PUBLIC POLICY FORUM

MAY 2023

The $100 Billion Difference

RELATIVE COSTS OF TWO NET ZERO APPROACHES

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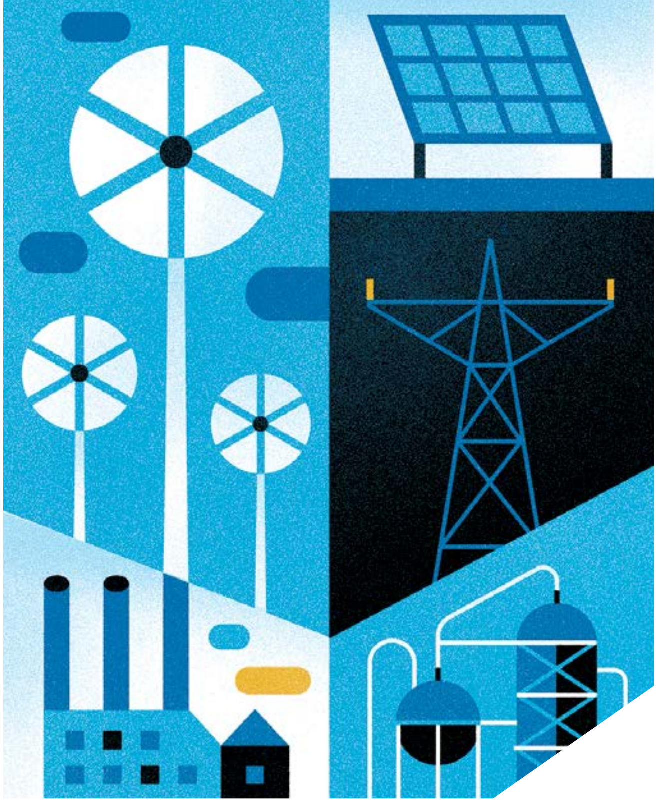

Preface

In launching its Energy Future Forum in 2019, the Public Policy Forum set out as its mission "to develop practical measures that help Canada meet or exceed our 2030 emissions targets on the way to a net zero future, and that strengthen an innovative economy, deepen shared prosperity and enhance national unity." From the beginning, PPF was concerned that the public dialogue around climate and energy involved people talking past each other, whereas climate policy in a democracy would require a strong and enduring consensus among the governed.

In our early meetings, some espoused the view that Canada was such a small part of global emissions that the cost of action (economically, socially and politically) outweighed the potential climate gain. We sought to tamp down this kind of reasoning with an analogy to the 20th century's world wars: imagine telling our Allies that Canadian soldiers constituted such a small percentage of the overall effort that it made no sense to send them to the front.

Meanwhile, others failed to pay adequate heed to the word 'transition' in "energy transition." They tended to conflate greenhouse gas emissions with fossil fuels themselves. In so doing, they ignore a possible solution set that seeks to decarbonize oil and gas production, allowing, where it makes sense, for their continued use with reduced emissions while the demand side makes its adjustments. The idea remains to get *emissions* out in the least costly and disruptive manner.

This basic cleavage re-appeared in our 2022 Blueprint for Canada's Net-Zero Transition. The **report observed** that two basic narratives continued to vie for the hearts and minds of Canadians. We called one the aggressive decarbonization model. It involves a two-track strategy of investing in both non-emitting energy sources *and* in lowering emissions from oil and gas production.

PPF labelled its competing narrative the accelerated phaseout model. By that, we meant measures that would suppress supply of fossil fuels at a faster pace than demand would otherwise dictate. This could be operationalized directly in the form of a cap on the production of fossil fuels—although a production cap in Canada is almost certainly beyond the powers of the federal government. Then again, policy could just as easily shrink production via indirect means, such as limiting pipeline or other infrastructure approvals and permits, constraining or discouraging investment, or setting an emissions cap level so stringent it is only achievable through production cuts. Directly or indirectly, an accelerated phaseout model would deny existing producers the opportunity to innovate their way to a net-zero future.

By and large, the logic of many government policies, including recent tax credits, adheres to the aggressive decarbonization model. But some policy decisions, and much rhetoric, come closer to an accelerated phaseout.

Having described these two approaches, we felt the need to understand their relative consequences. Would one over the other make a difference to the economic welfare of Canadians? Would one more readily deliver emissions reductions?

We met with Vancouver-based Navius Research, a highly respected environmental modelling firm that grew out of Simon Fraser University and which has done work in the past for all orders of governments, environmental groups, labour, academia and industry. Navius told us that the impacts of the two alternate pathways to net zero emissions in 2050 could be measured. We agreed that understanding these differences would better inform policymakers and public discourse.

Navius also included a third pathway, where Canada implements only those policies that have already been announced, and does not reach net zero. This scenario was included for comparison purposes. We should all be clear—this is not a viable scenario for Canada, as per the military analogy above, or for the planet. Climate change must be addressed.

With that said, the results provide important context for Canada's climate policy. Five take-aways captured our attention:

1. **We are not headed to net zero on the basis of current policy.** In fact, Navius projects Canada is likely to narrowly miss even our 2030 target. Achieving our net-zero ambitions will require additional policy, whether consistent with an accelerated phaseout or aggressive decarbonization.

2. **An accelerated phaseout introduces economic pain with no added environmental gain.** Both pathways arrive at net zero but with unequal economic impacts along the way. Canada grows at a rate that is 0.1% slower per year under an accelerated phaseout than aggressive decarbonization. This apparently small difference compounds over time, leading to $100 billion excess lost GDP in 2050, a three percent contraction of the overall economy. This essentially amounts to a deep recession without a recovery ever materializing. The lost output carries forward each year in perpetuity.

3. **This gap in growth falls disproportionately on oil and gas producing provinces, particularly Alberta.** About $60 billion of Canada's $100 billion growth shortfall falls directly on Alberta. The province experiences miniscule growth of less than one percent for the 30 years from 2020 to 2050, according to the model. If anything, Navius expects its assumptions may actually be underestimating the severity of this impact.

4. **The incomes of everyday Canadians decline as well in response to the phasing out of oil and gas.** Navius tested this result under different assumptions and, while the number was sometimes higher or lower, the direction was always the same when Canadian workers lose one of their most productive and highest-paying sectors under the accelerated phaseout model. Think of the hollowing out of the U.S. Midwest with workers going from pay of $30 or more an hour to something closer to half that.

5. **Canada's trade balance naturally weakens with the curtailment one way or another of its largest export category.** The accelerated phaseout approach leads to net exports declining by nearly twice as much as the aggressive decarbonization model. Perhaps less obvious is that imports also fall in the overall economy because Canadians have lower incomes to spend on imports.

Once the modeling results were in, PPF convened a roundtable in March 2023 to put the assumptions and outcomes under a collective microscope.

Some participants, largely from environmental groups, argued that the entire exercise was based on a false premise. In their opinion, nobody is advocating for an accelerated phaseout. They regarded that as a straw man; that, despite the fact that a recent report by the Winnipeg-based International Institute for Sustainable Development called for "an oil and gas production phaseout by 2034 for rich countries"; that there was a strong push at last year's COP in Egypt to include language in the final agreement calling for a phaseout of all fossil fuels as advocated by Environmental Defence Canada, among others; or that the objective of the Beyond Oil and Gas Alliance, which includes the province of Quebec, is to phase out oil and gas production worldwide.

Those are just some of the phaseout interventions related to direct means. Indirect means, such as divestment campaigns, are meant to arrive at the same end.

A model cannot produce a definitive projection of the future. No model from 30 years ago could have projected the technology and events that have shaped our world of 2023, for example. Nobody would have forecast negative-priced oil in 2020 or the run-up in prices following the invasion of Ukraine. Similarly, the Navius model cannot fully grasp Canada's emerging opportunities in such net-zero sectors as critical minerals, hydrogen or industries we may not yet imagine.

The value in a model, rather, is informing the *relative* impacts of comparable paths in a way that can help to inform policymaking. On this front, the modelling is clear. Oil and gas production can be a part of a net-zero future if significant investments are made to transform the sector. The alternative causes extensive economic damage while not bringing us any closer to our climate change goals.

The energy transition is complicated and difficult stuff. Climate policy will have to continue to unfold, given that current measures do not yet appear to bring emissions down sufficiently. One cannot lose sight of the Energy Future Forum's original principles that a policy regimen that must be executed over several decades will have to maintain political support throughout. The only way to win the battle is to be environmentally, economically and politically sound and ensure that energy reliability and affordability are not forsaken as we move toward net zero.

There is no way of doing nothing in the face of the climate emergency. The question is what course produces the best environmental outcome for Canadians while causing the least disruption possible on the way to net zero?

It is in that spirit that we present the Navius findings.

—**Edward Greenspon**,
President & CEO, Public Policy Forum

Modeling Energy Transition Scenarios for Canada

Aggressive decarbonization vs. accelerated oil and gas phaseout

Prepared for Public Policy Forum by Navius Research Inc.

About Navius

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. We 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.

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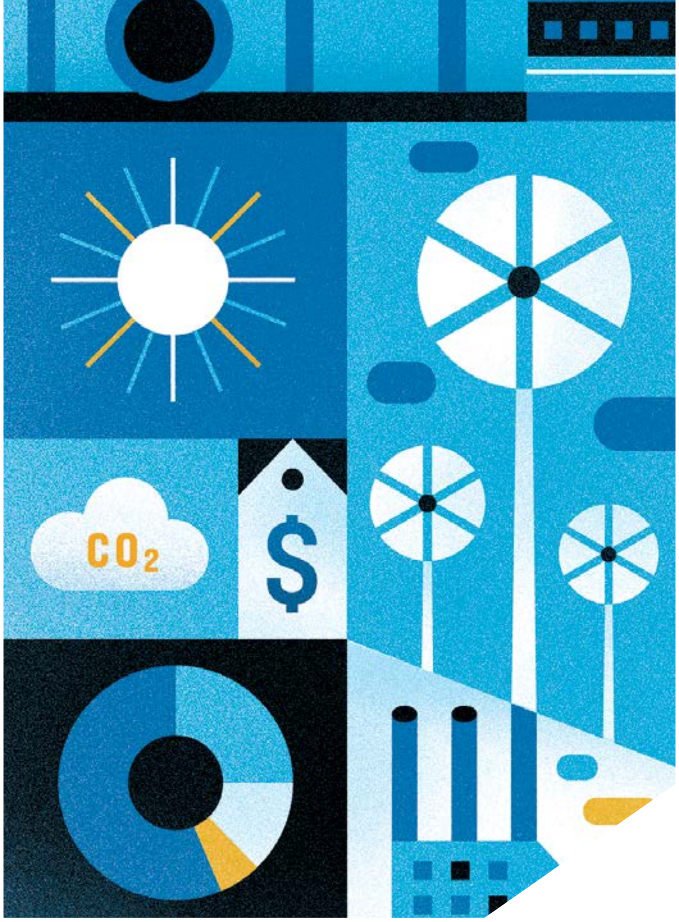


Executive Summary

The Public Policy Forum (PPF) is interested in understanding the differences between two net zero visions for Canada—one where Canada pursues the least costly pathway to achieve net zero emissions without prescribing the industrial composition of the economy (aggressive decarbonization) and another where oil and gas production is purposely reduced regardless of demand (accelerated phaseout). Both lead to a shared outcome of net zero emissions by 2050 but are likely to arrive at that objective having had different impacts on the Canadian economy.

Navius Research used its technologically explicit energy-economy model, gTech, to simulate these two net zero futures for Canada and quantify the economic impacts, including domestic income and the cost of achieving Canada's net zero target. Three policy scenarios were simulated:

1. **Announced policy.** This includes all existing federal and provincial policies as well as policies announced as of October 2022, including in the *A Healthy Environment and Healthy Economy* climate plan and Canada's 2030 *Emissions Reduction Plan* (ERP).

2. **Net zero policy.** This includes policies currently legislated and announced in the ERP, plus a cap at net zero emissions economy-wide in 2050.

3. **Net zero with oil and gas production phaseout.** This includes policies currently legislated and announced in the ERP, a cap at net zero emissions economy-wide in 2050, and the addition of an explicit phaseout of oil and gas production. Oil and gas production is limited starting in 2035 and phases down linearly to a 95% reduction from 2015 production levels by 2050.

We refer to the net zero scenario without sector-specific policy as "net zero" for simplicity throughout the report, even though the oil and gas production phase out scenario also achieves net zero. We refer to the net zero with oil and gas production phaseout scenario as "oil and gas production phase out".

Each policy scenario was simulated under a range of uncertain assumptions, including the future global oil price, availability of direct air capture (DAC) technology, cost of DAC and carbon capture and storage (CCS), and the level of climate policy implemented in the U.S. We refer to the 'intermediate sensitivity' throughout the report. This refers to a scenario with an intermediate global oil price forecast, DAC technology unavailable, intermediate CCS costs, and baseline policy in the U.S.

