Meeting Canada's climate mitigation commitments under the Paris Agreement

An evaluation of alternative policy approaches prepared for Canada's Ecofiscal Commission

SUBMITTED TO

Canada's Ecofiscal Commission
December 2019

SUBMITTED BY

Navius Research Inc.
Box 48300 Bentall
Vancouver BC V7X 1A1

Contact@NaviusResearch.com

About Us

Navius Research Inc. ("Navius") is a private consulting firm in Vancouver. Our consultants specialize in analysing government and corporate policies designed to meet environmental goals, with a focus on energy and greenhouse gas emission policy. They have been active in the energy and climate change field since 2004, and are recognized as some of Canada's leading experts in modeling the environmental and economic impacts of energy and climate policy initiatives. Navius is uniquely qualified to provide insightful and relevant analysis in this field because:

- We have a broad understanding of energy and environmental issues both within and outside of Canada.
- We use unique in-house models of the energy-economy system as principal analysis tools.
- We have a strong network of experts in related fields with whom we work to produce detailed and integrated climate and energy analyses.
- We have gained national and international credibility for producing sound, unbiased analyses for clients from every sector, including all levels of government, industry, labour, the non-profit sector, and academia.

Page intentionally left blank to facilitate double-sided printing

Executive Summary

In 2015, Canada and 194 other countries reached the Paris Agreement to strengthen the global response to climate change[1]. As part of this Agreement, Canada set a target of reducing its greenhouse gas emissions by 30% below 2005 levels by 2030.

Achieving Canada's climate mitigation commitments requires the implementation of stringent polices to reduce emissions. The objects of this project are to:

1. Identify viable policy options for achieving the 2030 target.
2. Compare the economic costs of these approaches.
3. Describe options for improving the economic performance of each approach.

What approaches could Canada potentially pursue to meet its Paris Agreement commitments?

We consider the following broadly representative policy approaches:

- **Carbon pricing.** Applying a price on carbon provides an incentive for firms and households to reduce their greenhouse gas emissions. Carbon pricing can take the form of a tax, cap-and-trade system or tradable performance standard. Several provinces have implemented carbon pricing of one form or another (beginning with British Columbia's carbon tax in 2008), and in 2019 the federal government's carbon pricing backstop came into effect in provinces without their own carbon pricing system (Manitoba, Ontario, New Brunswick, Prince Edward Island and partially in Saskatchewan[2]).

  The costs of carbon pricing are by design visible, potentially leading this approach to have high perceived costs (despite economists frequently advocating for this approach on the grounds that it is the lowest cost option).

---

[1] United Nations Framework Convention on Climate Change. 2019. The Paris Agreement. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[2] Government of Canada. 2018. How we're putting a price on carbon pollution. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution.html

- **Economy-wide regulations.** Another way of achieving Canada's target is to require that firms and/or households undertake specific actions (e.g. requiring that technologies and processes meet a certain standard or banning certain types of technologies). These actions frequently have costs, although they tend to be less visible than those of carbon pricing.

  Regulations can be prescriptive (e.g. requiring a specific technology to be used) or flexible (e.g. specifying a standard while providing flexibility in how compliance is achieved). Federal and provincial governments have implemented a wide range of prescriptive regulations such as phasing out coal-fired electricity generation and requiring that furnaces meet a minimum energy efficiency. By contrast, fewer flexible regulations have been implemented. The most notable example is BC's low carbon fuel standard, which requires a reduction in the carbon intensity of transport fuels. This policy creates a market for compliance which is generally agnostic as to the means of reducing emissions while creating an incentive for market participants to identify the lowest cost options to reduce emissions.

- **Industry-focused regulations.** Governments can also develop regulations that focus on industry while seeking to avoid imposing financial costs on households. As shown in this report, it is likely difficult (if not impossible) to achieve Canada's 2030 target if policy coverage is restricted to non-households.

Our modeling toolkit

This analysis employs Navius' gTech model to forecast the effects of climate mitigation policy on Canada's greenhouse gas emissions and economy. gTech is ideally suited for examining the effects of climate policy because it combines the following features within a single integrated framework:

- A realistic representation of how households and firms select technologies and processes that affect their energy consumption and greenhouse gas emissions.
- An exhaustive account of the economy at large, including how provinces interact with each other and the rest of the world.
- A detailed representation of liquid fuel (crude oil and biofuel) and gaseous fuel (natural gas and renewable natural gas) supply chains.

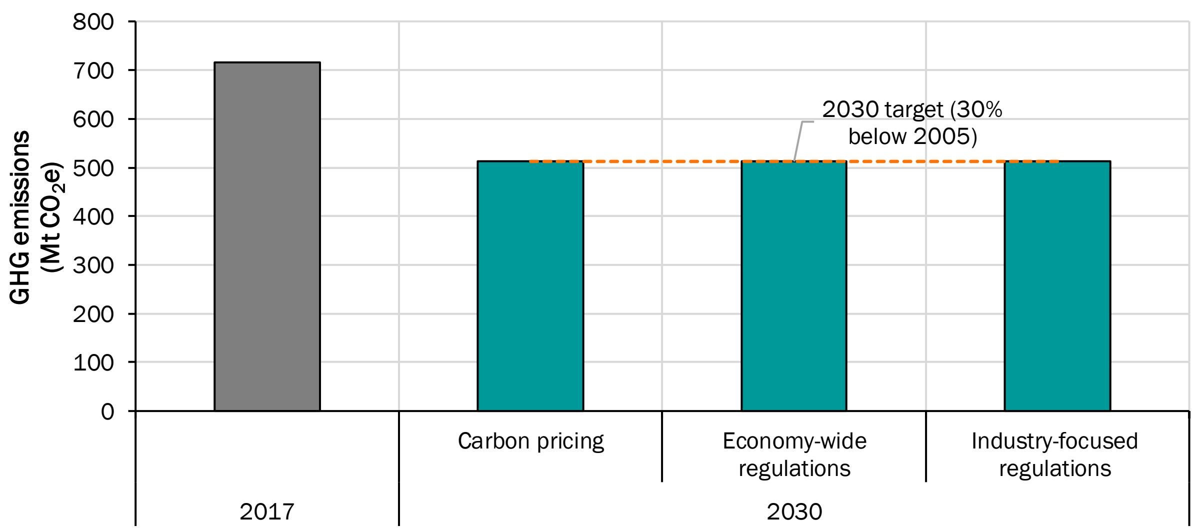
Which policy approaches achieve Canada's 2030 target?

Carbon pricing, economy-wide regulations and industry-focused regulations could all achieve Canada's 2030 target of 513 Mt CO_2e in 2030, as shown in Figure 1. The implication is that government is not constrained by policy choice for meeting its Paris commitments.

Viable options for achieving Canada's target include:

- Putting a price on carbon, via a carbon tax or cap-and-trade system. This policy provides an incentive for firms and consumers to reduce their emissions.
- Economy-wide regulations that require emission reductions from all major sources of emissions. This approach could take the form of prescriptive regulations (e.g. requiring the adoption of a specific types of technologies) or flexible regulations (e.g. requiring an emissions intensity improvement but being agnostic about how that improvement is achieved).
- Industry-focused regulations that seek to avoid imposing direct financial costs on households, to the extent that this is possible. As discussed next, achieving Canada's target using this approach may be challenging.

Figure 1: Achieving Canada's 2030 target using different policy approaches



Note: Source for historical data: Government of Canada. 2019. National Inventory Report. Available from: https://unfccc.int/documents/194925

Achieving Canada's 2030 target requires reductions from all major sources of emissions. This analysis considers two variations of industry-focused regulations, both designed to minimize the direct costs imposed on households. One variation of this approach extends policy coverage to households and electricity using subsidies. The other variation does not extend policy coverage to households and fails to meet Canada's target. In other words, it is likely not feasible to get to Canada's target without policies that generate emissions reductions from households and electricity.

The implication is that to be effective, climate mitigation policy must apply to households. At the same time, the emissions abatement actions induced by policy will inevitably impose costs on households. These costs can be minimized by careful policy design, including implementing policies that result in the best economic outcomes (see below) and using tools to protect vulnerable households (e.g. through direct transfers of carbon revenue).

What are the costs of achieving Canada's target?

All of the policy approaches for achieving Canada's 2030 target are expected to reduce the rate of GDP growth, as shown in Figure 2. Sustained lower growth rates cause GDP in 2030 to be lower than it would be if Canada doesn't achieve its Paris commitments (but GDP in 2030 would still be greater than it is today).

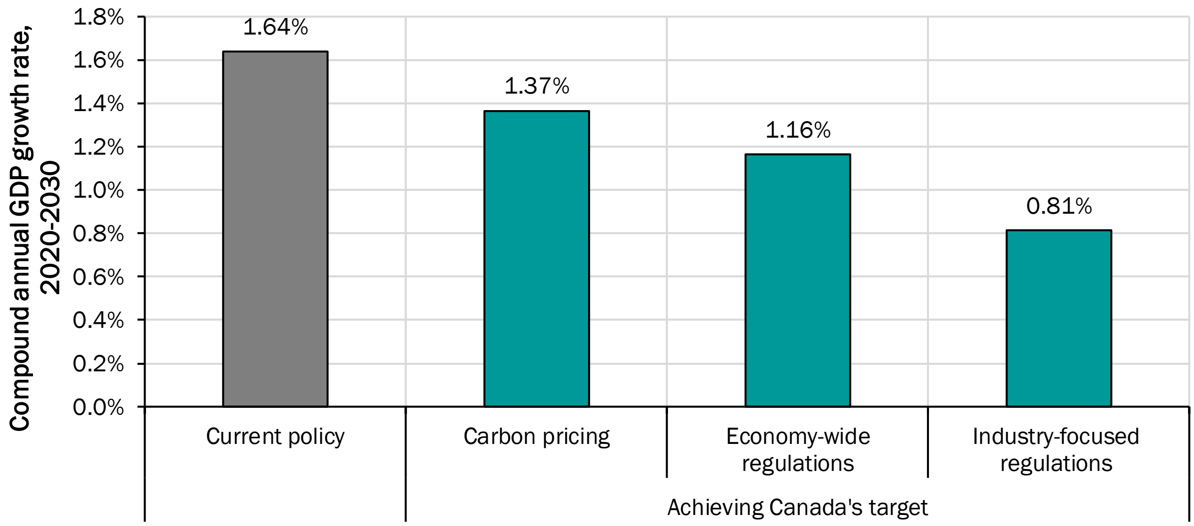
Note that these estimates don't reflect the potential benefit from global climate mitigation efforts (e.g. reduced flooding and forest fires). In addition, the policy impacts shown in Figure 2 reflect a worst-case scenario of "inefficient" policy design. Smart policy design can minimize these impacts, as discussed on page vi.

