avoid climate breakdown. The Guardian. Available from: https://www.theguardian.com/environment/2018/oct/10/huge-reduction-in-meat-eating-essential-to-avoid-climate-breakdown

48 Springmann, M., Clark, M., Mason-D'Croz, D. et al. (2018). Options for keeping the food system within environmental limits. Nature 562, 519–525.

49 Weathers & Hermanns. (2017). Open letter urges WHO to take action on industrial animal farming. *The Lancet. 389.* Available from: https://www.thelancet.com/action/showPdf?pii=S0140-6736%2817%2931358-2

50 Poore, J.; Nemecek, T. Reducing Food's Environmental Impacts through Producers and Consumers. Science 2018, 360 (6392), 987–992. https://doi.org/10.1126/science.aaq0216.

available for conservation, restoration and reforestation. In addition, agriculture is leading cause of biodiversity degradation globally, mainly due to the production of crops needed for animal feed.[51] Research suggests that this degraded land can recover its original carbon stocks and biodiversity levels if transitioned away from agricultural land.[52] Lastly, animal agriculture uses 43% of all the water consumed by the global food system and is responsible for a disproportional amount of water pollution.[53],[54] Switching to a lower animal consumption diet would therefore reduce not only greenhouse gas emissions, as quantified in this analysis, but could also reduce land use, water consumption, and water pollution, while increasing biodiversity levels.

[51] Machovina, B., Feeley, K., & Ripple, W. (2015). Biodiversity conservation: The key is reducing meat consumption. Science of the Total Environment, 536, 419-431. doi:10.1016/j.scitotenv.2015.07.022
[52] Silver, W. L., Ostertag, R. & Lugo, A. E. The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. Restor. Ecol. 8, 394–407 (2000).
[53] Davis, K. F., Gephart, J. A., Emery, K. A., Leach, A. M., Galloway, J. N., & D'Odorico, P. (2016). Meeting future food demand with current agricultural resources. Global Environmental Change, 39, 125-132.
[54] Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987-992.