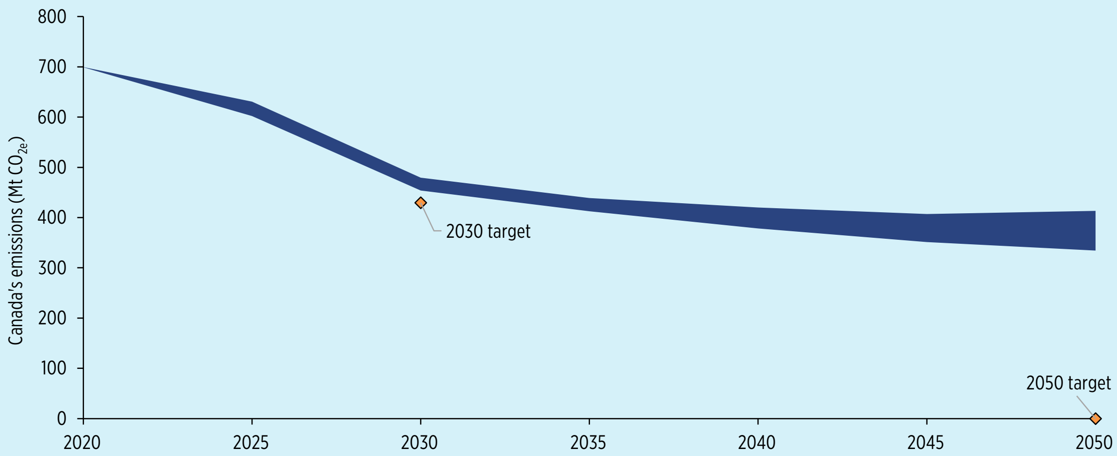
A key uncertainty is the future global oil price, as this assumption has a significant impact on results of this analysis, including economic outcomes for Canada's oil and gas sector and the economy as a whole. Unlike other uncertainties explored in this analysis that are within Canada's control, such as policy implementation or technology cost declines (to some extent), the future global oil price is not. See Section 2.2 for discussion of the global oil price in a net zero future.

Canada's emissions trajectory

Policies announced in Canada's ERP are projected to lead to a decline in emissions of 29% from current levels by 2030, getting Canada to within 25–50 Mt of its 2030 emissions target. Beyond

2030, emissions continue to decline under announced policy by 35% from current levels by 2050. It is clear, however, that **greater policy stringency is required to achieve net zero emissions by 2050 in Canada**, as announced policy leaves a 334–413 Mt gap to this 2050 target (Figure 1).

Figure 1: Canada's emissions under policies announced in the 2030 Emissions Reduction Plan (range across all sensitivities)[1]



Results indicate that when net zero policy is simulated without an explicit phaseout of oil and gas production (i.e., the model finds the most cost-efficient path to net zero), some oil and gas production and associated emissions remain in 2050. These emissions are offset by negative emissions including LULUCF offsets, bioenergy with CCS (BECCS), and DAC if available. **This indicates that Canada can achieve net zero emissions with or without continued oil and gas production.**

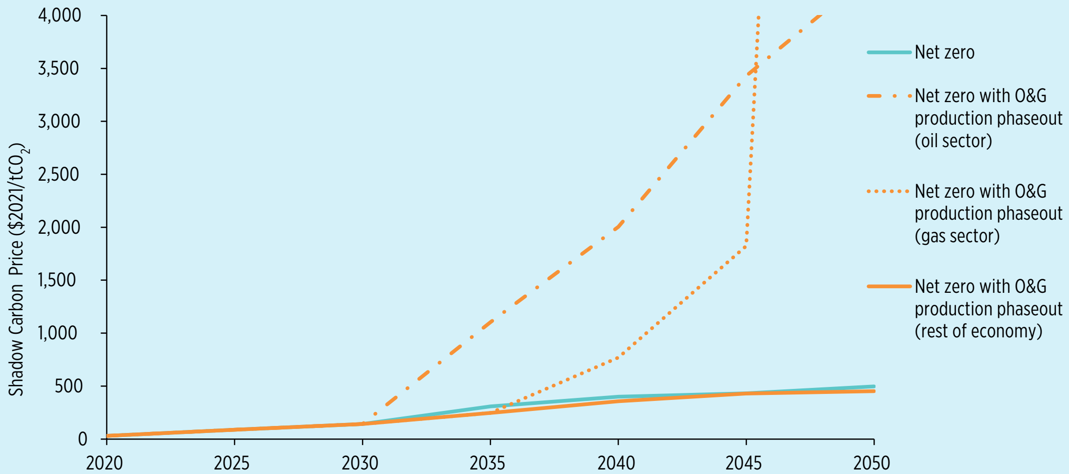
When an oil and gas production phaseout is simulated and virtually no emissions remain from the oil and gas sector in 2050, fewer negative emissions are needed economy-wide, and there is more flexibility for other sectors of the economy with expensive-to-abate emissions (such as heavy-duty transportation) to continue to emit in 2050.

Cost of achieving net zero emissions in Canada

The net zero scenarios simulated in this analysis use an emissions cap (i.e., effectively an economy-wide cap-and-trade system) to require net zero emissions by 2050. As such, the shadow carbon price (i.e., the price of carbon credits under the emissions cap) is a measure of the policy stringency required to achieve net zero in each scenario, presented in Figure 2.

The solid lines show the shadow price under the economy-wide emissions cap, which indicates that the additional policy stringency required to achieve net zero emissions is $307/t$CO_{2e}$ in 2035 and $497/t$CO_{2e}$ in 2050. When an oil and gas production phaseout is implemented, this price is slightly lower, $246/t$CO_{2e}$ in 2035 and $452/t$CO_{2e}$ in 2050. This is because as oil and gas production is phased out, there are fewer emissions remaining in this sector that need to be offset. As a result, more offsets are available for other sectors of the economy, driving down the economy-wide shadow carbon price.

Figure 2: Additional climate policy stringency required to achieve net zero in Canada (intermediate sensitivity)[2]

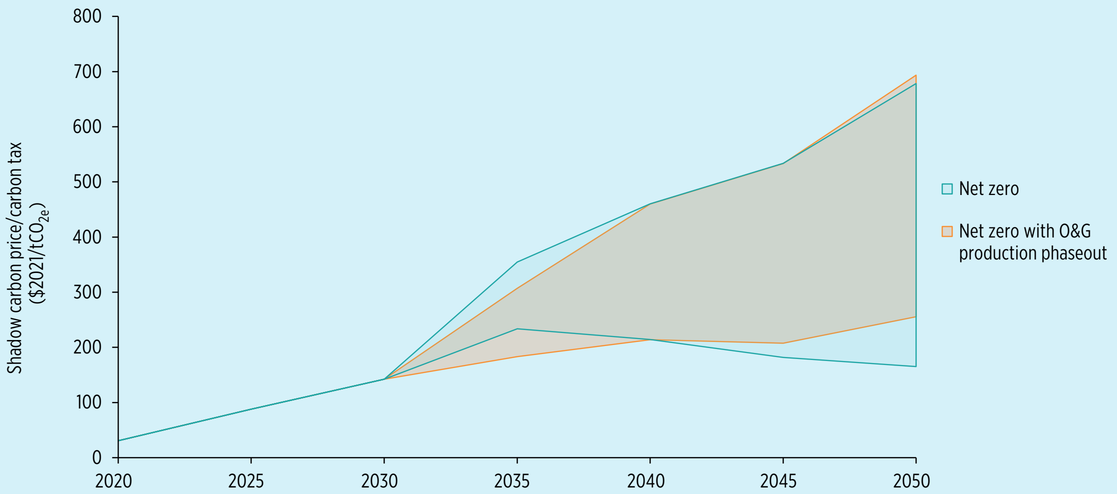


This does not, however, capture the policy compliance cost of phasing out oil and gas production. This cost is represented by the dotted lines in Figure 2, which indicate that the cost of complying with policy in the oil sector is four times greater in 2035 and nine times greater by 2050 in the oil and gas production phaseout scenario relative to the net zero scenario. Compliance costs are double in 2040 and almost 50 times greater by 2050 in the gas sector.

A net zero future with an explicit phaseout of oil and gas production makes it marginally less costly for the rest of the economy to achieve net zero emissions by 2050 but imposes significant additional compliance costs on the oil and gas sector.

The cost of achieving net zero emissions is highly uncertain. Figure 3 provides the range in shadow carbon prices across all sensitivities simulated for each net zero scenario. This indicates that the cost of achieving net zero ranges from \$234–\$355/tCO_{2e} in 2035 and from \$165–678/tCO_{2e} in 2050, depending on the assumptions made.

Figure 3: Additional climate policy stringency required to achieve net zero in Canada (range across all sensitivities)



The lower end of this range represents a net zero future in which DAC technology is widely available and carbon capture costs decline more rapidly over time. This makes it possible to achieve net zero emissions at a lower cost. If DAC does not become commercial and CCS costs come down more slowly over time, it is 76% more expensive to reduce emissions to net zero by 2050 relative to a low technology cost scenario. **This indicates that CCS and DAC technology are crucial to minimize the cost of achieving net zero emissions.**

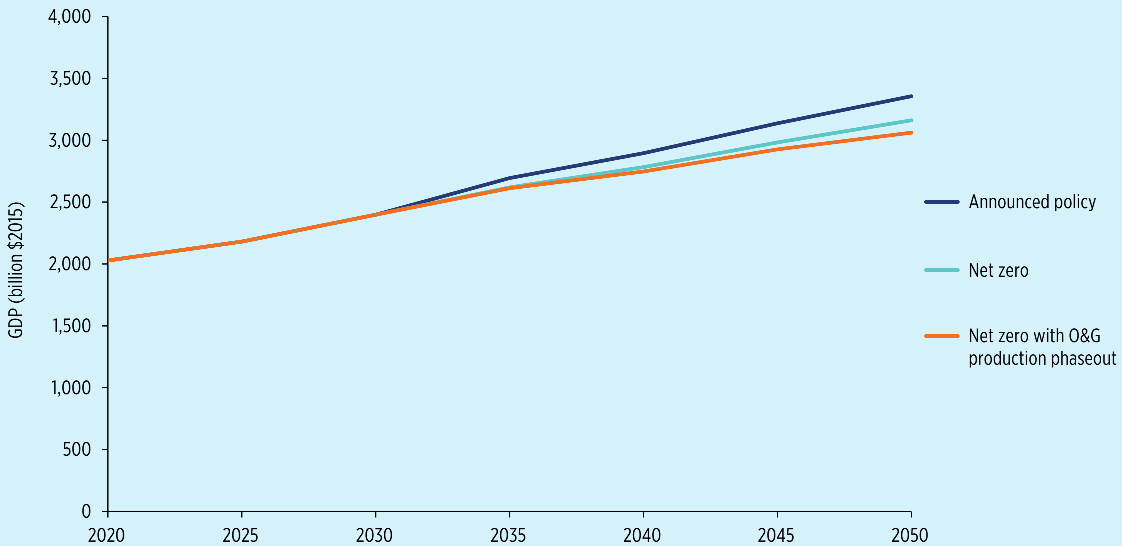
Economic impacts of two net zero futures for Canada

1. Domestic income

Achieving net zero emissions poses a significant challenge for the growth of Canada's economy, lowering Canada's GDP by \$75 billion in 2035 and \$196 billion in 2050 relative to announced policy under intermediate assumptions (Figure 4).

A net zero future where oil and gas production is explicitly phased out lowers GDP by an additional $6 billion in 2035 and $100 billion in 2050. **In other words, an oil and gas production phaseout exacerbates the negative GDP impact of net zero policy by 50% while providing no additional emissions reductions.**

Figure 4: Canada's GDP in three policy scenarios (intermediate sensitivity)[3]



The impact of net zero policy on Canadian GDP depends on the future price of oil, DAC availability and the extent to which CCS costs decline over time. In a future where there is more demand for Canadian oil (i.e., the global oil price is high) or it is less costly for the oil and gas sector to reduce emissions (i.e., DAC is available or CCS costs are low), the GDP impact of an explicit oil and gas production phaseout is greater.

For example, in a high oil price scenario, Canadian GDP is reduced by an additional $200 billion in 2050 with the addition of an oil and gas production phaseout relative to net zero policy. Similarly, if DAC technology is commercial, implementing an oil and gas production phaseout increases the negative GDP impact of net zero policy by $160 billion in 2050. In a low oil price scenario in which demand has fallen more steeply, however, implementing an explicit phaseout of oil and gas production reduces GDP by just an additional $27 billion in 2050 relative to net zero policy. The economic impact of explicitly phasing out oil and gas production is smaller in this scenario as the low oil price already incentivizes declines in production and diversification of Canada's economy.

Achieving net zero emissions by 2050 has negative GDP impacts across all Canadian regions, but the **economic impacts of net zero policy are more significant in oil and gas-producing regions.** In provinces with an economy more reliant on oil and gas production, complying with net zero policy results in a decline in oil and gas production, and therefore a greater decline in economic growth relative to the Canadian average.

Table 1 indicates that Canada's economy grows at an average annual rate of 1.5% under net zero policy, while an oil producing province like Alberta grows at a lower rate of 1.3% per year, and a non-oil producing province like Ontario grows at a higher rate of 1.6% per year in the intermediate sensitivity. Economic growth rates under net zero policy are dependent in all regions on the global oil price, though the price has the most significant impact on oil-producing regions like Alberta.