Carbon pricing imposes lower economic costs than a regulatory approach. As shown in Figure 2, the economy grows at an average annual rate of 1.37% in response to carbon pricing, compared to between 0.81% and 1.16% in response to a regulatory approach.

Carbon pricing performs best because it sets a consistent incentive across the whole economy. This approach ensures that no low-cost abatement opportunities are missed, and that no unnecessarily high-cost abatement actions are required.

By contrast, a regulatory approach inevitably imposes different abatement costs on different sources of emissions because policymakers don't have perfect foresight about policy impacts. This situation is exacerbated with the use of industry-focused regulations, which impose particularly high costs on industry while trying to avoid costs (and abatement opportunities) from households and electricity.

Figure 2: Impact of achieving Canada's target on GDP growth rate

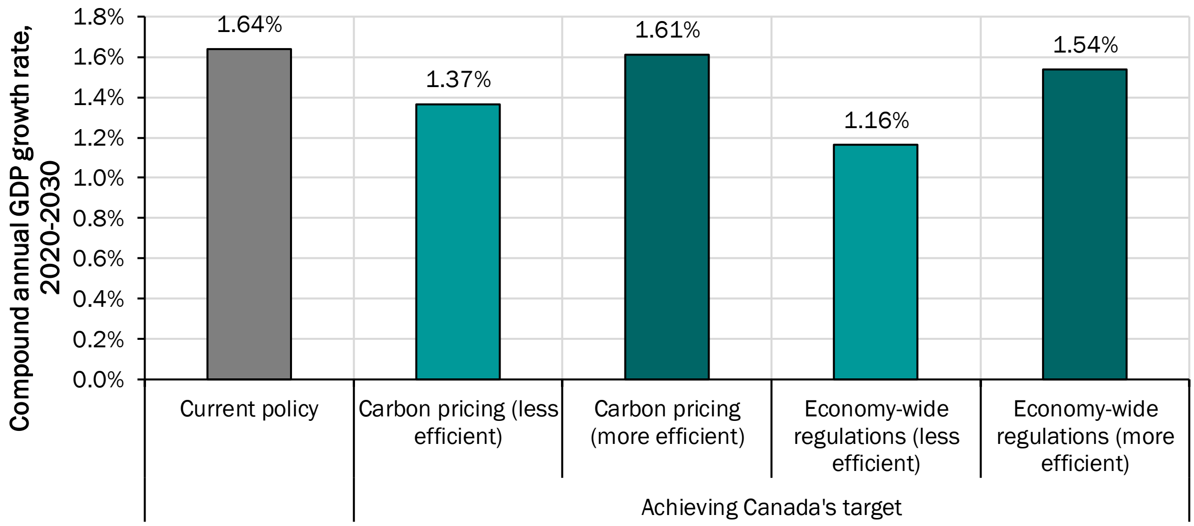


Scenarios shown: Less efficient variations.

Smart policy design can improve economic outcomes. Policy design matters, regardless of which policy approach is preferred for achieving Canada's 2030 target (e.g. carbon pricing or regulations). Canada's GDP growth can be maximized with the following choices, as shown in Figure 3:

- In the case of carbon pricing: (1) use carbon revenue to lower personal and/or corporate income taxes and (2) more targeted protection of emissions intensive and trade exposed sectors via free allocations and/or output rebates. Together, these design decisions can reduce most of the economic costs of carbon.
- In the case of a regulatory approach: (1) implement flexible regulations that provide options for how emissions reductions are achieved and (2) avoid the use of subsidies for low carbon technologies where possible. Subsidies are often inefficient due to free ridership and overlap with regulatory policies (meaning firms and consumers would reduce their emissions anyway); and taxes must be raised to fund them. Together, these design decisions can reduce the economic costs of a regulatory approach for achieving Canada's target by 72% in 2030 (based on a comparison of GDP between the less efficient and more efficient options considered in this analysis).

Figure 3: Impact of efficient policy design on GDP in 2030



What other factors might policymakers consider when choosing among policy options?

Policymakers can't predict the future (which makes designing good regulatory policies harder). The development of policy approaches for achieving Canada's 2030 target in this analysis benefited from the perfect foresight that is bestowed on any modeling exercise. We can simulate a given policy approach, review the results and then fine-tune the policies. Did we get enough abatement from freight transport? If not, we can adjust the policy.

Stepping away from modeling and into the real world of policy making, the regulatory approach may be harder to get right. The economic costs of this approach may therefore be understated in this analysis.

Table of Contents

1. Introduction

In 2015, Canada and 194 other countries reached the Paris Agreement to strengthen the global response to climate change[3]. This Agreement set a goal of limiting global temperature increases to well below 2 degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees. It also requires all parties to establish national greenhouse gas reduction targets. Under the Agreement, Canada set a target of reducing its greenhouse gas emissions by 30% below 2005 levels by 2030.

Achieving Canada's climate mitigation commitment under the Paris agreement will require the implementation of stringent polices to reduce emissions. In 2017 (the most recent year of available historical emissions data), Canada emitted 716 million tonnes of carbon dioxide equivalent (Mt CO_2e)[4]. Accounting for the impact of all existing provincial and federal policies, as well as those under development as of December 2018, federal government forecasts suggest that emissions in 2030 are likely to drop to 616 Mt CO_2e in 2030[5]. Yet this level of emissions is over 100 Mt CO_2e higher than Canada's 2030 target of 513 Mt CO_2e. The implication is that policy efforts to date are insufficient for achieving Canada's commitments under the Paris Agreement, and that more stringent policies are necessary.

Canada has many policies amongst which to chose for achieving greater greenhouse gas reductions. These options vary in terms of both the financial costs they will impose on firms and consumers as well as the perceived costs of the policy. For example, policies that impose visible costs on firms and households (such as carbon pricing) may be perceived as being more costly than regulations (which tend to impose less visible costs), despite the actual cost of the policy.

This study examines the economic effects of pursuing different policy approaches for achieving Canada's commitments under the Paris Agreement. It focuses on three approaches that are likely to have different actual and perceived costs:

- **Carbon pricing.** This approach seeks to apply a price on carbon emissions that provides an incentive for firms and households to reduce their emissions. The costs

[3] United Nations Framework Convention on Climate Change. 2019. The Paris Agreement. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[4] Government of Canada. 2019. National Inventory Report. Available from: https://unfccc.int/documents/194925

[5] Government of Canada. 2019. Progress towards Canada's greenhouse gas emissions reduction target. Available from: www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html

of carbon pricing are by design visible, potentially leading this approach to have high perceived costs (despite economists frequently advocating for this approach on the grounds that it is the lowest cost option).

Carbon pricing can take the form of a tax, cap-and-trade system or tradable performance standard. Several provinces have implemented carbon pricing of one form or another (beginning with British Columbia's carbon tax in 2008), and in 2019 the federal government's carbon pricing backstop came into effect in provinces without their own carbon pricing system (Manitoba, Ontario, New Brunswick, Prince Edward Island and partially in Saskatchewan[6]).

- **Economy-wide regulations.** Another way of achieving Canada's target is to require that firms and/or households undertake specific actions (e.g. requiring that technologies and processes meet a certain standard or banning certain types of technologies). These actions frequently have costs, although they tend to be less visible than those of carbon pricing.

  Regulations can be prescriptive (e.g. requiring a specific technology to be used) or flexible (e.g. specifying a standard while providing flexibility in how compliance is achieved). Federal and provincial governments have implemented a wide range of prescriptive regulations (e.g. phasing out coal-fired electricity generation, requiring that furnaces meet a minimum energy efficiency and banning incandescent light-bulbs). By contrast, fewer flexible regulations have been implemented. Perhaps the most notable example is BC's low carbon fuel standard, which requires a reduction in the carbon intensity of transport fuels. This policy creates a market for compliance which is generally agnostic as to the means of reducing emissions while creating an incentive for market participants to identify the lowest cost options for achieving compliance.

- **Industry-focused regulations.** Governments can also develop regulations that focus on industry while seeking to avoid imposing financial costs on households. As shown in this report, it is likely difficult (if not impossible) to achieve Canada's 2030 target if policy coverage is restricted to non-households.

The three policy approaches outlined above are not mutually exclusive. For example, regulations can be combined with carbon pricing. In addition, each type of policy can be implemented in ways that impose greater or fewer costs on the economy. For example, regulations can be imposed in such a way that leave firms few and expensive

[6] Government of Canada. 2018. How we're putting a price on carbon pollution. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution.html

means of compliance. Likewise, revenue collected from carbon pricing can be used for alternative purposes that will have varying impacts on the economy.

This report is structured as follows:

- Chapter 2 introduces the modeling approach used to conduct this analysis.
- Chapter 3 describes three policy approaches for achieving Canada's commitments under the Paris Agreement.
- Chapter 4 quantifies the greenhouse gas and economic impacts of the different policy approaches.
- Chapter 5 summarizes implications for policymakers.

2. Method

This Chapter provides an overview of the model used to evaluate alternative policy options for achieving Canada's 2030 greenhouse gas targets. It begins with an introduction to energy-economy modeling (Section 2.1), then describes Navius' gTech model (Section 2.2) and concludes with a discussion about key uncertainties (Section 2.3).

2.1. Introduction to energy-economy modeling

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.

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 climate mitigation targets under the Paris Agreement 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 greenhouse gas reduction targets will have effects throughout the economy and interact with each other. For example, the federal vehicle emission standard and federal/provincial 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.

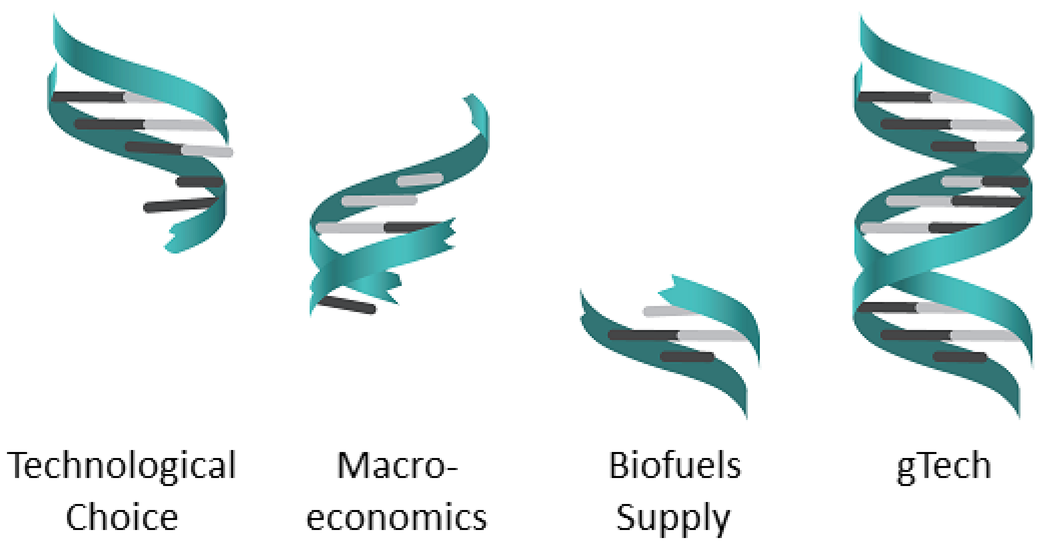
Estimating the greenhouse gas and economic impacts of Canadian climate policy therefore requires a modeling framework that captures the complexity of the energy-economic system as well as the range of policies implemented and proposed across the country.