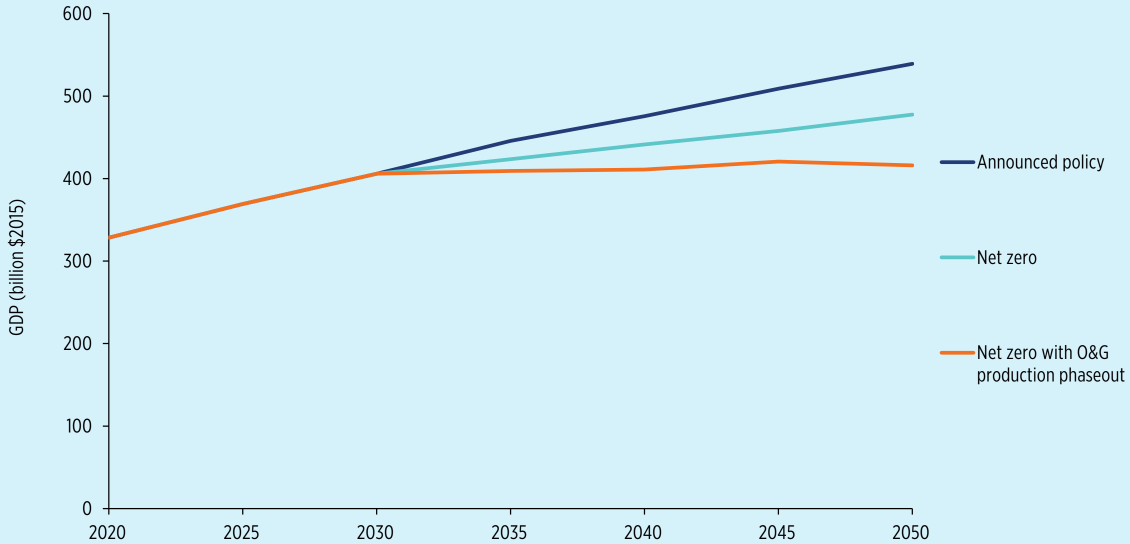
Table 1: Compound annual growth rate (CAGR) from 2020–2050 in three policy scenarios, three regions, and three oil price forecasts[4]

REGION/OIL PRICE	ANNOUNCED POLICY	NET ZERO	NET ZERO WITH O&G PRODUCTION PHASEOUT
Canada			
Low oil price	1.67%	1.46%	1.43%
Intermediate oil price	1.69%	1.49%	1.38%
High oil price	1.74%	1.58%	1.36%
Alberta			
Low oil price	1.39%	1.04%	0.93%
Intermediate oil price	1.67%	1.26%	0.79%
High oil price	1.89%	1.62%	0.67%

In Alberta, for example, the impact of net zero policy relative to announced policy is $60 billion in 2050, a third of the total Canada-wide impact of achieving net zero emissions. The impact of explicitly phasing out oil and gas in addition to net zero policy increases the GDP impact by another $60 billion, doubling the negative GDP impact of net zero policy (Figure 5). This means economic growth in the province would be 0.78% per year between 2020 and 2050.

In a net zero future where oil production is explicitly phased out, all regions experience the highest economic growth under a low oil price. If the global oil price is low, Canada's economy begins to diversify earlier as investment moves away sooner from the less-profitable oil and gas sector.

Figure 5: Alberta's GDP in three policy scenarios (intermediate sensitivity)[5]

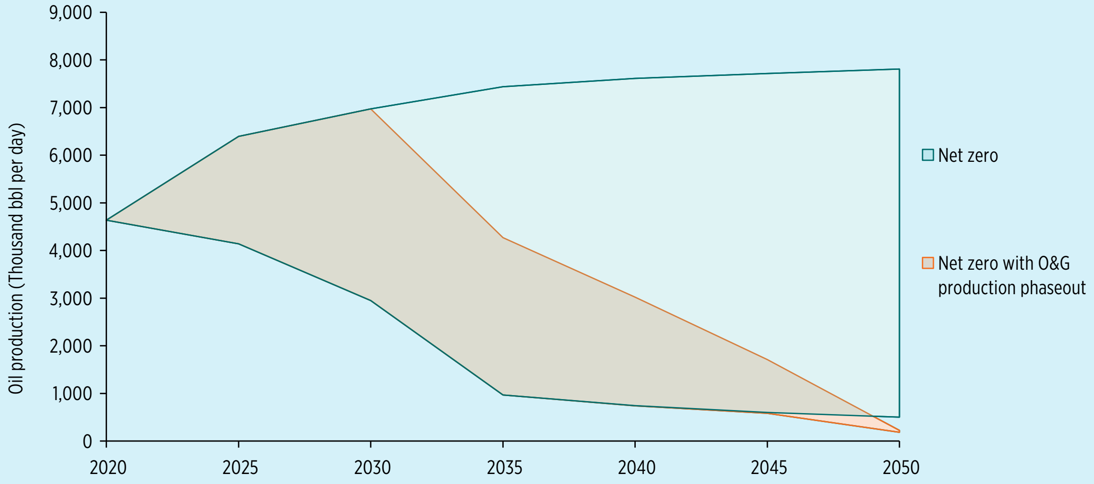


2. Oil and gas production

Achieving net zero emissions by 2050 in the most cost-effective way leads to a reduction in Canadian oil and gas production. Under intermediate assumptions, net zero policy results in 22% less oil and 27% less gas production in 2050 relative to announced policy. The greatest production declines occur in the oil sands in situ sector, where production is 52% lower in 2050 under net zero relative to announced policy. However, there is still significantly more oil and gas production remaining in 2050 under net zero policy than in the production phaseout scenario when production is forced to decline by 95%.

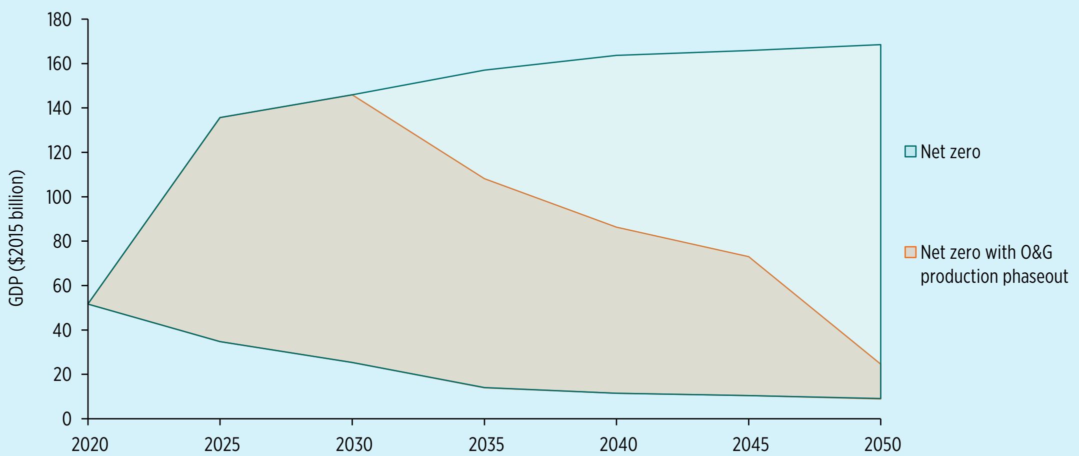
When accounting for all sensitivity scenarios simulated, there is significant uncertainty in the impact of net zero policy on the oil and gas sector. Figure 6 presents the range in oil production across all net zero scenarios simulated. Oil production ranges from 502,000 to 7.8 million barrels per day under net zero in 2050. The range is driven by the global oil price and the extent to which CCS and DAC costs decline over time. These factors also drive the range in natural gas production in 2050 (6 to 24 billion cubic feet (Bcf) per day under net zero).

Figure 6: Canadian oil production by type in two policy scenarios (range across all sensitivities simulated)



Changes in production in turn impact the oil and gas sector GDP, as shown in Figure 7. Under net zero policy, GDP in the oil and gas sector ranges from an 82% decline to a 226% increase from 2020 to 2050. When an oil and gas production phaseout is implemented, however, this range is much smaller—a 52–83% decline in GDP from 2020 levels. In other words, **explicitly phasing out oil and gas production guarantees a negative economic outcome for the oil and gas sector, which is not guaranteed by net zero policy on its own.**

Figure 7: Canada's oil and gas sector GDP in two policy scenarios (range across all sensitivities)

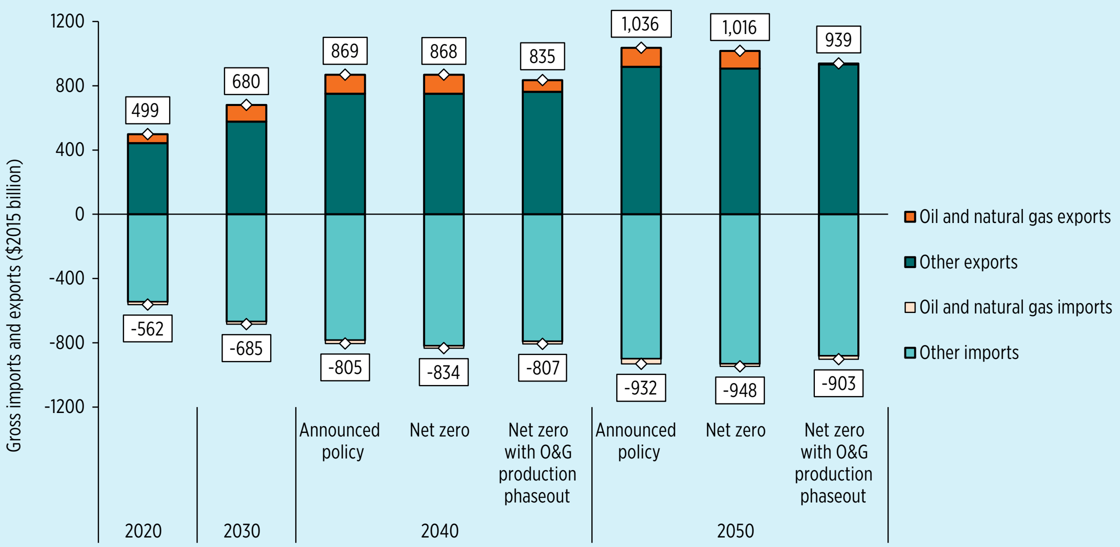


3. Trade balance

Implementation of net zero policy can have important implications for Canada's trade, particularly oil and gas exports. Figure 8 presents Canada's imports and exports under announced policy and two net zero futures. In 2050, net zero policy reduces Canada's trade balance by $36 billion relative to announced policy, including a reduction in net exports of oil and natural gas products.

Implementation of an oil and gas production phaseout leads to a significant decline is Canadian net exports by 2050 relative to a net zero future without an explicit oil and gas production phaseout. When an oil and gas production phaseout is implemented, net exports are reduced by an additional $33 billion relative to net zero policy in 2050. Canada is no longer a net exporter but is instead a net importer of $14 billion of oil and gas in this scenario. This reduction in net exports under the production phaseout scenario accounts for a third of the total GDP impact of this policy.

Figure 8: Canada's imports and exports in three policy scenarios (intermediate sensitivity)[6]



Key insights

Results of this analysis provide four key insights:

1. Canada is not on track to achieve net zero emissions under announced policy.
Greater policy stringency is required to achieve net zero emissions by 2050 in Canada.

2. There are many different net zero pathways for Canada. Some include continued oil and gas production.
When net zero policy is simulated without an explicit phaseout of oil and gas production, some oil and gas production and associated emissions remain in 2050. This suggests that Canada can achieve net zero emissions with or without continued oil and gas production. Continued oil and gas production in Canada depends on factors within our control (like policy implementation) but also factors outside of our control (i.e., global oil demand and price).

3. Different pathways to net zero have different economic implications for Canada.
Additional policy to phaseout oil and gas production:

- Makes it marginally less costly for other sectors of the economy to achieve net zero emissions while imposing significant additional policy compliance costs on the oil and gas sector;
- Increases the negative economic impact of net zero policy;
- Guarantees a negative economic outcome for the oil and gas sector that is not guaranteed by net zero policy; and
- Leads to a reduction in Canada's net exports.

4. The cost of achieving net zero emissions in Canada is uncertain and is not felt equally across regions.
Key uncertainties in the cost of achieving net zero emissions and the economic impacts of net zero policy in Canada is the availability and cost of DAC and CCS technology, as well as the global oil price. In a future where there is more demand for Canadian oil (i.e., high global oil price) or it is less costly for the oil and gas sector to reduce emissions (i.e., DAC is available, CCS costs are low), the impact of an explicit oil and gas production phaseout is greater. On the other hand, if the future global oil price is low, the addition of an oil and gas production phaseout has a smaller economic impact in Canada. The economic impact of net zero policy is also most significant in oil and gas producing regions across Canada.

Limitations

gTech is the most comprehensive model available for forecasting the techno-economic impacts of climate policy in Canada. Its representation of technological change, macroeconomic dynamics and fuel markets mean that it is ideally positioned to forecast the economic impacts of achieving net zero emissions. However, no model can predict the future.

An important limitation of this analysis, which likely leads to an underestimate of the economic impacts of an oil and gas production phaseout, are the assumptions made about labour mobility. gTech assumes that labour is fully mobile within wage classes within a province. This may underestimate the challenges associated with a declining oil and gas sector, such as relocation costs, retraining costs, and periods of unemployment between jobs. gTech also assumes that labour is immobile between provinces. This underestimates the impacts of a declining oil and gas sector in oil and gas producing regions, as these provinces may, in fact, experience a loss in labour force to other regions in Canada, exacerbating negative economic impacts.