2.2. The gTech model

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 interact with each and the rest of the world.
- A detailed representation of liquid fuel (crude oil and biofuel) and gaseous fuel (natural gas and renewable natural gas) supply chains.

Figure 4: The gTech model



gTech builds on three of Navius' previous models (CIMS, GEEM and OILTRANS), 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 manufacturing facility chooses to electrify their operations, that decision reduces their emissions.

gTech provides a detailed accounting of the types of energy-related technologies available to households and businesses. In total, gTech includes 200 technologies across more than 50 end-uses (e.g., 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.

Criteria	Description
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.[7] The implication is that using a financial discount rate would overvalue future savings relative to revealed behavior 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, research on electric vehicles indicates that Canadians often have very strong preferences (positive or negative) towards electric vehicles. One segment of the population prefers electric vehicles to such an extent that capital and energy costs are almost irrelevant. Another segment dislikes electric vehicles to such an extent that there are relatively few circumstances in which they will be willing to purchase such a vehicle. And then there are many other groups in between.[8] gTech quantifies these technology-specific preferences as "non-financial" costs, which are added to the technology choice algorithm.
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 one 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[9]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.

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

[8] Axsen, J., Cairns, J., Dusyk, N., & Goldberg, S. (2018). What drives the Pioneers? Applying lifestyle theory to early electric vehicle buyers in Canada. *Energy Research & Social Science*, *44*, 17-30.

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

Criteria	Description
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 couple of years, and costs are expected to continue declining in the future[10]. 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.
Policy	One of the most important drivers of technological choice is government policy. Current federal and provincial 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 PST on a given technology); and (5) flexible regulations, like BC's low-carbon fuel standard which creates a market for compliance credits. gTech simulates the combined effects of all these policies implemented together. Policies included in the forecasting are described in Chapter 3.

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.

[10] 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[11]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and a large number of 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, etc.
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 finally 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).
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 natural gas sector produces natural gas, while the services sector produces services) and requires specific inputs into production. Of these inputs, some are not directly related to energy consumption or greenhouse gas emissions (e.g., the demand by the natural gas sector for services or labor requirements). But other inputs are classified as "energy end-uses". Covered energy end-uses (along with sectors and fuels) are listed in Appendix A: "Modeled sectors, fuels and end-uses".
Labor and capital markets	Labor 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". Capital markets are introduced in more detail below.

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

Dynamic	Description
Interactions between BC and other regions	Economic activity in Canada is highly influenced by interactions among provinces and with the United States and 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 governments). The version of gTech used for this project accounts for 10 Canadian provinces, the three 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. In other words, the model can forecast how a policy may affect the trade of natural gas between Canada and the United States; or whether a policy would affect how corporations invest in Canada.
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 petroleum, natural gas and biofuels markets

gTech offers two additional features that are critical to understand Canada's future energy-economy. First, it accounts for "nascent" sectors that may develop in the future, including Liquified Natural Gas (LNG) production and biofuels manufacturing. Second, the model accounts for the transportation costs of liquid and gaseous fuels between regions. It can also simulate constraints on fuel transport, such as occurs when pipeline capacity is full.

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 effect of climate and energy policy.

First, gTech can provide insights that would typically be provided by a technologically explicit model. These include 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 further provide insights associated with macroeconomic models (in this case "computable general equilibrium" models) by answering questions such as:

- How do policies affect 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 biofuels and natural gas module:

- Will a policy generate more supply of renewable fuels?
- Does policy affect the cost of transporting natural gas, and therefore the price for natural gas in BC?

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 answer can only be answered with a model such as gTech.
- What are the macroeconomic impacts of technology-focused policies (e.g. how might a zero-emissions vehicle standard impact provincial 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 policies to achieve Canada's greenhouse gas targets.

2.3. Uncertainty

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

First, all models are simplified representations of reality. Navius' models are, 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 or CGE models (gTech) is well founded in the academic literature.[12] 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.

Nevertheless, Navius' tools do not account for every factor that will influence the future. 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 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 labor productivity and the rate of improvement in battery technologies. If any of the assumptions used prove incorrect, the resulting forecast could be affected.

> *"All models are wrong, but some are useful".*
> George Box

The uncertainties in modeling mean that all models will err in their forecasts of the future. But some models are more correct than others. This analysis of options for achieving Canada's 2030 greenhouse gas targets employs a highly sophisticated model that provides powerful insights into the effect of policy alternatives.

gTech is the most comprehensive model available for forecasting the greenhouse gas and 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 how the broad range of policies implemented in Canada will affect energy consumption, greenhouse gas emissions, the economy and a large array of other indicators.

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

3. Policy options for achieving Canada's Paris Agreement commitments

Canada has several types of policies that it can implement to achieve its greenhouse gas reduction targets under the Paris Agreement. This Chapter reviews the policy options that are considered in this analysis:

- Section 3.1 provides a summary of the policy options.
- Section 3.2 delves into the full details about each policy.
- Section 3.3 provides some comments about how to interpret the results.

3.1. Policy options

Several policy approaches have the potential for achieving substantive greenhouse gas reductions in Canada, including (1) carbon pricing, (2) economy-wide regulations and (3) industry-focused regulations that try to avoid imposing direct financial costs on households. This analysis examines the effect of achieving Canada's 2030 greenhouse gas commitments using variations of these policy approaches.

Any of these approaches can be implemented in various ways, with potentially significant implications for policy outcomes such as economic efficiency. For example, all carbon pricing policies generate revenue (or what economist like to call "rent") which must be distributed in some fashion. The method by which this revenue is "recycled" back to the economy is a key driver of the economic impact of carbon pricing. Likewise, regulations can be designed in ways that impose greater or fewer costs on firms and consumers.

This analysis considers the following three policy approaches for achieving Canada's 2030 greenhouse gas targets. In addition, two variations of efficiency are considered for each approach, as summarized in Table 3:

- **Carbon pricing.** This approach applies an economy-wide carbon price across all major sources of greenhouse gas emissions in Canada. It is representative of either a carbon tax or a cap-and-trade policy, although it is modeled as the latter. Emissions-intensive and trade exposed (EITE) sectors are protected via output-based allocations or output rebates (in the more efficient variation, these protections are more carefully targeted). Remaining carbon revenue is returned to households via dividend cheques (the less efficient variation) or used to lower corporate and personal income taxes (the more efficient variation).

- **Economy-wide regulations.** This policy approach avoids carbon pricing by implementing regulations that require firms and consumers to undertake actions to reduce their emissions. The less efficient variation pairs prescriptive technology-focused regulations (e.g. requiring that heat pumps be used for space heating) with subsidies for low carbon technologies. The more efficient variation employs "flexible" regulations (e.g. requiring a percentage reduction in emissions intensity from fuels used in buildings, while being agnostic about how this reduction is achieved) and does not include subsidies.
- **Industry-only regulations.** This option implements regulations that avoid imposing direct costs on households, to the extent that this is possible. In other words, it focuses on regulations for industry while avoiding regulations on residential buildings, passenger transport and electricity. The less efficient variation expands policy scope by subsidizing technologies used by households (e.g. heat pumps) and electricity (e.g. renewable electricity generation).

Table 3: Summary of modeled policy options for achieving Canada's 2030 target

Policy option	Description	Variation 1 (less efficient)	Variation 2 (more efficient)
Carbon pricing	Economy-wide price on carbon Output-based allocations/rebates for emissions-intensive trade-exposed (EITE) sectors	Less targeted protection for EITE sectors. Return remaining carbon revenue directly to households.	More targeted protection for EITE sectors. Use remaining carbon revenue to lower corporate and personal income taxes.
Economy-wide regulations	Avoids carbon pricing by using regulatory policies	Technology-focused regulations with less flexibility, targeting most major sources of emissions. Subsidies for low carbon technologies.	Flexible regulations applied to four sources of emissions: electricity, industry, transport and buildings. No subsidies.
Industry-only regulations	Avoids carbon pricing by using regulatory policies Attempts to avoid imposing direct costs on households	Regulations on sources of emissions other than households. Subsidies for low carbon technologies used by households and electricity.	Regulations on sources of emissions other than households. No subsidies.

Please note: All policy approaches include (1) federal and provincial climate policies implemented as of early 2019 and (2) gap-filling policies targeting methane emissions from landfills and agriculture. These policies are summarized in Section 3.2.4.

3.2. Policy specifications

With the policy archetypes established, the stringency of each policy was adjusted to achieve Canada's Paris commitments. The policy specifications for each policy approach are described below.

3.2.1. Carbon pricing

The analysis examines two variations of carbon pricing that achieve Canada's 2030 target: the first which is deemed to be less efficient while the second is deemed to be more efficient. A distinguishing feature between the two variations is that the first uses a large portion of carbon revenue to provide lump-sum transfers to households (i.e., households receive a cheque every year to represent carbon tax receipts by government for the entire economy). In the more efficient variation, carbon revenues are used to reduce both corporate and personal income taxes. In addition, the more efficient variation employs a more targeted protection for EITE sectors.

The policies have other similar and distinguishing features, as shown in Table 4 and summarized below:

- Both policies provide free allocations to facilities with emissions in excess of 25,000 tonnes of carbon dioxide or equivalent per year. In both cases, these free allocations are provided to industry based on its historical emissions intensity in each province.

  In the less efficient version of carbon pricing, industry receives 90% of their combustion emissions intensity for free, and 100% of the process emissions intensity for free. In the more efficient variation, industry receives 70% of their combustion emissions intensity as free allocations in 2030, while still receiving 100% of their process emissions intensity for free.

- To prevent interprovincial transfers, any remaining carbon revenue is reallocated back to the province from which it came. In the less efficient version, all revenue is recycled to households as lump-sum transfers. In the more efficient version, 64% of carbon revenue is used to reduce personal income taxes and 21% is used to reduce corporate income taxes. Because reducing income taxes alone could have regressive effect on some households, 15% is used to provide transfers to households (i.e., to compensate low income households).

The carbon pricing options (as well as the regulatory options described next) also include policies that (1) were implemented by the federal and provincial governments as of early 2019 and (2) address policy gaps, including methane emissions from landfill gas and agriculture. These policies are summarized in Section 3.2.4.

Table 4: Summary of modeled carbon pricing options for achieving Canada's 2030 target

Policy lever	Variation 1 (less efficient)	Variation 2 (more efficient)
Stringency	Sufficient to achieve Canada's 2030 target	
Protection for emission-intensive trade-exposed (EITE) sectors	Free allocations based on historical emissions intensity: 90% combustion emissions. 100% non-combustion emissions.	Free allocations based on historical emissions intensity: 80% combustion emissions in 2025 and 70% in 2030. 100% non-combustion emissions.
Use of remaining carbon revenue	Lump-sum transfers to households.	64% to lower personal income taxes. 21% to lower corporate income taxes. 15% lump-sum transfers to households.

Please note: All policy approaches include (1) federal and provincial climate policies implemented as of early 2019 and (2) gap-filling policies targeting methane emissions from landfills and agriculture. These policies are summarized in Section 3.2.4.

3.2.2. Economy-wide regulations

This analysis considers two variations of a regulatory approach for achieving Canada's 2030 target. The less efficient variation includes prescriptive regulations combined with subsidies for low carbon technologies. These policies take their cue from historical climate policy experience in Canada. The more efficient option includes a fewer number of flexible regulations and no subsidies.

Less efficient variation: Prescriptive regulations with subsidies

The less efficient variation of this approach includes regulations that are generally prescriptive and technology-focused. These regulations target most major sources of emissions in the country and are designed to achieve Canada's 2030 target.

This approach includes the following policies, as summarized in Table 5:

- All new equipment installed in **buildings** must emit no direct emissions after 2020. In other words, new space and water heating systems must not consume fossil fuels. Electric baseboards are also banned such that space heating must be provided by electric heat pumps.

- The **electricity** sector is subject to renewable portfolio standards in each province. These standards require an increase in the share of electricity generated from renewable resources over time. The standards vary from 50-70% by 2030 for currently coal-dominated provinces (e.g. Alberta, Saskatchewan, New Brunswick and Nova Scotia) to over 90% for hydro-dominated provinces (e.g. BC, Manitoba, Québec and Newfoundland). The standards for each province are shown in Table 6.

- Each **industrial** sector faces emissions intensity targets (i.e., greenhouse gas emissions per level of physical output). These targets call for a 47% reduction in emissions intensity by 2030 relative to 2010. These policies are not flexible in that each individual sector must comply with this intensity target (but firms within a given sector can trade compliance obligations with each other).

- **Transport** is targeted by four regulatory policies:

  - An increase in the stringency for Canada's light-duty vehicle emissions intensity standard. By 2030, this target reaches 63 grams of CO_2e per vehicle kilometre traveled (for the average size vehicle). For context, this policy reduces the emissions intensity requirement from the current federal policy by almost half. The implication is that by 2030, the average vehicle would have the emissions intensity of a 2019 model year Hyundai Sonata plug-in hybrid[13].

  - An increase in the stringency of Canada's heavy-duty vehicle regulations. The strengthened standard requires the average carbon intensity of model year 2030 medium and heavy-duty freight trucks to be 91 grams of CO_2e per tonne-kilometre traveled.

  - An increase in the stringency for the federal renewable fuel requirements. Currently, federal regulations require 5% renewable content for gasoline and 2% for diesel (by volume). These requirements are increased to 50% and 47% for gasoline and diesel, respectively, by 2030.

  - A zero-emission vehicle (ZEV) mandate. This policy is modeled based on the policies implemented in Québec[14] and California[15], but with more stringent requirements. The analysis assumes that automakers selling light-duty vehicles

[13] Natural Resources Canada. 2019 Fuel Consumption Guide. Available at: www.nrcan.gc.ca/energy/efficiency/transportation/21002

[14] Government of Québec. 2018. The zero-emission vehicle standard. Available from: www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm

[15] California Air Resources Board. 2018. Zero emission vehicle (ZEV) program. Available from: www.arb.ca.gov/msprog/zevprog/zevprog.htm

in Canada earn a certain amount of "credits" through the sale of plug-in electric vehicles (these credits are tradable among automakers). This requirement means that by 2030, 47% of all new light-duty vehicles sold in Canada must be plug-in electric (either battery electric or plug-in hybrid electric). In addition, at least 34% of all vehicle sales must be pure battery electric.

This policy approach also includes subsidies to qualifying technologies, as identified in Table 5. Revenue to finance the subsidies is raised by increasing corporate and personal income taxes. To maintain consistency with the approach to recycling revenue used in the carbon pricing option (see section 3.2.1), 75% of revenue is raised from personal income taxes and 25% from corporate income taxes. An additional assumption is that no interprovincial transfers are made to finance subsidies. In other words, a province that pays $100 million of subsidies must raise $100 million from income within that province.

Table 5: Summary of modeled prescriptive regulations and subsidies to achieve Canada's 2030 target (i.e., less efficient regulatory approach)

Sector	Policy	Stringency
Buildings sector regulations and subsidies	A regulation on heating and cooling equipment used in buildings.	All new equipment installed after 2020 must be zero emissions. For space and water heating, heat pumps must be used.
	Financial incentives for the adoption low-emitting heating and cooling equipment, energy-saving lighting and efficient appliances.	*Subsidies cover 28% of capital costs between 2021 and 2025 and 47% between 2026 and 2030.*
Electricity sector regulations and subsidies	Standards for the share of electricity generation coming from renewable sources.	Standards differ by province, ranging from 50-70% by 2030 for thermal provinces to 99% for hydro-dependent provinces (see Table 6).
	Public investment in renewable electricity generation capacity and carbon capture and storage (CCS) technology.	*Subsidies cover 28% of capital costs between 2021 and 2025 and 47% between 2026 and 2030.*
Industry sector regulations	Provincial standard for the emissions intensity of production in the industry sector.	The standard requires a 47% reduction in emissions intensity by 2030 (relative to 2010) for each industrial sector in each province.
Transport sector regulations and subsidies	Emissions standards for new light-duty vehicles.	This policy tightens the existing standard for light-duty vehicles to 96 grams of CO_2e per vehicle kilometer traveled by 2025 and 63 by 2030.
	Emissions standards for new medium and heavy-duty vehicles.	The standard requires grams of CO_2e per tonne-kilometer traveled by medium and heavy-duty vehicles to fall to 108 by 2025 and to 91 by 2030.
	A tightening of the standard for minimum renewable fuel content in gasoline and diesel.	The regulation requires a renewable content of 50% (gasoline) and 47% (diesel) by 2030 (by volume).

Sector	Policy	Stringency
	Requirements for the share that partial or zero-emissions vehicles (ZEVs) comprise of total new vehicle sales.	The mandate requires 28% of new light-duty vehicles sold in 2025 to be plug-in electric, rising to 47% in 2030.
	Investment in public transit and plug-in electric vehicles.	*Subsidies cover 28% of capital costs between 2021 and 2025 and 47% between 2026 and 2030.*

Please note: All policy approaches include (1) federal and provincial climate policies implemented as of early 2019 and (2) gap-filling policies targeting methane emissions from landfills and agriculture. These policies are summarized in Section 3.2.4.

Table 6: Summary of renewable portfolio standards (share of electricity that must be generated from renewable sources)

Province	2025	2030
BC	97%	99%
AB	38%	62%
SK	37%	54%
MB	99%	99%
ON	46%	60%
QC	95%	93%
NB	57%	67%
NS	56%	68%
PE	99%	99%
NL	99%	99%
TR	64%	67%

More efficient variation: Flexible regulations and no subsidies

In the more efficient version of the regulatory approach, a smaller number of regulations apply emissions intensity requirements to four main sources of emissions as shown in Table 7: (1) electricity generation, (2) industry, (3) transport and (4) buildings. The regulations are also are made "flexible" in that (1) the policy is agnostic in terms of what technologies and fuels are used to achieve the standards and (2) regulated entities can trade compliance obligations among each other.

The emissions intensity targets for each sector are shown in Table 8. These targets are flexible because they provide options for how compliance is achieved within each sector group. For example, although the regulation for transport specifies a reduction in the carbon intensity of four fuel pools (gasoline, diesel, navigation and aviation), each fuel pool doesn't necessarily need to achieve the target shown in Table 8. Rather, the intensity for one fuel pool can under comply with the target if another transport pool over complies. This flexibility allows firms and consumers to undertake emissions abatement opportunities that have the lowest cost.

The targets for **buildings** are disaggregated by province and by residential/commercial buildings. Compliance with the policy can be achieved through electrification and the use of renewable natural gas. The targets apply to all energy consumption (rather than solely that used for space and water heating) because it would be difficult for utilities to distinguish between electricity used for different end-uses.

The intensity targets for buildings were designed to minimize (but not eliminate) interprovincial transfers by using province-specific benchmarks. These benchmarks were developed by simulating the building sector until 2030 in the absence of new policy and requiring a percentage reduction from each region's forecast intensity. As such, provinces with greater electrification (mostly due to lower electricity prices in hydroelectric provinces) receive a lower benchmark.

The intensity targets for **electricity** are likewise province-specific in order to minimize (but not eliminate) interprovincial transfers. As such, the electricity sectors in hydroelectric provinces (e.g., British Columbia, Manitoba, Québec and Newfoundland and Labrador) receive a lower carbon intensity benchmark, while fossil fuel-dependent provinces (e.g., Alberta, Saskatchewan, New Brunswick and Nova Scotia) receive a higher carbon intensity benchmark.

The intensity target for **industry** calls for a reduction from a sector-specific benchmark. As in the discussion in carbon pricing (see Section 3.2.1), a historical benchmark is assumed. The policy calls for a 16% reduction in intensity in 2025 and a 32% by 2030.

The flexible regulation for **transport** calls for a reduction in the carbon intensity of four fuel pools: (1) gasoline, (2) diesel, (3) domestic navigation and (4) domestic aviation. Although this policy functions like British Columbia's Renewable and Low Carbon Fuel Requirements Regulation,[16] it only covers direct sources of emissions as opposed to life-cycle emissions. This difference is justified on the basis that other sources of emissions are covered by other policies under this approach.