Another limitation of this analysis is that it does not account for the comparative advantage of heavier grades of crude oil (like bitumen) in producing non-combustion commodities for which demand will remain in a net zero future—known as "bitumen beyond combustion". When accounting for this advantage, it is likely that the oil sands sector is more resilient to net zero policy and conventional oil less resilient. If accounted for, this dynamic could impact the results of this analysis, making an explicit phaseout of oil and gas production more expensive for the oil sands sector and less expensive for the conventional oil sector in a net zero future.

More detailed representation of impacts associated with retraining, skill building, relocation, unemployment and regional migration under strong climate policy, as well as representation of the role for bitumen beyond combustion, is an important area of research for future analysis.

ENDNOTES

1 Note that this includes policies announced as of October 2022. See Appendix B for additional details.

2 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

3 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

4 These scenarios assume intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

5 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

6 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

1. Introduction

The Energy Future Forum recently published "A Leadership Blueprint for Canada's Net-Zero Energy Transition"[7] which presents two visions for achieving Canada's net zero emissions goal. One vision involves an accelerated phaseout of fossil fuel production in Canada, while the other involves a strategy for aggressive decarbonization. As such, one vision focuses on reducing fossil fuel production as a key strategy for emissions reductions and the other focuses on reducing emissions from oil and gas production, thereby extending the natural lifecycle of these resources. Both lead to a shared outcome of net zero emissions by 2050 but are likely to have different implications for the Canadian economy.

The Public Policy Forum (PPF) is interested in understanding the differences between these two net zero futures, particularly the economic impacts, including domestic income and the cost of achieving Canada's net zero target. Navius Research undertook an analysis of these two options for meeting Canada's net zero commitment – one where Canada pursues the least costly pathway to net zero, without prescribing the industrial composition of the economy, and the other where the phaseout of the oil and gas sector is a discrete policy objective of Canada's net zero strategy.

This report presents the analytical approach taken and key findings of this analysis. It is structured as follows:

- Section 2 summarizes the modeling scenarios simulated and key modeling assumptions.
- Section 3 discusses key results, including Canada's current emissions trajectory, the cost of achieving net zero emissions and the economic impact of two net zero futures for Canada.
- Section 4 provides a summary of the key insights.
- Section 5 discusses key limitations of the analysis and opportunities for future research.

[7] Public Policy Forum. February 2022. *A Leadership Blueprint for Canada's Net-Zero Energy Transition*. Available from: https://ppforum.ca/wp-content/uploads/2022/02/Leadership-Blueprint-CanadasNetZeroEnergyTransition-Public-Policy-Forum-Feb-2022.pdf

2. Analytical Approach

This section provides an overview of the approach used for this analysis, which relies on Navius' energy-economy model, gTech. The gTech model is described in Appendix A.

Section 2.1 describes the scenarios modeled in this analysis and Section 2.2 discusses global oil price assumptions. Policy assumptions are described in more detail in Appendix B, and key technology costs are provided in Appendix C.

2.1. Scenario design

2.1.1. Policy scenarios

Three policy scenarios were simulated for this analysis and are summarized in Table 2.

Net zero policy simulated for the "aggressive decarbonization" and "accelerated oil and gas phaseout" scenarios was done by simulating a cap-and-trade system that is implemented economy-wide and requires emissions reductions in line with an emissions cap at net zero in 2050. This approach allows the model to determine the least cost pathway to achieve the emissions cap, without making assumptions about specific policies that may be implemented to achieve net zero (in addition to those announced to date). Both the "aggressive decarbonization" and "accelerated oil and gas phase out" scenario include this economy-wide net zero emissions cap, with the difference between these scenarios being that the "accelerated oil and gas phaseout" scenario also includes a cap on oil and gas production.

We refer to the net zero scenario without sector-specific policy as "net zero" for simplicity throughout the report, even though the oil and gas production phase out scenario also achieves net zero. We refer to the net zero with oil and gas production phaseout scenario as "oil and gas production phase out".

Table 2: Policy scenarios simulated

Baseline policy	
1. Announced policy	This scenario includes all existing federal and provincial policies as well as policies announced as of October 2022, including in the *A Healthy Environment and Healthy Economy* (HEHE) climate plan[8] and Canada's *2030 Emissions Reduction Plan*[9] (ERP). This includes a carbon price that rises to $170/tCO_{2e}$ by 2030, implementation of the Clean Fuel Regulations and an emissions cap on the oil and gas sector at 110 Mt in 2030. A full list of policies included in the announced policy scenario is provided in Appendix B.
Net Zero Vision 1: "Aggressive decarbonization"	
2. Net zero policy	This scenario includes policies currently legislated and announced in the ERP, plus a cap at net zero emissions economy-wide in 2050. This is simulated as an economy-wide cap-and-trade system. The cap starts in 2035 and is phased down linearly to net zero in 2050.
Net Zero Vision 2: "Accelerated oil and gas phaseout"	
3. Net zero with oil and gas production phaseout	This scenario includes policies currently legislated and announced in the ERP, a cap on emissions at net zero in 2050, and the addition of an explicit phaseout of oil and gas production. Oil and gas production is limited by a production cap starting in 2035 and phases down linearly to a 95% reduction from 2015 production levels by 2050.

Land-use offsets

Emission offsets from land-use, land-use change, and forestry (LULUCF) are an exogenous input to the model and assumptions about the offset availability are made in all scenarios. We assume 30 Mt of LULUCF offsets are available Canada-wide in 2030, based on the federal government's Emissions Reduction Plan[10], and 103 Mt of

[8] Government of Canada. (2020). *A Healthy Environment and Healthy Economy*. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

[9] Government of Canada. (2022). *2030 Emissions Reduction Plan – Canada's Next Steps for Clean Air and a Strong Economy*. Available from: https://www.canada.ca/en/environment-climate-change/news/2022/03/2030-emissions-reduction-plan--canadas-next-steps-for-clean-air-and-a-strong-economy.html

[10] Environment and Climate Change Canada. (2022). *2030 Emissions Reduction Plan*. Available from: https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf

offsets are available Canada-wide in 2050, based on a recent report in Science Advances[11].

Table 3: Assumed offsets available from LULUCF in Canada

	2030	2035	2040	2045	2050
LULUCF offsets available in Canada ($MtCO_2$)	30	48	66.5	85	103

2.1.2. Uncertainty analysis

Simulating Canada's economy to 2050 is fundamentally uncertain and results are subject to several key assumptions that must be made when forecasting policy impacts. To account for this, key uncertainties were examined for each policy scenario using sensitivity analysis. Table 4 outlines the sensitivities examined in this analysis. All possible combinations of the sensitivities listed below were examined for each policy scenario.

We refer to the 'intermediate sensitivity' throughout this report. This refers to a sensitivity with intermediate CCS costs, DAC technology unavailable, an intermediate global oil price forecast, and baseline policy implementation in the U.S.

Table 4. Four key uncertainties examined via sensitivity analysis

Sensitivity	Low	Intermediate	High
Technology uncertainty			
1. Availability of DAC	Not available	Not available	Available
2. Cost of CCS and DAC (if available)	Low cost	Intermediate cost	High cost

[11] Drever et al. (2021). Natural Climate Solutions for Canada. *Science Advances, 7(23).* Available from: https://www.science.org/doi/10.1126/sciadv.abd6034

Sensitivity	Low	Intermediate	High
Commodity price uncertainty			
3. Future oil price	Low price forecast	Intermediate price forecast	High price forecast
Policy uncertainty			
4. Level of policy implementation in the U.S.	Baseline policy		Stringent climate policy

Detailed assumptions about the future oil price are provided in the next section, and about DAC and CCS costs are provided in Appendix C.

2.2. Global oil price

What is the price of oil in a net zero future?

The future global price of oil is a key assumption made in this analysis, as the value of this commodity has a significant impact on the cost of phasing out its production in Canada. There is significant uncertainty in what the future global oil price will be, including what it will be in a net zero future. The International Energy Agency (IEA) provides one price forecast for oil under a global net zero scenario.[12] It assumes that in a future in which the world achieves net zero emissions, demand for oil will be significantly reduced, and as a result, so will its price (see Table 5).

It is important to acknowledge that we do not know what the price for oil will be in a net zero future. First, there is uncertainty about whether the world will achieve net zero emissions. This analysis simulates a net zero future for Canada, and accounts for uncertainty in whether the U.S. will also achieve net zero. It makes no assumption about whether the rest of the world will achieve net zero emissions along with Canada. In a future in which Canada (and other countries in the Global North responsible for significant historical emissions, like the U.S.) achieves net zero emissions while some countries in the Global South do not, the price of oil could remain high.

[12] International Energy Agency. (2022). *World Energy Outlook 2022.* Available from: https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

Second, if the world achieves net zero emissions, there is uncertainty in how. It is possible that oil production and consumption is phased out and replaced by other fuels and technologies in order to decarbonize the global economy. It is also possible that we continue to rely on oil and capture and store carbon to achieve net zero emissions. For example, it is possible that more developed countries responsible for significant historical emissions seek to offset historical emissions using negative emission technologies, allowing less developed nations to continue to use fossil fuels. These visions of the net zero future have different implications for future oil demand, and therefore the future price of oil.

Finally, the global oil price is set in a broad geopolitical environment that is constantly changing and is historically uncertain. How this market will unfold between now and 2050 is significantly uncertain.

This is why it is important to account for uncertainty in the future oil price rather than make assumptions about what the price will be as Canada achieves net zero. The Canadian Energy Regulator's[13] low oil price forecast used in this analysis falls in between the IEA net zero scenario and the U.S. Energy Information Administration's (EIA) low oil price forecast (Table 5).[14]

Table 5: WTI oil price forecasts from three sources (2020 USD per barrel)

Forecast	2025	2030	2035	2040	2045	2050
IEA net zero[15]		36		29		24
CER low[16]	40	37	36	36	36	35
EIA low[17]	34	36	40	41	41	43

[13] Canada Energy Regulator. (2021). Canada's Energy Future 2021. Available from: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/index.html

[14] U.S. Energy Information Administration. (2023). *Annual Energy Outlook 2023.* Available from: https://www.eia.gov/outlooks/aeo/

[15] International Energy Agency. (2022). *World Energy Outlook 2022.* Available from: https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

[16] Canada Energy Regulator. (2021). Canada's Energy Future 2021. Available from: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/index.html. Note: to come up with a low oil price forecast, we use the last year the CER released a low oil price forecast (2018) and scale it based on the most recent CER (2021) reference price forecast.

[17] U.S. Energy Information Administration. (2023). *Annual Energy Outlook 2023.* Available from: https://www.eia.gov/outlooks/aeo/

Assumptions in gTech

Table 6 outlines the WTI oil price forecast assumptions used in gTech. We account for uncertainty in this analysis by conducting sensitivity analysis using the Canadian Energy Regulator's oil price forecasts, which include a low price forecast consistent with the IEA's net zero scenario (Table 5 above), as well as other possible oil price outcomes. We simulate all net zero scenarios under a low, intermediate, and high oil price. The intermediate oil price scenario should not be considered the most likely. Rather, all three scenarios should be considered equally as likely and are explored throughout this report as a possible future in which Canada may achieve net zero.

Table 6: WTI oil price forecast assumptions in gTech (2020 USD per barrel)

Sensitivity	2025	2030	2035	2040	2045	2050
Low[18]	39.5	37.1	36.2	35.9	35.6	35.1
Intermediate[19]	68.9	67.8	66.2	65.7	65.1	64.1
High[20]	97.5	93.1	90.9	90.2	89.5	88.0

[18] Canada's Energy Regulatory. (2018). Canada's Energy Future 2018. Available from: https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

[19] Canada Energy Regulator. (2021). Canada's Energy Future 2021. Available from: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/index.html

[20] Canada's Energy Regulatory. (2018). Canada's Energy Future 2018. Available from: https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

3. Results

3.1. Canada's emissions trajectory

Policies announced in Canada's Emissions Reduction Plan (ERP) are projected to lead to a decline in national emissions of 29% from current levels by 2030. Figure 9 shows the range in emissions outcomes in Canada across all announced policy scenarios simulated.

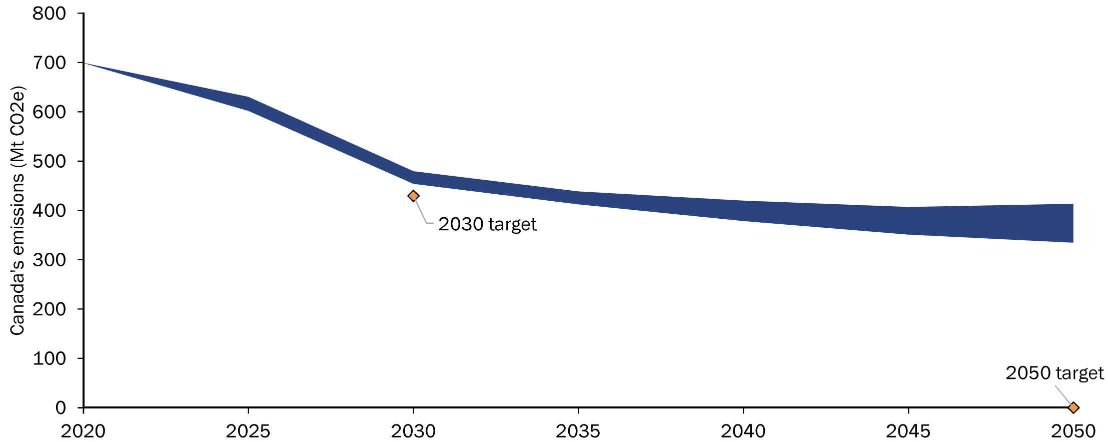
Insight: Canada is not on track to achieve net zero emissions under announced policy

Emissions reductions achieved under announced policy get Canada to within 25-50 Mt of its 2030 emissions target[21]. These reductions are occurring across sectors in response to the range of policies announced in the ERP, including transportation (adoption of electric vehicles and renewable fuels), industry (adoption of CCS, renewable fuels and electrification), and electricity (increase in renewable generation and CCS installed on natural gas generation). Because the ERP policy package is largely comprised of regulatory policies, including zero emission vehicle mandates, low carbon fuel standards, methane regulations and clean electricity regulations, there is a small range in the impact of these policies across scenarios in 2030. There is greater uncertainty in their impact in the longer term (2050).