Table 7: Summary of modeled flexible regulations to achieve Canada's 2030 target (i.e., more efficient regulatory approach)

Sector	Policy	Stringency (relative to 2010 emissions intensity)
Buildings	A clean fuel standard for building energy use, with compliance trading among regulated entities permitted.	The standard requires a 5% reduction in the direct greenhouse gas intensity of the fuels used by buildings by 2025 and a 27% reduction by 2030.
Electricity	An emissions intensity standard for electricity generation, with compliance trading among regulated entities permitted.	The standard requires a 37% reduction in the greenhouse gas intensity of electricity generated and sold in Canada by 2025 and a 50% reduction by 2030.
Industry	A standard for the emissions intensity of production in the industry sector, with compliance trading among regulated entities permitted.	The standard requires a 16% reduction in the greenhouse gas intensity of production by 2025 and a 32% reduction by 2030.
Transport	A low-carbon fuel standard for transportation, with compliance trading among regulated entities permitted.	The standard requires a 16% reduction in the direct greenhouse gas intensity of transportation fuels sold in Canada by 2025 and a 42% reduction by 2030.

Please note: All policy approaches include (1) federal and provincial climate policies implemented as of early 2019 and (2) gap-filling policies targeting methane emissions from landfills and agriculture. These policies are summarized in Section 3.2.4.

[16] Government of British Columbia. (2016). Renewable and Low Carbon Fuel Requirements Regulation: B.C. Reg. 287/2016. http://www.bclaws.ca/civix/document/id/lc/statreg/394_2008

Table 8: Summary of intensity targets

Sector / province	*Unit*	2025	2030
Electricity Generation			
British Columbia	*kg CO_2e per MWh*	4	2
Alberta	*kg CO_2e per MWh*	132	106
Saskatchewan	*kg CO_2e per MWh*	132	106
Manitoba	*kg CO_2e per MWh*	2	1
Ontario	*kg CO_2e per MWh*	16	12
Québec	*kg CO_2e per MWh*	1	2
New Brunswick	*kg CO_2e per MWh*	132	106
Prince Edward Island	*kg CO_2e per MWh*	0	0
Nova Scotia	*kg CO_2e per MWh*	132	106
Newfoundland Labrador	*kg CO_2e per MWh*	0	0
Territories	*kg CO_2e per MWh*	36	35
Industry			
	% reduction from benchmark	16%	32%
Transportation			
Gasoline Pool	*g CO_2e per MJ*	56	38
Diesel Pool	*g CO_2e per MJ*	60	41
Domestic Navigation	*g CO_2e per MJ*	63	43
Domestic Aviation	*g CO_2e per MJ*	60	41
Buildings			
Commercial			
British Columbia	*g CO_2e per MJ*	24	18
Alberta	*g CO_2e per MJ*	32	24
Saskatchewan	*g CO_2e per MJ*	32	22
Manitoba	*g CO_2e per MJ*	31	24
Ontario	*g CO_2e per MJ*	31	23
Québec	*g CO_2e per MJ*	26	18
New Brunswick	*g CO_2e per MJ*	28	21
Prince Edward Island	*g CO_2e per MJ*	24	17
Nova Scotia	*g CO_2e per MJ*	26	20
Newfoundland Labrador	*g CO_2e per MJ*	15	9
Territories	*g CO_2e per MJ*	36	28

Sector / province	*Unit*	2025	2030
Residential			
British Columbia	*g CO_2e per MJ*	23	18
Alberta	*g CO_2e per MJ*	35	27
Saskatchewan	*g CO_2e per MJ*	35	29
Manitoba	*g CO_2e per MJ*	21	16
Ontario	*g CO_2e per MJ*	34	26
Québec	*g CO_2e per MJ*	13	9
New Brunswick	*g CO_2e per MJ*	17	10
Prince Edward Island	*g CO_2e per MJ*	32	19
Nova Scotia	*g CO_2e per MJ*	28	19
Newfoundland Labrador	*g CO_2e per MJ*	13	8
Territories	*g CO_2e per MJ*	38	29

3.2.3. Industry-only regulations

Some of the economy-wide regulations introduced in the previous section would impose costs on households, both directly and indirectly. For example, transport policies would raise the cost of driving (including the renewable content of gasoline requirement, the ZEV mandate, and the increase in stringency of the vehicle emissions standard). Regulations applying to residential buildings would impose additional costs on households. And policies targeting the electricity sector mean households would face higher electricity prices.

An alternative to this approach is to implement regulations only for industry while "trying" to avoid those that impose costs on households. Two versions of industry-only regulations are considered in this analysis, as summarized in Table 9. Both options exclude regulatory policies that directly affect households or that obviously impose indirect costs on households (i.e., through higher electricity prices).

The less efficient option expands coverage to households by subsidizing (1) low- and zero-emissions technologies used directly by households (e.g. electric vehicles) and (2) low carbon electricity generation technologies. The revenue raised to finance the subsidies follows the same approach as described in Section 3.2.2 (i.e., by raising personal and corporate income taxes).

The stringency of the regulatory policies is lower in the less efficient variation because the subsidies achieve additional greenhouse gas reductions which makes it relatively easier to get to the target. Without subsidies to expand the scope of this policy package to households and electricity, the regulatory policies must be strengthened under the more efficient variation. Despite this strengthening, the modeling suggests it will be difficult (if not impossible) to achieve Canada's 2030 targets without achieving greater greenhouse gas reductions from households and electricity than is required by current policy.

As shown in Table 9, the following industry-only regulations are included in this approach:

- Commercial buildings are subject to a ban of new heating equipment that consume fossil fuels after 2021.
- Industry is the focus of a tradable performance standard that seeks to reduce the emissions intensity of industry by 60%-68% by 2030 (relative to 2010).
- Freight vehicles must improve their emissions intensity to 79 grams of CO_2e per tonne-kilometre by 2030.

Table 9: Summary of modeled industry-only regulations and subsidies to achieve Canada's 2030 target

Sector	Policy	Variation 1: Less efficient	Variation 2: More efficient
Buildings sector regulations and subsidies	A regulation on heating and cooling equipment used in commercial and institutional buildings.	All new equipment installed after 2020 must be zero emissions. For space and water heating, heat pumps must be used.	
	Financial incentives for the adoption low-emitting heating and cooling equipment, energy-saving lighting and efficient appliances.	*Subsidies cover 53% of capital costs between 2021 and 2025 and 68% between 2026 and 2030.*	*No subsidies provided.*
Electricity sector subsidies	*Public investment in renewable electricity generation capacity and carbon capture and storage (CCS) technology.*	*Subsidies are 53% of capital costs between 2021 and 2025 and 68% between 2026 and 2030.*	*No subsidies provided.*
Industry sector regulations	Provincial standard for the emissions intensity of production in the industry sector.	The standard requires a 68% reduction in emissions intensity by 2030 (relative to 2010) for each industrial sector in each province.	The 2025 standard is strengthened from 53% to 60%.
Transport sector regulations and subsidies	Emissions standards for freight vehicles.	The standard requires grams of CO_2e per tonne-kilometer traveled by medium and heavy-duty vehicles to fall to 92 by 2025 and to 79 by 2030.	The standard in 2025 is strengthened from 92 to 87 grams of CO_2e per tonne-kilometer.
	Investment in public transit and plug-in electric vehicles.	*Subsidies cover 53% of capital costs between 2021 and 2025 and 68% between 2026 and 2030.*	*No subsidies provided.*

Please note: All policy approaches include (1) federal and provincial climate policies implemented as of early 2019 and (2) gap-filling policies targeting methane emissions from landfills and agriculture. These policies are summarized in Section 3.2.4.

3.2.4. Policies included in all scenarios

A number of policies are included in all forecasts, including (1) those that are currently in place at a federal or provincial level and (2) "gap-filling" policies that cover sources of emissions that aren't covered by the policy approaches described above, but that are important for helping Canada achieve its 2030 target. These policies are described below.

Existing policies

The key policies that have been implemented as of early 2019, and included in all scenarios are:

- Federal policies:
    - **Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds**[17]. Oil and gas facilities must adopt methane control technologies and practices.
    - **Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations**[18]. New light-duty passenger vehicles sold in Canada must meet fleet-wide greenhouse gas emission standards. Cars and light trucks/SUVs face different standards. The weighted average requirement (i.e., accounting for the current share of cars and light trucks) declines from 200 g/km in 2015 to 119 g/km by 2025. Note that some regulatory policies that we model envision an increase in stringency for this policy.
    - **Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations**[19]. This policy applies efficiency standards in line with the US Environmental Protection Agency standards for on-road heavy-duty vehicles

---

[17] Government of Canada. (2018). Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector): SOR/2018-66. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.html

[18] SOR/2010-201. Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. Available from: http://laws-lois.justice.gc.ca

[19] SOR/2018-98. Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and other Regulations Made Under the Canadian Environmental Protection Act, 1999. Available from: https://pollution-waste.canada.ca

and engines[20]. According to the amendments, the analysis assumes: (1) a 20% reduction in emissions intensity in 2025 relative to 2015 and (2) a 24% reduction in emissions intensity in 2030 relative to 2015.

- **Energy Efficiency Regulations**[21]. Federal standards exist for new space conditioning equipment, water heaters, household appliances, and lighting products. The modeling accounts for the most important of these standards, including a minimum annual fuel utilization efficiency of 90% for natural gas furnaces, a minimum energy factor of 0.61 for gas water heaters and ban of incandescent light bulbs.

- **Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations**[22]. This policy closes coal-fired power plants by 2030 unless they emit less than 420 tonnes CO_2e/GWh (effectively requiring carbon capture and storage technology) [23].

- **Renewable Fuels Regulation**[24]. Specifies a minimum renewable content of 5% for gasoline and 2% for diesel, by volume.

- **Hydrofluorocarbon Controls**[25]. The Canadian government was one of the signatories of the 2016 Montreal Protocol-amending Kigali Agreement on ozone-depleting substances. Canada has pledged to reduce its HFC-related emissions by 15% by 2036 relative to 2011 to 2013 levels by amending the Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations.

---

[20] SOR/2018-98. Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and other Regulations Made Under the Canadian Environmental Protection Act, 1999. Available from: https://pollution-waste.canada.ca

[21] Natural Resources Canada. 2017. *Guide to Canada's Energy Efficiency Regulations*. Available from: www.nrcan.gc.ca

[22] Government of Canada. (2018). Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations: SOR/2018-263. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-167/page-2.html#h-4

[23] In gTech, we allow for a small amount of generation from coal (in this case 0.1 TWh per year).