Beyond 2030, emissions continue to decline under announced policy, by 35% from current levels by 2050. It is clear, however, that greater policy stringency is required to achieve net zero emissions by 2050 in Canada. To achieve its net zero emissions target, Canada must reduce emissions by a further 334-413 Mt from announced policy in 2050. The range in emissions reductions achieved by 2050 is driven by the global oil price, as well as the level of climate policy implementation in the U.S., and the declining cost of key technologies such as CCS (see Section 0 for a description of these uncertainties).

[21] 40-45% reduction in emissions from 2005 levels

Figure 9: Canada's emissions under policies announced in the *2030 Emissions Reduction Plan* (range across all sensitivities)[22]



Insight: There are many different net zero pathways for Canada. Some include continued oil and gas production.

Figure 10 shows emissions by sector in the three policy scenarios simulated in this analysis – announced, net zero and net zero with an explicit phaseout of oil and gas production (see Section 2.1.1 for descriptions of each policy scenario). Results indicate that when net zero policy is simulated without an explicit phaseout of oil and gas production (i.e., the model finds the most cost-efficient path to net zero), some oil and gas production and associated emissions remain in 2050. These emissions are offset by negative emissions including LULUCF offsets, bioenergy with CCS (BECCS), and DAC if available (not available in the intermediate sensitivity shown in Figure 10).

When an oil and gas production phaseout is simulated, virtually no emissions remain from the oil and gas sector in 2050. As a result, fewer negative emissions are needed economy-wide in this scenario, and there is more flexibility for other sectors of the economy with expensive-to-abate emissions (such as heavy-duty transportation) to continue to emit in 2050. This suggests that Canada can achieve net zero emissions with or without continued oil and gas production.

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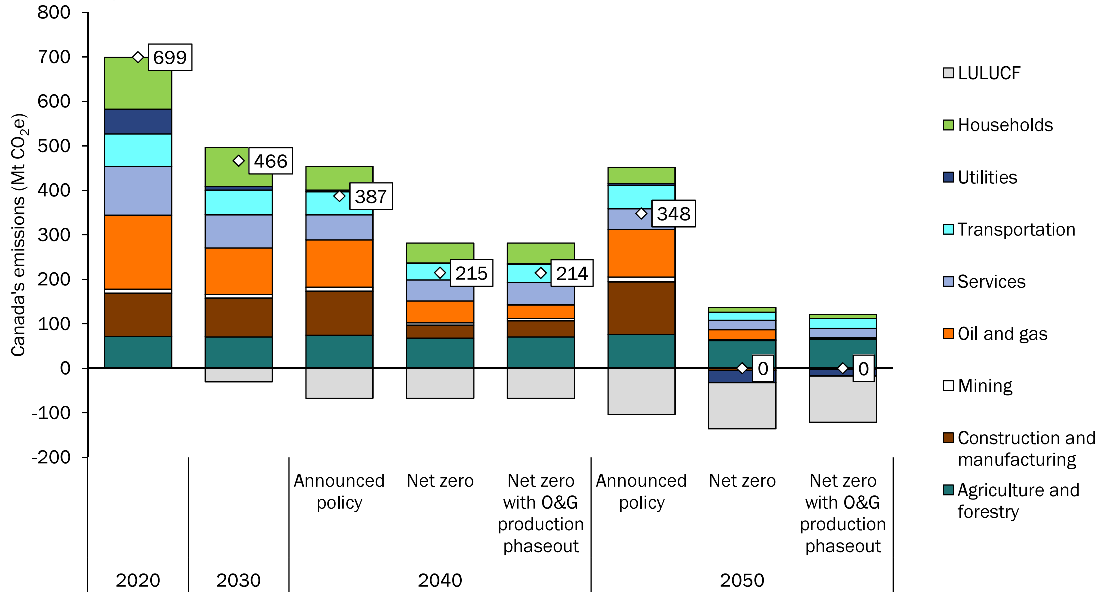
22 Note that this includes policies announced as of October 2022. See Appendix B for additional details.

Figure 10: Canadian emissions by sector in three policy scenarios (intermediate sensitivity)[23]



3.2. Cost of achieving net zero emissions in Canada

The net zero scenarios simulated in this analysis use an emissions cap (i.e., an economy-wide cap-and-trade system) to require net zero emissions by 2050. As such, the shadow carbon price (i.e., the price of carbon credits under the emissions cap) is a measure of the policy stringency required to achieve net zero in each scenario. Note that this is a measure of the policy stringency needed *if* Canada were to implement a cost-efficient market-based mechanism (such as a carbon price or a cap-and-trade system) economy-wide to achieve net zero. This cost is additional to the compliance cost associated with other policies, including currently announced regulatory policies.

Insight: Additional policy to phaseout oil and gas production makes it less costly for other sectors of the economy to achieve net zero while imposing significant additional compliance cost on the oil and gas sector.

Figure 11 presents the shadow carbon price under the emissions cap in each net zero scenario. The solid lines show the shadow price under the economy-wide emissions cap, which indicates that the additional policy stringency required to achieve net zero

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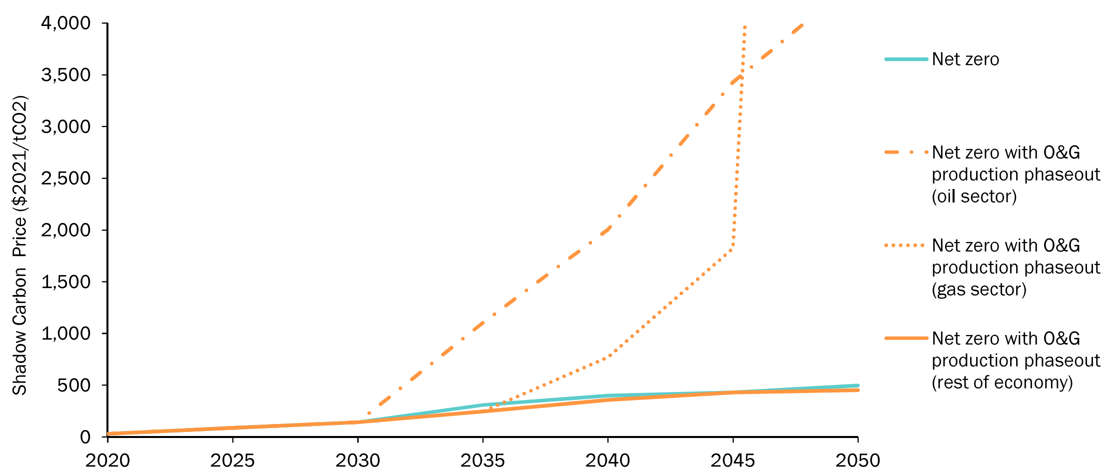
[23] Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

emissions is $307/tCO_{2e}$ in 2035 and $497/tCO_{2e}$ in 2050. When an oil and gas production phaseout is implemented in addition to an economy-wide net zero emission cap, this price is slightly lower: $246/tCO_{2e}$ in 2035 and $452/tCO_{2e}$ in 2050. This is because as oil and gas production is phased out, there are fewer emissions remaining in this sector that need to be offset. As a result, more offsets are available for other sectors of the economy, driving down the economy-wide shadow carbon price.

This does not, however, capture the policy compliance cost of phasing out oil and gas production. The shadow carbon price in this case represents the cost of complying with policy that requires declined production of a valuable commodity. This cost is represented by the dotted lines in Figure 11, which indicate that the cost of achieving net zero in the oil sector is four times greater in 2035 and nine times greater by 2050 in the oil and gas production phaseout scenario relative to the net zero scenario. Costs are double for the gas sector in 2040 and fifty times greater by 2050.

As such, the oil and gas production phaseout makes it marginally (9%) less costly for the rest of the economy to achieve net zero emissions by 2050 but imposes a significantly higher cost on the oil and gas sector to comply with policy in 2050.

Figure 11: Additional climate policy stringency required to achieve net zero emissions in Canada in two policy scenarios (intermediate sensitivity)[24]



It is important to note that the cost of achieving net zero emissions is highly uncertain. Figure 12 provides the range in shadow carbon prices across all sensitivities simulated for each net zero scenario. This indicates that the cost of achieving net zero ranges

24 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

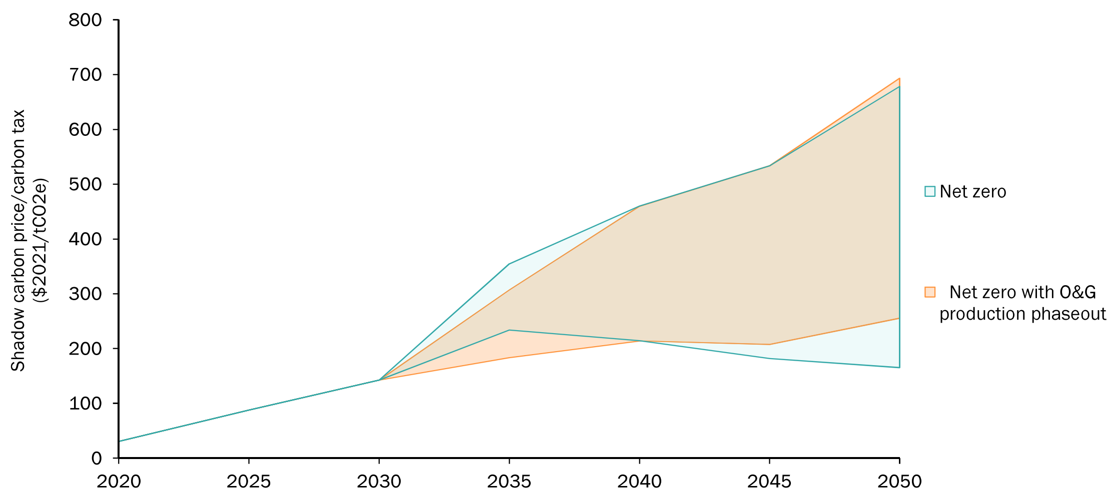
from \$234-\$355/tCO_{2e} in 2035 and from \$165-678/tCO_{2e} in 2050, depending on the assumptions made.

Insight: CCS and DAC technology are crucial to minimize the cost of achieving net zero emissions

The lower end of this range represents a net zero future in which DAC technology is widely available and CCS and DAC costs decline more rapidly over time. This makes it possible to achieve net zero at a lower cost. The upper end of this range is a net zero future in which DAC does not become commercial and CCS costs come down more slowly over time. In this case, it is 76% more expensive to reduce emissions to net zero by 2050 relative to a scenario with low technology costs.

Figure 12 also highlights the significant overlap in potential future shadow prices between the two net zero scenarios. This suggests that explicitly phasing out oil and gas production in addition to net zero policy guarantees a high compliance cost for the oil and gas sector but does not guarantee a lower economy-wide cost of achieving net zero emissions.

Figure 12: Additional climate policy stringency required to achieve net zero emissions in two policy scenarios (range across all sensitivities)



3.3. Economic impacts of two net zero futures for Canada

While the two net zero scenarios simulated in this analysis achieve the same level of emissions reductions by 2050, they have different impacts on the Canadian economy. This section explores how achieving net zero with or without explicitly phasing out oil and gas production impacts Canadian GDP, oil and gas production, employment, and trade.

This section also explores uncertainty in the economic impacts of these two net zero futures. A key uncertainty is the future global oil price, as this assumption has a significant impact on results of this analysis, including economic outcomes for Canada's oil and gas sector and the economy as a whole. Unlike other uncertainties explored in this analysis that are within Canada's control, such as policy implementation or technology cost declines (to some extent), the future global oil price is not. See Section 2.2 for discussion of the global oil price in a net zero future.

3.3.1. Domestic income

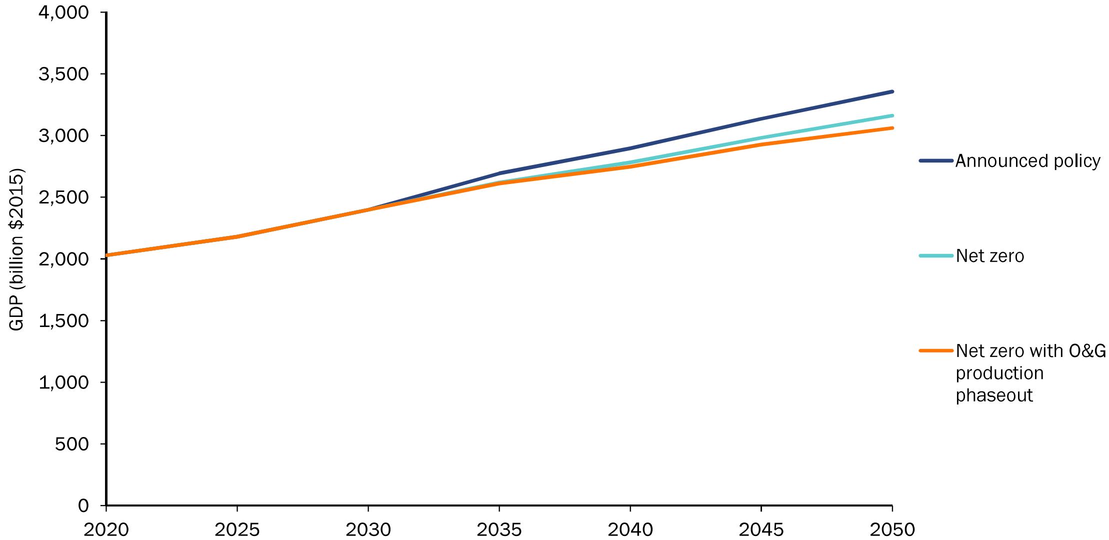
Achieving net zero emissions is a significant challenge and doing so has implications for the growth of Canada's economy, lowering Canada's GDP by $75 billion in 2035 and $196 billion in 2050 relative to announced policy (intermediate sensitivity, Figure 13). The average annual growth rate from 2020 to 2050 is 1.5% under net zero policy, while it is 1.7% under announced policy. Under net zero policy, economic activity is lower across all sectors except for electricity, hydrogen and biofuels production.

Insight: Additional policy to phaseout oil and gas production increases the negative economic impact of net zero policy

A net zero future where oil and gas production is explicitly phased out lowers Canada's GDP by an additional $6 billion in 2035 and $100 billion in 2050 (intermediate sensitivity). An oil and gas production phaseout exacerbates the negative GDP impact of net zero policy by 50% while providing no additional emissions reductions.

Similarly, implementation of net zero policy reduces investment in the Canadian economy, by $40 billion in 2030 and $28 billion in 2050 relative to announced policy (intermediate sensitivity). In 2050, 35% of this reduction in investment is in the oil and gas sector. A net zero future with an explicit phaseout of oil and gas production reduces investment in the Canadian economy by a further $45 billion in 2050. $33 billion of this, or 75% of this reduction in investment occurs in the oil and gas sector.

Figure 13: Canada's GDP in three policy scenarios (intermediate sensitivity)[25]



Insight: Economic impacts of net zero policy depend on the future price of oil, DAC availability and the extent to which CCS costs decline over time

The impact of net zero policy on Canadian GDP is sensitive to several assumptions including the global oil price, DAC availability and policy implementation in the U.S. In a future where the global oil price is high, the GDP impact of an explicit oil and gas production phaseout is exacerbated (see Figure 14). While implementation of net zero policy results in a slightly smaller GDP impact in this scenario (GDP is $60 billion lower in 2035 and $161 billion lower in 2050 relative to announced policy), the GDP impact of explicitly phasing out oil and gas production is greater (GDP is reduced by an additional $41 billion in 2035 and $203 billion in 2050 relative to net zero policy).

In a future where there is greater global demand for oil, there is a greater incentive for oil and gas production, which in turn leads to greater GDP growth in Canada under announced and net zero policy. As a result, there are greater economic consequences to constraining production of a more valuable commodity and implementation of an oil and gas production phaseout more than doubles the negative GDP impact of net zero policy, without providing any additional emissions benefit.

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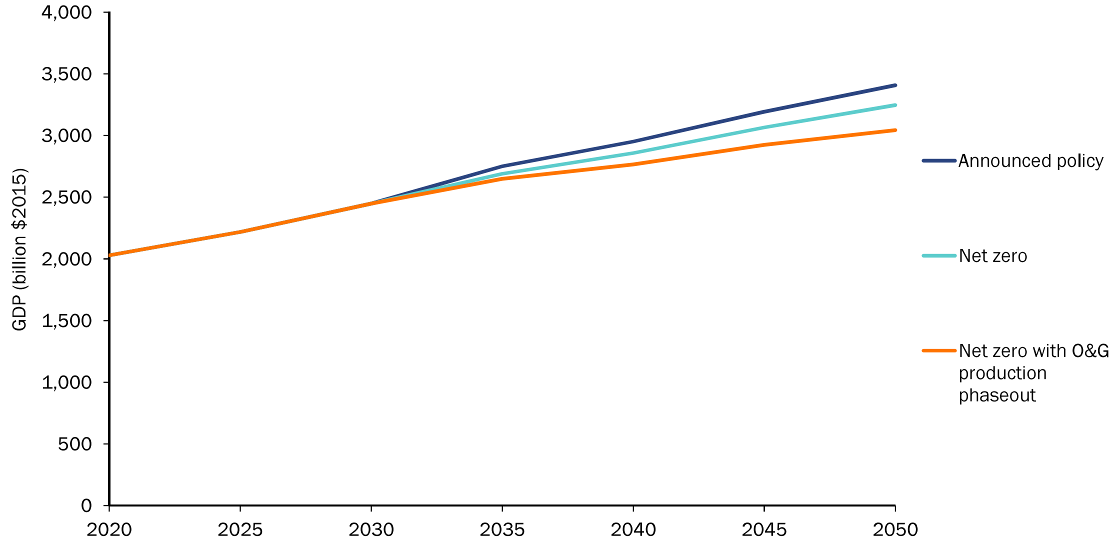
[25] Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

Figure 14: Canada's GDP in three policy scenarios (high global oil price forecast)[26]



Similarly, in a future where DAC technology is widely available, this technology can be used to offset oil and gas sector emissions and it is possible to continue oil and gas production while complying with net zero policy. If DAC is available, 29 Mt is adopted in 2040 and 187 Mt in 2050 in the net zero policy scenario (intermediate sensitivity). Continued oil and gas production as a result of DAC availability leads to higher economic growth in the net zero policy scenario, such that Canada's GDP is $97 billion higher in 2050 than when DAC is not available.

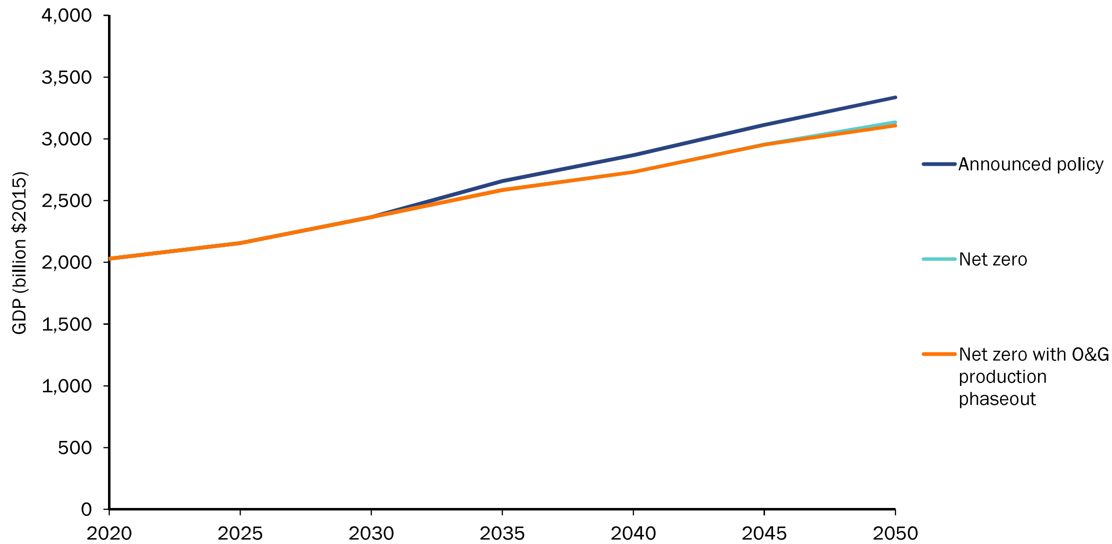
When oil and gas production is explicitly phased out, less DAC is needed – 9 Mt in 2040 and 10 1Mt in 2050. In this case, implementing an oil and gas production phaseout when DAC is available increases the negative GDP impact of net zero policy by $5 billion in 2035 and $160 billion in 2050. This suggests that if DAC technology becomes widely available, the GDP impact of net zero policy in Canada is lower, but the GDP impact of an oil and gas production phaseout is higher.

A future in which the impact of net zero policy and the oil and gas production phaseout are most similar is one with a low global oil price (see Figure 15). In this case, there is little demand for Canadian oil and oil and gas production declines as a result. Additionally, the oil and gas that remains is less valuable. In this scenario, achieving net zero emissions lowers Canadian GDP by $202 billion in 2050 relative to announced policy, and implementing an explicit phaseout of oil and gas production reduces GDP by an additional $27 billion. The economic impact of explicitly phasing

[26] This sensitivity includes a high global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

out oil and gas production is smaller in this scenario as the low oil price already incentivizes declines in production and diversification of Canada's economy.

Figure 15: Canada's GDP in three policy scenarios (low global oil price forecast)[27]



The impact of explicitly phasing out oil and gas production is even smaller if CCS costs are high in addition to a low global oil price. In this case, not only is there low demand for oil production, incentivizing production declines under net zero policy, but decarbonizing oil and gas production (and other industry) is more expensive. Because of this, reducing oil and gas production is one of the most cost-efficient ways to achieve net zero emissions, even in the absence of a production phaseout. In this scenario, the GDP impact of net zero policy is $215 billion in 2050 relative to announced policy, and explicitly phasing out oil and gas production costs the economy an additional $22 billion in 2050.

Regional impacts

Achieving net zero emissions by 2050 has negative GDP impacts across all Canadian regions. However, in provinces with an economy more reliant on oil and gas production, complying with net zero policy results in a decline in oil and gas production, and therefore a greater decline in economic growth relative to the Canadian average.

[27] This sensitivity includes a low global oil price forecast, Intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

Insight: Economic impacts of net zero policy are more significant in oil and gas producing regions

Table 7 indicates that Canada's economy grows at an average annual rate of 1.5% under net zero policy, while an oil producing province like Alberta grows at a lower rate of 1.3% per year, and a non-oil producing province like Ontario grows at a higher rate of 1.6% per year in the intermediate sensitivity.

Economic growth rates under net zero policy are dependent on the global oil price in all regions, though oil price has the most significant impact on oil-producing regions. In Alberta, the growth rate ranges from 1.0-1.6% under net zero, while it stays relatively constant at 1.6% in Ontario (Table 7).

Table 7: Compound annual growth rate (CAGR) from 2020-2050 in three policy scenarios, three regions, and three oil price forecasts[28]

Region/Oil price	Announced policy	Net zero	Net zero with O&G production phaseout
Canada			
Low oil price	1.67%	1.46%	1.43%
Intermediate oil price	1.69%	1.49%	1.38%
High oil price	1.74%	1.58%	1.36%
Alberta			
Low oil price	1.39%	1.04%	0.93%
Intermediate oil price	1.67%	1.26%	0.79%
High oil price	1.89%	1.62%	0.67%
Ontario			
Low oil price	1.75%	1.60%	1.60%
Intermediate oil price	1.73%	1.58%	1.56%
High oil price	1.73%	1.60%	1.55%

In a net zero future where oil and gas production is explicitly phased out, GDP impacts are especially large in oil and gas producing regions. In Alberta, the impact of net zero policy relative to announced policy is $60 billion in 2050, a third of the total Canada-wide impact of achieving net zero emissions. The impact of explicitly phasing out oil and gas production in addition to net zero policy increases the GDP impact by another $60 billion, doubling the negative GDP impact of net zero policy (Figure 16). However, in a non-oil producing province like Ontario, implementation of an oil and gas

[28] These sensitivities include Intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

production phaseout has a smaller impact, increasing the cost of net zero policy by 11% in 2050.

These impacts are also sensitive to oil price assumptions, with implementation of an oil and gas production phaseout having a greater economic impact relative to net zero policy in a high oil price scenario and a smaller economic impact in a low oil price scenario (Table 8).

In a net zero future where oil production is explicitly phased out, all regions experience the highest economic growth under a low oil price forecast (Table 7 above). If the global oil price is low, Canada's economy begins to diversify in earlier years, investing in other sectors of the economy as oil and gas production is less profitable. This makes the economy more resilient to a phaseout of oil production by 2050.