[24] Government of Canada (2010). Renewable Fuels Regulations: SOR/2010-189. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-189/index.html

[25] Government of Canada. (2018). Canada agrees to control hydrofluorocarbons under the Montreal Protocol. www.canada.ca/en/environment-climate-change/services/sustainable-development/strategic-environmental-assessment/public-statements/canada-agree-control-hydrofluorocarbons.html

- Provincial policies:
  - **British Columbia's Renewable and Low-Carbon Fuel Requirement Regulation**[26]. Note that this policy was simulated before the recent update via CleanBC, and so calls for a 10% reduction in the life-cycle carbon intensity of fuels sold in the province.
  - **Québec's zero-emissions vehicle mandate**[27]. Requires automakers to sell a minimum share of zero emission vehicles.
  - **Various provincial renewable portfolio standards**. Several provinces require that a certain share of electricity be generated from renewable sources, including British Columbia (93%)[28], Nova Scotia (40% by 2020)[29] and New Brunswick (40% by 2020)[30].
  - **Various provincial renewable fuel requirements.** Several provinces require a greater share of renewable fuels in the gasoline and/or diesel pools than is required by federal standards, including British Columbia (4% biodiesel by volume)[31], Saskatchewan (7.5% ethanol)[32], Manitoba (8.5% ethanol)[33] and Ontario (4% biodiesel)[34].

---

26 Government of British Columbia. (2016). Renewable and Low Carbon Fuel Requirements Regulation: B.C. Reg. 287/2016. http://www.bclaws.ca/civix/document/id/lc/statreg/394_2008

27 Gouvernement du Québec. (2018). The zero-emission vehicle (ZEV) standard. www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm

28 Government of British Columbia. (2010). Clean Energy Act. SBC 2010, Chapter 22. http://www.bclaws.ca/civix/document/id/lc/statreg/10022_01

29 Government of Nova Scotia. Renewable Electricity Regulations made under Section 5 of the Electricity Act. https://novascotia.ca/just/regulations/regs/elecrenew.htm

30 Government of New Brunswick. 2015. New Brunswick Regulation 2015-60 under the Electricity Act (O.C. 2015-263). www.gnb.ca/0062/acts/BBR-2015/2015-60.pdf

31 Government of British Columbia. (2016). Renewable and Low Carbon Fuel Requirements Regulation: B.C. Reg. 287/2016. http://www.bclaws.ca/civix/document/id/lc/statreg/394_2008

32 Government of Saskatchewan. (2002). The Ethanol Fuel (General) Regulations. http://www.qp.gov.sk.ca/documents/english/Regulations/Regulations/e11-1r1.pdf

33 Government of Manitoba. (2008). Biofuels. Available from: www.gov.mb.ca/jec/energy/biofuels/index.html

34 Government of Ontario. (2012). Greener Diesel Regulation. Available from: www.ontario.ca/page/greener-diesel-regulation

"Gap-filling" policies

In addition to existing policies, each policy approach to achieve Canada's target includes the following "gap-filling" policies:

- Requirements for anerobic digestion of manure. By 2030, half of all feedlots must employ anerobic digestion to capture methane from manure.
- Requirements for landfill gas management. By 2030, 50% of landfill gas must be captured and (1) flared or (2) used to produce renewable natural gas or generate electricity.

3.3. Interpreting the results

The results presented in this report are highly dependent on the policy specifications chosen for achieving Canada’s Paris commitments. As such, the policy approaches shown here should not be considered the only way of meeting Canada’s 2030 targets. In particular:

- An alternative selection of policies within each policy approach may achieve the same aggregate greenhouse gas reduction while altering the economic outcome. All approaches could be altered in some fashion. For example, the carbon pricing options could be implemented with different revenue recycling regimes. Likewise, some of the subsidy programs envisioned under the regulatory approach could be replaced with different types of policies (like more regulatory policies). Such differences could significantly alter the economic outcomes of a given policy approach.
- An alternative selection of policy stringency within each approach could also affect economic outcomes. In many cases it would be possible to increase the stringency of one policy and reduce the stringency of another, while still achieving Canada’s target. For example, a regulatory approach could induce more abatement in industry and less in transport. Although the impact on Canada’s emissions might not change, the economic outcomes would likely be different.

4. Impacts of achieving Canada's Paris commitments

This Chapter compares three different approaches for achieving Canada's 2030 greenhouse gas reduction targets made under the Paris Agreement: carbon pricing, economy-wide regulations and industry-focused regulations. As described in the previous Chapter, two variations of each approach are considered, reflecting a more or less efficient implementation.

The following sections focus on different types of policy impacts:

- **Greenhouse gas reductions (Section 4.1).** All but one of the policy approaches achieves Canada's 2030 greenhouse gas target.
- **Economic activity (Section 4.2).** Achieving Canada's 2030 target imposes costs on the economy. Smart policy design can help reduce these costs.

This Chapter concludes with a discussion about policy stringency in Section 4.3.

4.1. Greenhouse gas reductions

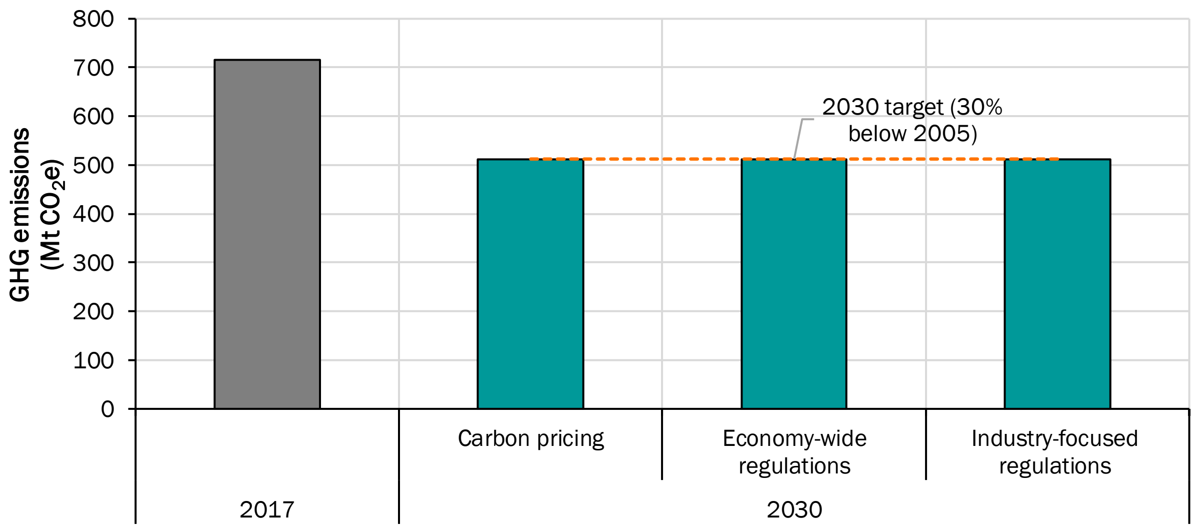
Canada can pursue a variety of policy approaches to achieve its 2030 target. As shown in Figure 5, carbon pricing, economy-wide regulations and industry-focused regulations can all achieve Canada's 2030 target of 513 Mt CO_2e in 2030. The implication is that government is not constrained by policy choice for meeting its Paris commitments.

Viable options for achieving Canada's target include:

- Putting a suitably stringent price on carbon, via a carbon tax or cap-and-trade system. This policy provides an incentive for firms and consumers to reduce their emissions. For a discussion about the carbon price required to achieve Canada's target, please see Section 4.3.
- Economy-wide regulations that require emission reductions from all major sources of emissions. This approach could take the form of prescriptive regulations (e.g. requiring the adoption of a specific types of technologies) or flexible regulations (e.g. requiring an emissions intensity improvement but being agnostic in how that improvement is achieved).

- Industry-focused regulations that seek to avoid imposing direct financial costs on households, to the extent that this is possible. As discussed next, achieving Canada's target using this approach may be challenging.

Figure 5: Achieving Canada's 2030 target using different policy approaches

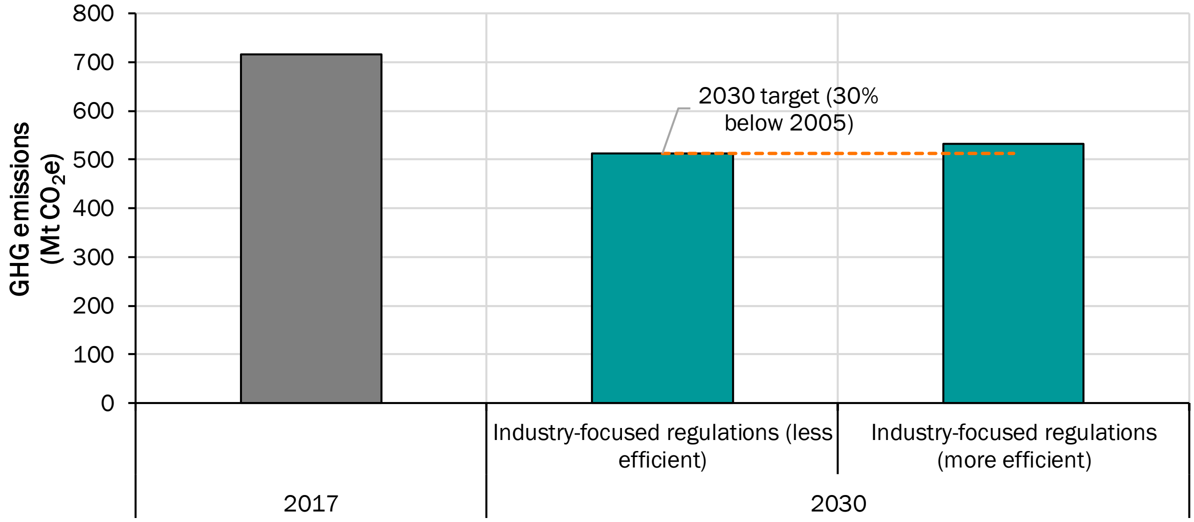


Note: Less efficient policy variations shown. Source for historical data: Government of Canada. 2019. National Inventory Report. Available from: https://unfccc.int/documents/194925

The analysis considered two variations of industry-focused regulations, both designed to minimize the direct costs imposed on households. While the efficient approach imposed no climate policies on households or electricity, the less efficient variation extended policy coverage to these sources of emissions through subsidies for the adoption of low carbon technologies. By contrast, the second variation did not include subsidies (on the basis that they are generally inefficient due to free ridership, the economic cost of funding them and overlap with other policies). The efficient version therefore did not encourage abatement from households.