Figure 16: Alberta's GDP in three policy scenarios (intermediate sensitivity)[29]

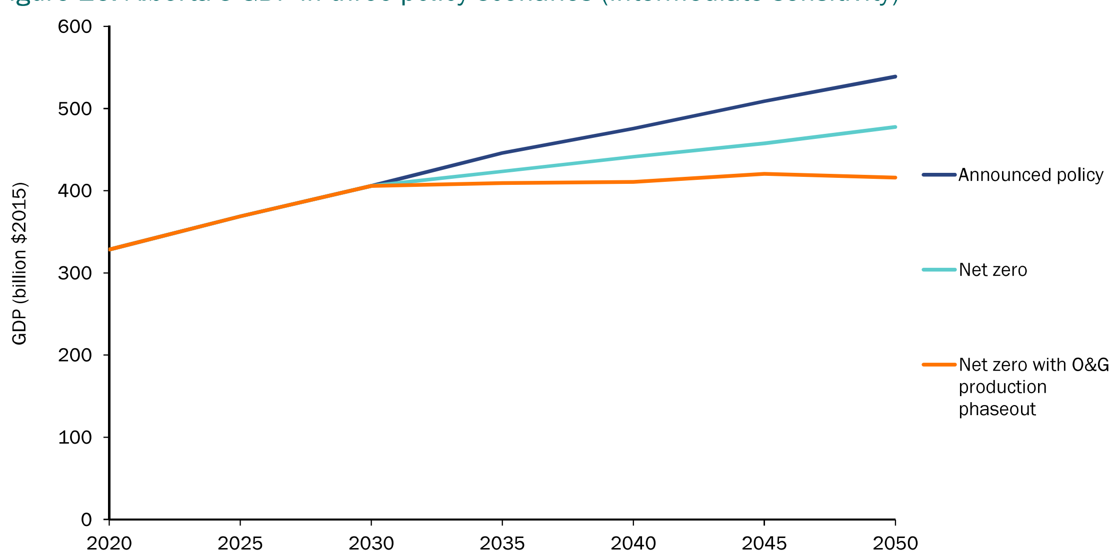


Table 8: Alberta's GDP in three policy scenarios and under three oil prices[30]

Oil price forecast	Unit	Announced policy	Net zero	Net zero with O&G production phaseout
Low	$2015 billion	$497	$448	$434
Intermediate	$2015 billion	$539	$478	$416
High	$2015 billion	$575	$531	$402

29 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

30 These sensitivities include Intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

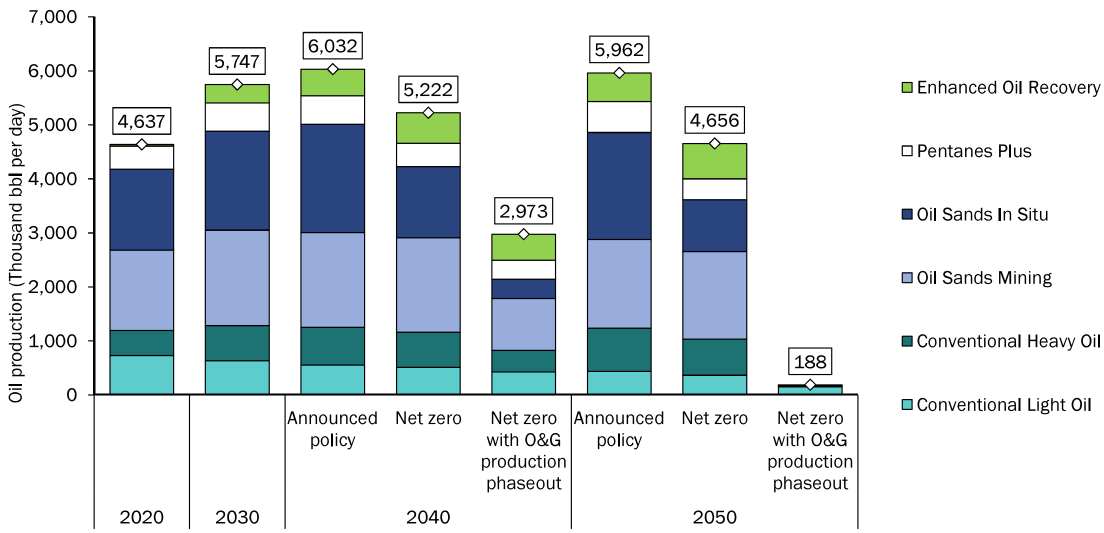
3.3.2. Oil and gas production

Achieving net zero emissions by 2050 using a cost-efficient net zero emissions cap leads to a reduction in oil and gas production in Canada. Under intermediate assumptions, net zero policy results in 13% less oil production in 2040 and 22% less oil production in 2050 relative to announced policy. However, there remains over 4.5 million barrels of oil produced per day in 2050 in this scenario (Figure 17).

The greatest production declines occur in the oil sands in situ sector, where production is 52% lower in 2050 under net zero relative to announced policy. Production is also lower in the conventional oil sector (16% in 2050 relative to announced policy). Declines in oil production are to some extent offset by an increase in enhanced oil recovery (EOR). The price for CO_2 is lower in a net zero future, as more CCS is deployed in response to greater policy stringency, incentivizing the use of CO_2 for EOR and resulting in oil production using EOR being 23% higher in 2050 under net zero policy relative to announced policy.

In the net zero scenario with an explicit phaseout of oil and gas production, oil production is forced to decline to 188,000 barrels per day in 2050 (Figure 17).

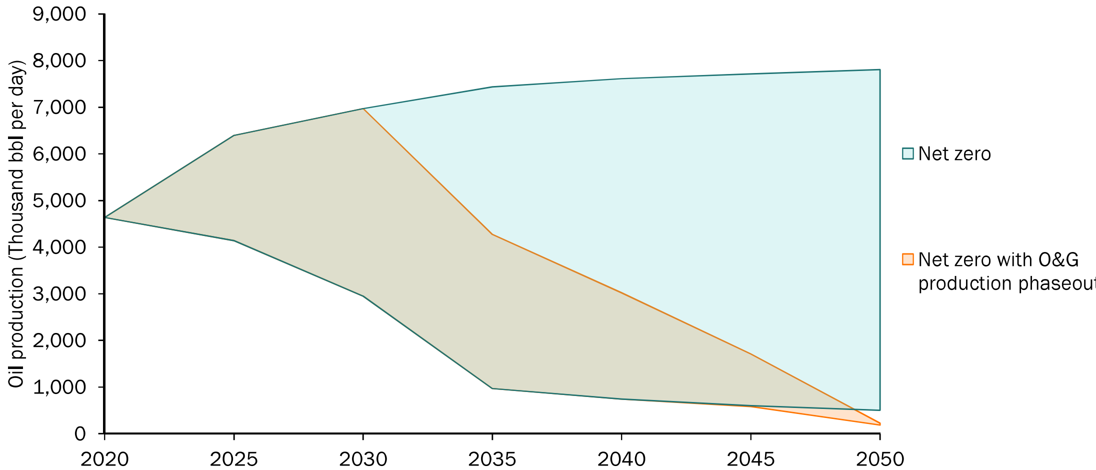
Figure 17: Canadian oil production by type in three policy scenarios (intermediate sensitivity)[31]



[31] Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

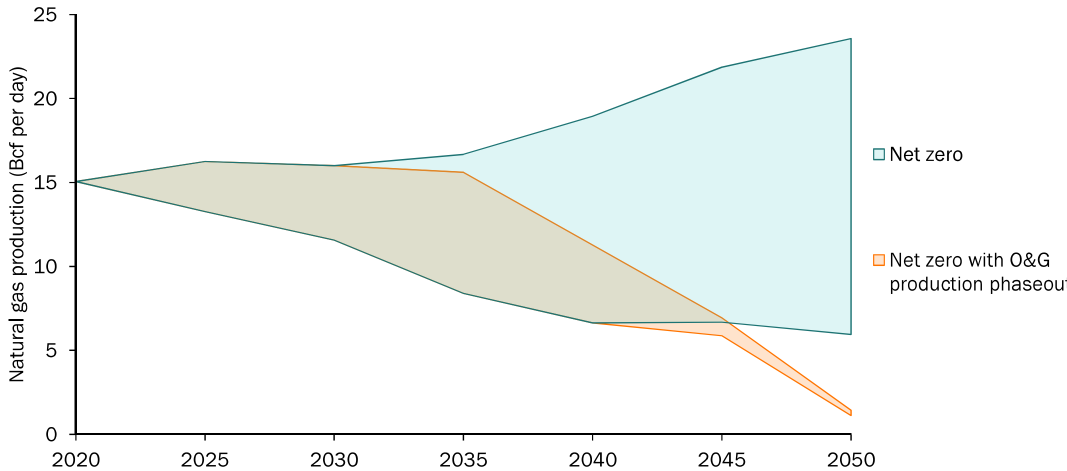
When accounting for all sensitivity scenarios simulated, there is significant uncertainty in the impact of net zero policy on the oil and gas sector. Figure 18 presents oil production across all net zero scenarios simulated. Production ranges from 502,000 to 7.8 million barrels per day under net zero in 2050, The range is driven by the global oil price and the extent to which CCS and DAC costs decline over time. When oil and gas production is explicitly phased out, the range is significantly narrower as a result of the policy design.

Figure 18: Canadian oil production in two policy scenarios (range across all sensitivities)



Natural gas production follows a similar trend, as shown in Figure 19. Under intermediate assumptions and net zero policy, natural gas production declines from 15 billion cubic feet (Bcf) per day in 2015 to 13 Bcf in 2035 and 14 Bcf in 2050. In 2050, production ranges from 6-24 Bcf per day with the range driven by the global oil price and the extent to which CCS and DAC costs decline over time. When oil and gas production is explicitly phased out, this range is significantly narrower as a result of the policy design.

Figure 19: Canadian natural gas production in two policy scenarios (range across all sensitivities)



Insight: Additional policy to phaseout oil and gas production guarantees a negative economic outcome for the oil and gas sector that is not guaranteed by net zero policy

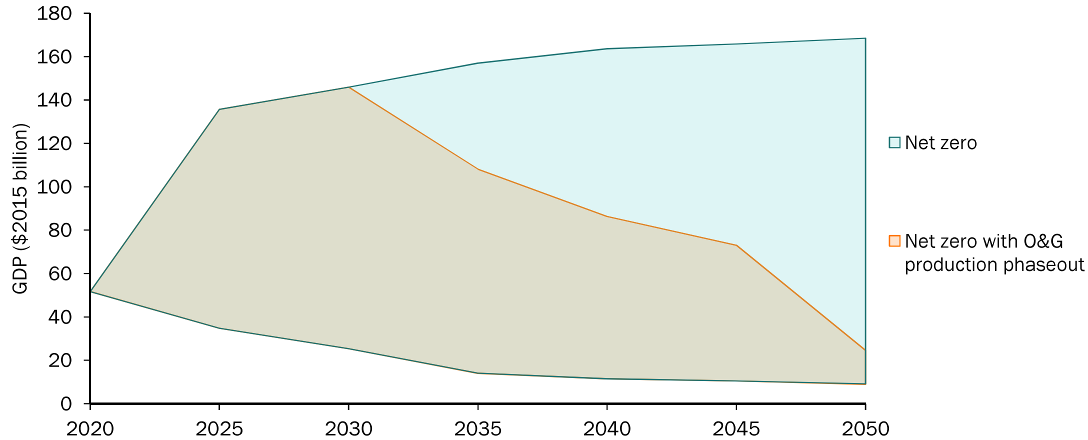
Changes in production in turn impact oil and gas sector GDP. Figure 20 presents Canada's oil and gas sector GDP across all net zero scenarios simulated. Under net zero policy, GDP in the oil and gas sector ranges from an 82% decline to a 226% increase from 2020 to 2050. When an oil and gas production phaseout is implemented, however, this range is much smaller in 2050 (52-83% decline in GDP by from 2020 levels by 2050).

In a scenario in which DAC is unavailable, CCS costs are high, and the global oil price is low, Canada's oil and gas sector GDP fares similarly under both net zero scenarios. This is because oil production is low under net zero policy in this scenario (502,000 barrels per day in 2050 - 90% lower than under intermediate assumptions) as there is less demand for Canadian oil and DAC is not available to offset emissions.

However, If DAC is available at low cost, CCS costs decline faster than expected, and the global oil price is high, Canada's oil and gas sector GDP is $134 billion higher in 2050 in a net zero future where oil and gas production is not explicitly phased out compared to a net zero future with an explicit oil and gas production phaseout. This is because oil production is high (7.8 million barrels per day in 2050) in this net zero scenario due to high demand for Canadian oil coupled with low-cost DAC offsets.

In other words, explicitly phasing out oil and gas production guarantees a negative economic outcome for the oil and gas sector, which is not guaranteed by net zero policy on its own.

Figure 20: Canada's oil and gas sector GDP in two policy scenarios (range across all sensitivities)



3.3.3. Employment

The number of jobs in Canada grows in all policy scenarios simulated as Canada's population and economy grow from 2020 to 2050. Jobs increase less in the net zero scenarios relative to the announced policy scenario, as indicated in Figure 21. As a result of lower economic growth relative to announced policy, implementation of net zero policy leads to 507,000 fewer jobs in 2035 and 874,000 fewer in 2050 in Canada. Although some sectors of the economy experience growth under net zero policy, including the biofuels, electricity, hydrogen, and carbon capture sectors, economy-wide employment is lower with losses occurring across the economy, from services to construction, manufacturing, agriculture, forestry and transportation.

Explicitly phasing out oil and gas production in addition to net zero policy exacerbates the negative impact of net zero policy on employment by 26%, with 230,000 fewer jobs in 2050 relative to the net zero scenario. Employment impacts of the oil and gas production phaseout are more weighted in the oil and gas sector, with 35% of employment impacts occurring in this sector, and the rest spread across other sectors of the economy including services, transportation, construction and manufacturing due to downstream economic impacts of a smaller oil and gas sector.