As shown in Figure 6, the efficient version of the industry-focused regulations failed to achieve Canada's 2030 target. This finding exemplifies the challenge of achieving Canada's target while excluding large sources of emissions (i.e., households and electricity). These sources of emissions alone are projected to account for 137 Mt CO_2e in 2030 in the absence of new policies. Making matters worse, the industrial and transportation policies increase electricity demand and therefore emissions from the electricity sector (which lacks an incentive to reduce its emissions). In total, emissions from electricity are 42 Mt CO_2e more than they would have been in the absence of this policy in 2030. As such, industry, commercial buildings and non-household transportation would have to reduce their emissions to 340 Mt CO_2e in 2030 (from 579 Mt CO_2e in 2030 in the absence of policy). Achieving this level of greenhouse gas reduction proved to be an insurmountable task, with national emissions exceeding the target by 18 Mt CO_2e.

Figure 6: The challenge of achieving Canada's 2030 target using industry-focused regulations



Source for historical data: Government of Canada. 2019. National Inventory Report. Available from: https://unfccc.int/documents/194925

4.2. Economic impacts

The previous section shows how Canada can implement various policy approaches while still achieving the level of greenhouse gas reductions required under the Paris Agreement. Yet despite achieving similar greenhouse gas impacts, the policies are likely to impact the economy in different ways.

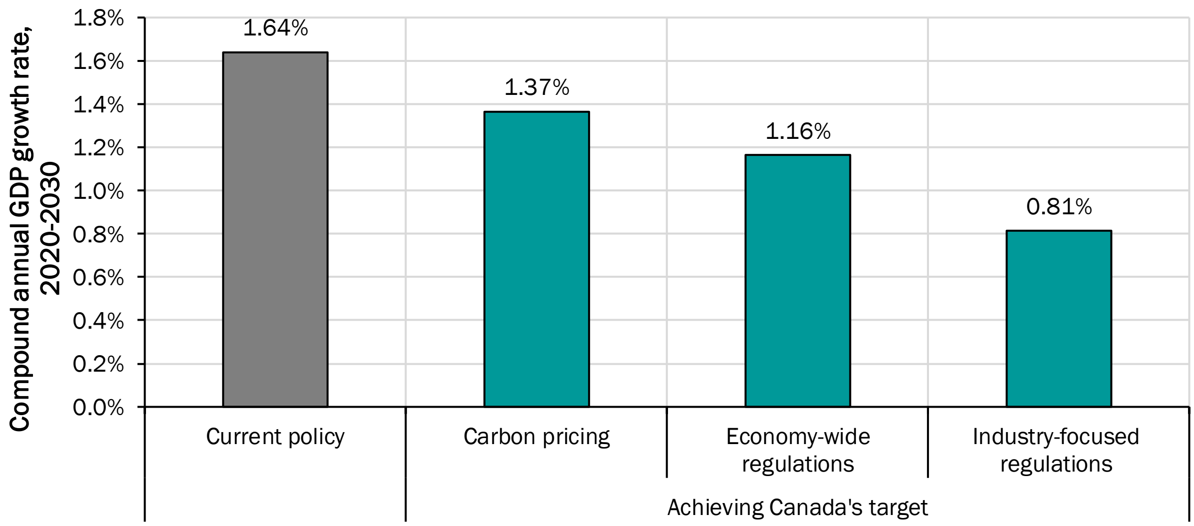
A common way of measuring economic activity is gross domestic product (GDP). GDP is the value of goods and services produced in a given region over the course of the year.

All of the policy approaches for achieving Canada's 2030 target are expected to reduce the rate of growth of GDP. Figure 7 shows that under current policies, Canada's GDP grows at an average annual rate of 1.64%. Achieving Canada's target reduces this growth rate to between 0.81% and 1.37%, based on the less efficient policy variations. In other words, GDP continues to grow, but at a slower pace. Note that these estimates don't reflect the potential costs of climate change (e.g. flooding) or the potential benefit from global climate mitigation efforts (e.g. reduced flooding).

Carbon pricing has the smallest impact on GDP, reducing the growth rate from 1.64% to 1.37%. By contrast, economy-wide regulations reduce the GDP growth rate to 1.16% while industry-focused regulations reduce the GDP growth rate to 0.81%.

Carbon pricing performs best because it sets a single carbon price across the whole economy. This approach ensures that no low-cost abatement opportunities are missed, and that no unnecessarily high abatement actions are required. By contrast, a regulatory approach inevitably imposes different abatement costs on different sources of emissions because policymakers don’t have perfect foresight. This situation is exacerbated with the use of industry-focused regulations, which impose particularly high costs on industry while avoiding costs (and abatement opportunities) from households and electricity.

Figure 7: Impact of achieving Canada’s greenhouse gas target on GDP growth rate



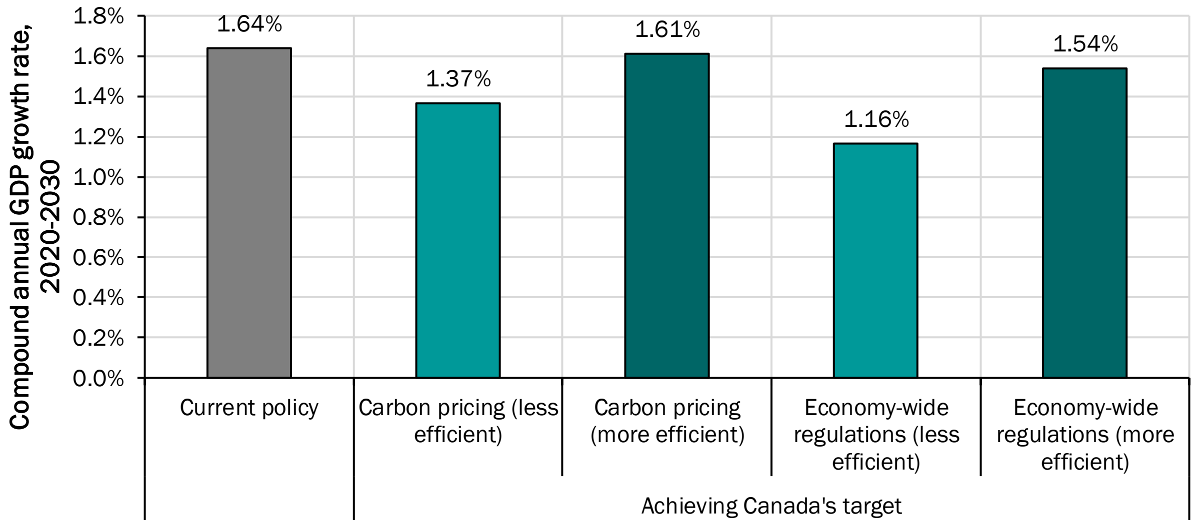
Scenarios shown: Less efficient variations.

Could efficient policy design improve these economic outcomes? Figure 8 shows that it can:

- Using carbon revenue to lower income taxes rather than returning it directly to households boosts GDP growth from 1.37% annually to 1.61% annually. Under this policy approach, achieving Canada’s target has a negligible impact on GDP growth.
- Implementing flexible regulations and avoiding the use of subsidies for low carbon technologies increases GDP growth under the regulatory approach from 1.16% annually to 1.54% annually.

As discussed in Section 4.1, the efficient variation of industry-focused regulations (i.e. with no subsidies to households and the electricity sector) did not achieve Canada's 2030 target and so its GDP impacts are not shown here.

Figure 8: Impact of efficient policy design on GDP growth



4.3. Case study: Policy stringency

The stringency of a climate policy is often discussed in the context of the cost or price of reducing a tonne of greenhouse gas emissions (i.e., $ per tonne of CO_2e abated). Everything else equal, policies with higher stringency impose greater costs/prices, while policies with lower stringency impose lower costs/prices.

The cost of abatement for carbon pricing and flexible regulations can be easily understood since these policies generate explicit prices. Under a carbon tax, the stringency of the policy is explicitly set by government. Under a cap-and-trade program, a market is created to trade emissions "allowances", generating an explicit carbon price. Flexible regulations also create a market for compliance credits, leading to an explicit $ per tonne CO_2e.

However, the stringency of climate policies is not always transparent. Conventional regulations and subsidies do not produce explicit prices for reducing greenhouse gas emissions. While such policies can be more or less stringent, their carbon price is implicit or hidden.

Estimating implicit prices is challenging. As an example, consider the strengthening of a residential building code by requiring greater thermal efficiency. While this policy will certainly impose a cost (or benefit) on households, and it will certainly reduce energy consumption, its stringency in terms of reducing emissions is opaque. First, the exact cost or benefit of the policy will not be reported by the market or set by policymakers. For a building standard, the final cost of the policy will be based on many households making many different decisions, the cost of these decisions is not "reported" anywhere directly. Second, thermal building shell improvements do not directly reduce emissions, but rather reduce heating requirements. Any emissions reduced due to the policy depends on the technologies for providing heat. If the heating requirements are met with a natural gas furnace, improved shell efficiency would reduce natural gas use and therefore greenhouse gas emissions. If those heating requirements are met with an electric heat pump, the extent to which shell efficiency reduces greenhouse gas emissions becomes more difficult to assess. The policy could achieve few to no reductions if electricity is generated by low- or zero-emissions sources (e.g., hydroelectricity in Québec) or reductions could be more significant if electricity is generated using coal (e.g., currently in Saskatchewan).

Modeling can be used to estimate the implicit price of policies to achieve Canada's Paris commitment, although doing so is complex. This discussion therefore provides a qualitative discussion of policy prices, as well as the estimated prices for explicit pricing policies (i.e., carbon pricing and flexible regulations).

For a given level of emission reduction, policies will tend to be less stringent if they:

- **Cover more sources of emissions.** Greater policy coverage of greenhouse gas emissions introduces a greater number of pathways for reducing emissions. With policies that cover fewer sources, some low-cost abatement opportunities could be missed, thereby requiring greater effort from the sources of emissions that are covered.

  This difference is evident when comparing the economy-wide regulations with the industry-focused regulations. As described in Section 3.2.2, the economy-wide regulations are able to be less stringent because they apply to most sources of emissions. By contrast, the industry-focused regulations must be more stringent because this approach avoids targeting abatement opportunities from households and electricity.

- **Apply "similar" policy costs among various sources of emissions.** Policies can accidentally or deliberately apply different abatement costs among different sources of emissions. If the abatement cost on one source of emissions proves to be relatively low, it would require that a higher abatement cost be applied on other sources of emissions in order to achieve the desired reductions.

  For example, achieving Canada's target with carbon pricing results in a single price on carbon for all covered emissions across the country. Under the efficient carbon pricing option, the carbon price reaches $229 per tonne CO_2e (2019$) in 2030[35]. By contrast, under the economy-wide regulatory approach each regulation results in a different carbon price. These prices range from $211 to $301 per tonne CO_2e in 2030.

- **Directly target emissions.** Some policies target emissions indirectly (typically by focusing on energy efficiency instead of emissions intensity). These policies can apply widely different abatement costs on actions to reduce emissions within the same end-use. For example, efficiency standards for natural gas furnaces would apply one abatement cost; while efficiency standards for electric heating systems would apply a different abatement cost (and this abatement cost would vary between provinces depending on how electricity is generated). In an extreme (but realistic) case, the abatement cost of building thermal envelope improvements would be near infinite if that building relied on electric heating in a province where all electricity was generated hydroelectricity.

To sum up, climate policies can be compared on the basis of stringency, which is measured in a carbon price. This price is explicit and transparent in the case of carbon pricing policies (i.e., carbon tax or cap-and-trade) as well as flexible regulations (e.g. a low carbon fuel standard that creates a market for compliance). Prices are less transparent for regulatory policies, but even these policies have "implicit" prices which can be estimated, with varying levels of effort.

For a given level of emission reductions, policies will tend to be less stringent (i.e., with a correspondingly lower carbon price) if they have greater coverage, apply similar costs across emission sources and directly target emissions.

[35] The carbon price is lower under the less efficient version ($210 per tonne CO_2e) because it results in lower levels of economic activity.

5. Lessons for policy development

This Chapter summarizes lessons for policy development that were learned during this analysis.

Canada can pursue different policy approaches for achieving its Paris commitments

Canada's Paris Agreement commitments are achievable. Viable options for achieving Canada's target include:

- **Putting a price on carbon**, via a carbon tax or cap-and-trade system. This approach provides an incentive for firms and consumers to reduce their emissions.
- **Economy-wide regulations** that require reductions of all major sources of emissions. This approach could take the form of prescriptive regulations (e.g. requiring the adoption of specific types of technologies) or flexible regulations (e.g. requiring an emissions intensity improvement but being agnostic about how that improvement is achieved).
- **Industry-focused regulations** that seek to avoid imposing direct financial costs on households, to the extent that this is possible. This approach is perhaps the most challenging, as discussed next.

Achieving the 2030 target requires reductions from all major sources of emissions

Canada needs to target all major sources of emissions if it is to get to 2030. In particular, this analysis shows that policy must target emission reductions from households and electricity or risk not meeting its Paris commitments. The implication is that effective climate mitigation policy will inevitably impose some costs on households. These costs can be minimized by careful policy design, including implementing policies that result in the best economic outcomes (see below) and using tools to protect vulnerable households (e.g. through direct transfers of carbon revenue).

Carbon pricing imposes lower economic costs than other approaches

Achieving Canada's 2030 target is likely to reduce the rate of GDP growth (before accounting for the benefits of mitigating climate change). But choice of policy type and design has a large influence on economic costs.

Carbon pricing performs best because it sets a single carbon price across the whole economy. This approach ensures that no low-cost abatement opportunities are missed, and that no unnecessarily high abatement actions are required.

By contrast, a regulatory approach inevitably imposes different abatement costs on different sources of emissions because policymakers don't have perfect foresight about policy impacts. In addition, careful attention is required to minimize gaps and overlap among policies. This situation is exacerbated with the use of industry-focused regulations, which impose particularly high costs on industry while trying to avoid costs (and abatement opportunities) from households and electricity.

Smart policy design can improve economic outcomes

Whichever policy approach is preferred for achieving Canada's 2030 target, design matters. Impacts on Canada's GDP can be improved via the following choices:

- In the case of carbon pricing: (1) use carbon revenue to lower personal and/or corporate income taxes and (2) protect emissions intensive and trade exposed sectors via free allocations and/or output rebates. Together, these design decisions can reduce the economic costs of carbon pricing by 78% in 2030 (based on a comparison of GDP between the less efficient and more efficient options considered in this analysis).
- In the case of a regulatory approach: (1) implement flexible regulations that provide options for how emissions reductions are achieved and (2) avoid the use of subsidies for low carbon technologies where possible. Subsidies are often inefficient due to free ridership and overlap with regulatory policies; and taxes must be raised to fund them. Together, these design decisions can reduce the economic costs of a regulatory approach for achieving Canada's target by 72% in 2030 (based on a comparison of GDP between the less efficient and more efficient options considered in this analysis).

Policymakers may face other constraints in achieving Canada’s 2030 target

Policymakers can’t predict the future (which makes designing good regulatory policies harder). The development of policy approaches for achieving Canada’s 2030 target in this report benefited from the perfect foresight that is bestowed on any modeling exercise. We can simulate a given policy approach, review the results and then fine-tune the policies. Did we get enough abatement from freight transport? If not, we can adjust the policy. Was the carbon capture and storage requirement too costly? If so, we can reduce the stringency.

Stepping away from the modeling world and into the real world of policy making, the regulatory approach may be harder for policymakers to get right. The economic costs of this approach may therefore be understated in this analysis.

Appendix A: Modeled sectors, fuels and end-uses

Table 10: List of sectors in gTech

Sector	NAICS code
Soybean farming	11111
Oilseed (except soybean) farming	11112
Wheat farming	11114
Corn farming	11115
Other farming	Rest of 1111
Animal production and aquaculture	112
Forestry and logging	113
Fishing, hunting and trapping	114
Agriculture services	115
Natural gas extraction (conventional)	211113
Natural gas extraction (tight)	
Natural gas extraction (shale)	
Light oil extraction	
Heavy oil extraction	
Oil sands in-situ	211114
Oil sands mining	
Bitumen upgrading (integrated)	
Bitumen upgrading (merchant)	
Coal mining	2121
Metal mining	2122
Non-metallic mineral mining and quarrying	2123
Oil and gas services	213111 to 213118
Mining services	213119
Fossil-fuel electric power generation	221111
Hydro-electric and other renewable electric power generation	221112 and 221119
Nuclear electric power generation	221113
Electric power transmission, control and distribution	22112
Natural gas distribution	222
Construction	23
Food manufacturing	311
Beverage and tobacco manufacturing	312

Sector	NAICS code
Textile and product mills, clothing manufacturing and leather and allied product manufacturing	313-316
Wood product manufacturing	321
Paper manufacturing	322
Petroleum refining	32411
Coal products manufacturing	Rest of 324
Petrochemical manufacturing	32511
Industrial gas manufacturing	32512
Other basic inorganic chemicals manufacturing	32518
Other basic organic chemicals manufacturing	32519
Biodiesel production from canola seed feedstock	
Biodiesel production from soybean feedstock	
Ethanol production from corn feedstock	
Ethanol production from wheat feedstock	
HDRD (or HRD) production from canola seed feedstock	
Renewable gasoline and diesel production	
Cellulosic ethanol production	
Resin and synthetic rubber manufacturing	3252
Fertilizer manufacturing	32531
Other chemicals manufacturing	Rest of 325
Plastics manufacturing	326
Cement manufacturing	32731
Lime and gypsum manufacturing	3274
Other non-metallic mineral products	Rest of 327
Iron and steel mills and ferro-alloy manufacturing	3311
Electric-arc steel manufacturing	
Steel product manufacturing from purchased steel	3312
Alumina and aluminum production and processing	3313
Other primary metals manufacturing	3314
Foundries	3315
Fabricated metal product manufacturing	332
Machinery manufacturing	333
Computer, electronic product and equipment, appliance and component manufacturing	334 and 335
Transportation equipment manufacturing	336
Other manufacturing	Rest of 31-33
Wholesale and retail trade	41-45
Air transportation	481
Rail transportation	482
Water transportation	483

Sector	NAICS code
Truck transportation	484
Transit and ground passenger transportation	485
Pipeline transportation of crude oil	4861 and 4869
Pipeline transportation of natural gas	4862
Other transportation, excluding warehousing and storage	4867-492
Landfills	Part of 562
Services	Rest of 51-91

Table 11: List of fuels in gTech

Fuel
Fossil fuels
Coal
Coke oven gas
Coke
Natural gas
Natural gas liquids
Gasoline and diesel
Heavy fuel oil
Still gas
Electricity
Electricity
Renewable fuels (non-transportation)
Spent pulping liquor
Wood
Wood waste (in industry)
Renewable natural gas
Renewable fuels (transportation)
Ethanol produced from corn
Ethanol produced from wheat
Cellulosic ethanol
Biodiesel produced from canola
Biodiesel produced from soy
Hydrogenated renewable diesel (HDRD)
Renewable gasoline and diesel from pyrolysis of biomass

Table 12: List of end-uses in gTech

End use
Stationary industrial energy/emissions sources
Fossil-fuel electricity generation
Process heat for industry
Process heat for cement and lime manufacturing
Heat (in remote areas without access to natural gas)
Cogeneration
Compression for natural gas production and pipelines
Large compression for LNG production
Electric motors (in industry)
Other electricity consumption
Transportation
Air travel
Buses
Rail transport
Light rail for personal transport
Marine transport
Light-duty vehicles
Trucking freight
Diesel services (for simulating biodiesel and other renewable diesel options)
Gasoline services (for simulating ethanol options)
Oil and gas fugitives
Formation CO_2 removal from natural gas processing
Flaring in areas close to natural gas pipelines
Flaring in areas far from natural gas pipelines
Venting and leaks of methane (oil and gas sector)
Industrial process
Mineral product GHG emissions
Aluminum electrolysis
Metallurgical coke consumption in steel production
Hydrogen production for petroleum refining and chemicals manufacturing
Non-fuel consumption of energy in chemicals manufacturing
Nitric acid production
Agriculture
Process CH_4 for which no know abatement option is available (enteric fermentation)
Manure management
Agricultural soils
Waste
Landfill gas management

End use
Residential buildings
Single family detached shells
Single family attached shells
Apartment shells
Heat load
Furnaces
Air conditioning
Lighting
Dishwashers
Clothes washers
Clothes dryers
Ranges
Faucet use of hot water
Refrigerators
Freezers
Hot water
Other appliances
Commercial buildings
Food retail shells
Office building shells
Non-food retail shells
Educational shells
Warehouses (shells)
Other commercial shells
Commercial heat load
Commercial hot water
Commercial lighting
Commercial air conditioning
Auxiliary equipment
Auxiliary motors (in commercial buildings)

At Navius, we offer our clients the confidence to make informed decisions related to energy, the economy, and the environment.

We take a collaborative approach to projects, drawing on a unique suite of modeling, research and communication tools to provide impartial analysis and clear advice.

contact@naviusresearch.com