Employment impacts of policy are subject to key uncertainties, similar to the GDP results presented in Section 3.3.1, including DAC availability and the cost of carbon capture. If DAC and CCS technologies are available at low cost, the impact of net zero policy on Canadian jobs is smaller – instead of 874,000 fewer jobs in 2050 relative to announced policy, we see 235,000 fewer. This is driven by an increase in jobs in the DAC sector (79,000) and a smaller decline across other sectors of the economy due to the less costly abatement options allowing for greater economic growth under net zero.

A net zero future with an oil and gas production phaseout exacerbates negative employment impacts in a low-cost CCS and DAC scenario, leading to an additional 501,000 fewer jobs in 2050 relative to a net zero future without an explicit oil and gas production phaseout.

Figure 21. Canadian jobs in three policy scenarios (intermediate sensitivity)[32]

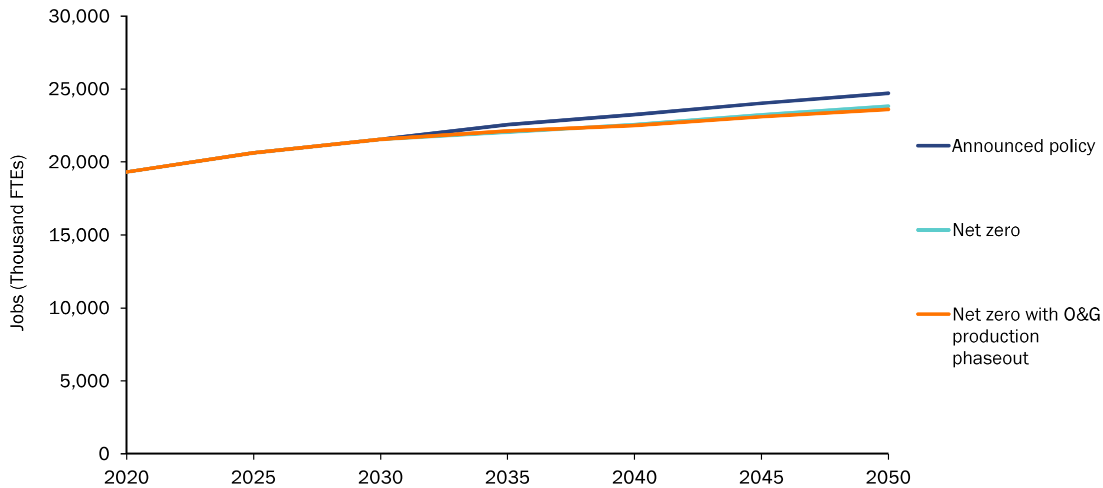


Table 9: Canadian jobs in thousand of fulltime equivalents in 2050 in three policy scenarios and oil prices[33]

Oil price forecast	Unit	Announced policy	Net zero	Net zero with O&G production phaseout
Low	Thousand FTEs	24,769	23,823	23,723
Intermediate	Thousand FTEs	24,709	23,835	23,606
High	Thousand FTEs	24,703	23,981	23,581

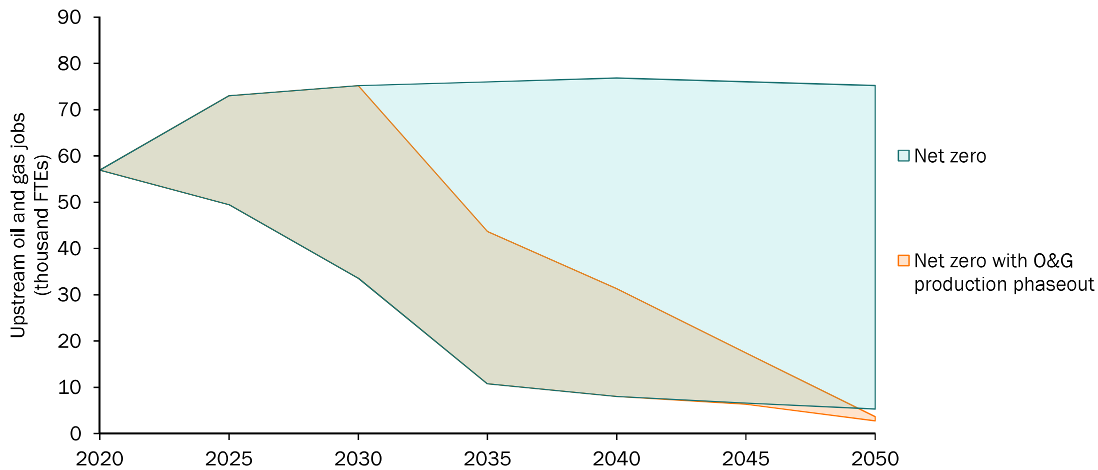
A decline in demand for oil and gas production as a result of net zero policy leads to a reduction in jobs in the oil and gas sector by 12,000 full time equivalents in 2050 (see Figure 22). The most significant job losses occur in the in-situ oil sands, as this is the most emissions intensive sector, with significant losses also occurring in the natural gas and conventional heavy oil sectors.

32 Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

33 These scenarios assume intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

Implementation of an oil and gas production phaseout in addition to net zero policy leads to an additional 39,000 job losses in 2050, increasing the employment impact of net zero policy on this sector by more than 3 times.

Figure 22: Canadian upstream oil and gas jobs in three policy scenarios (range across all sensitivities)



3.3.4. Trade balance

Implementation of net zero policy can have important implications for Canada's trade, particularly oil and gas exports. Figure 23 presents Canada's imports and exports under announced policy and two net zero futures. It separates trade of oil and gas from all other commodities and services, including refined petroleum products, agricultural products, wood products, transportation, chemicals, metals, minerals, machinery, manufacturing goods and other energy such as electricity, biofuels and hydrogen.

Insight: Additional policy to phaseout oil and gas production leads to a reduction in Canada's net exports.

In 2050, net zero policy reduces Canada's trade balance by $36 billion[34] relative to announced policy, including a reduction in net exports of oil and natural gas products and most other products, such as agriculture and wood products as a result of a smaller Canadian economy in a net zero future.

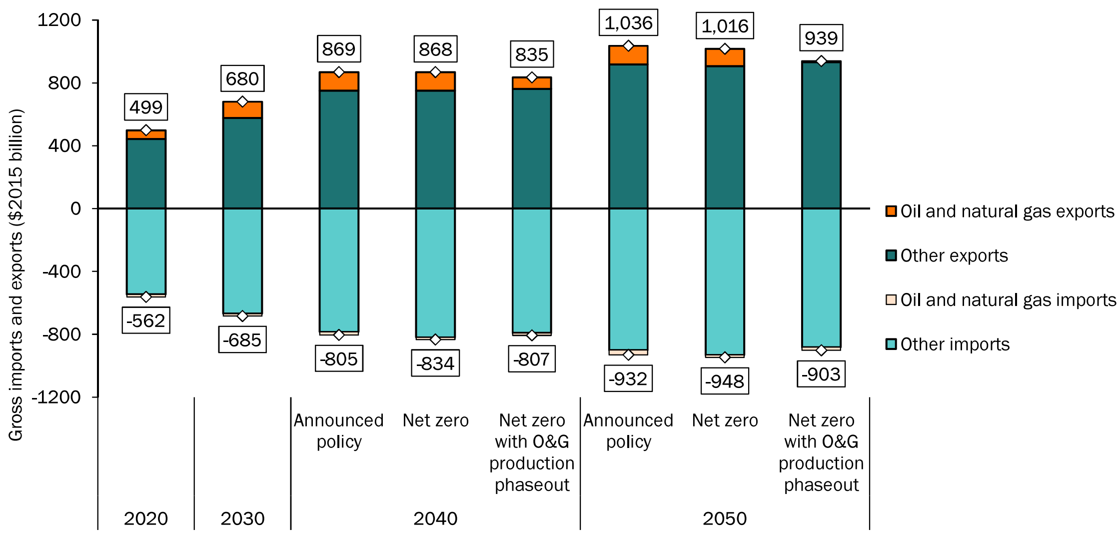
When an oil and gas production phaseout is implemented, the impact of net zero policy on Canada's trade balance is more significant. Net exports are reduced by an additional 33 billion relative to net zero policy in 2050. Canada is no longer a net

[34] All trade balance numbers are presented in $2015

exporter of oil and gas in this scenario but is a net importer of $14 billion of oil and gas. Overall, this reduction in net exports under the production phaseout accounts for a third of the total GDP impact of this policy.

This reduction in oil and gas exports is partially offset by an increase in other exports – wood products, agricultural products and services, as well as a reduction in total imports, as Canada's economy is smaller in this scenario. However, implementation of an oil and gas production phaseout leads to a significant decline is Canadian net exports by 2050 relative to a net zero future without an explicit oil and gas production phaseout.

Figure 23: Canada's gross imports and exports in three policy scenarios (intermediate sensitivity)[35]



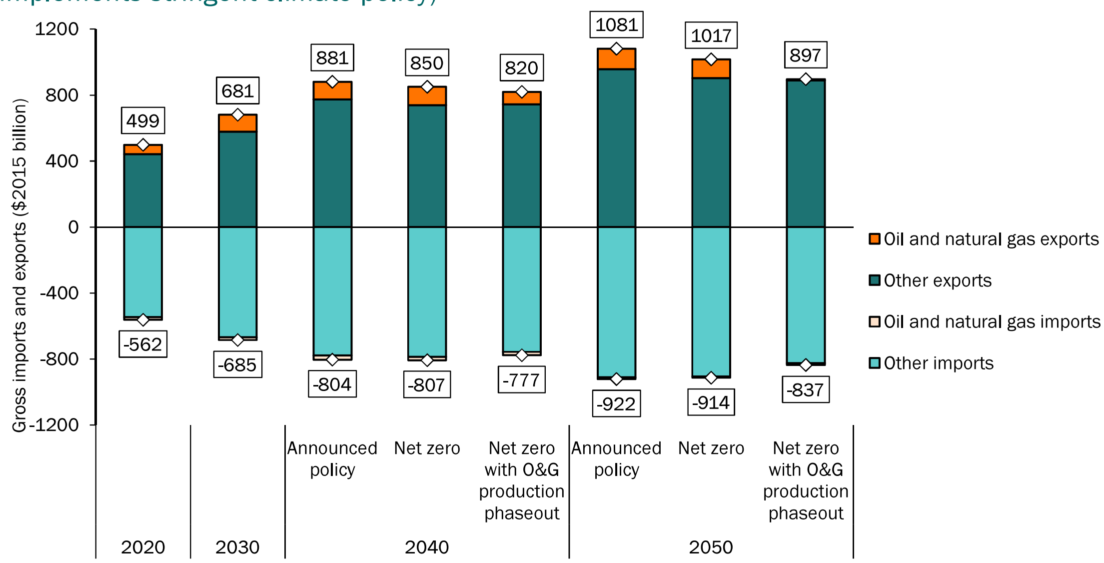
Impacts of net zero policy on Canada's trade balance depend on the assumption made about climate policy implementation in the U.S. When it is assumed that the U.S. implements stringent climate policy along with Canada, Canada's net exports are higher in all policy scenarios as Canadian industries become more competitive as the U.S. industries also become subject to emissions reduction requirements.

However, the impact of net zero policy on Canada's overall trade balance is greater (reduction in net exports of $57 billion in net zero relative to announced policy in 2050). Similarly, phasing out oil and gas production in addition to implementing net zero policy impacts Canada's trade balance more when the U.S. also implements

[35] Intermediate sensitivity refers to an intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and baseline policy in the U.S.

stringent climate policy, reducing the overall trade balance by $99 billion in 2050 relative to announced policy ($69 billion reduction when the U.S. does not implement stringent climate policy). Additionally, Canada is a net importer of $5 billion worth of oil and natural gas in this scenario.

Figure 24: Canada's gross exports and imports in three policy scenarios (U.S. implements stringent climate policy) [36]



36 This scenario assumes intermediate global oil price forecast, intermediate CCS costs, DAC unavailable, and stringent climate policy in the U.S.

4. Key Insights

Results of this analysis provide four key insights, summarized below.

Insight 1: Canada is not on track to achieve net zero emissions under announced policy.

Reductions achieved under announced policy get Canada to within 25-50 Mt of its 2030 emissions target. To achieve its 2050 net zero target, Canada must reduce emissions by a further 334-413 Mt from announced policy in 2050.

Insight 2: There are many different net zero pathways for Canada. Some include continued oil and gas production.

When net zero policy is simulated without an explicit phaseout of oil and gas production (i.e., the most cost-efficient path to net zero), some oil and gas production and associated emissions remain in 2050. These emissions are offset by negative emissions including LULUCF offsets, BECCS, and DAC if available. This suggests that Canada can achieve net zero emissions with or without continued oil and gas production. Continued oil and gas production in Canada depends on factors within our control (like policy implementation) but also factors outside of our control (i.e., the global oil price). Whether there is continued international demand for Canadian oil, and the value of this commodity in a net zero future, is uncertain.

Insight 3: Different pathways to net zero have different economic implications for Canada. Additional policy to phaseout oil and gas production:

3a. Makes it marginally less costly for other sectors of the economy to achieve net zero while imposing significant additional compliance cost on the oil and gas sector.

When an oil and gas production phaseout is implemented in addition to net zero policy, the shadow carbon price is 9% lower in the rest of the economy in 2050 relative to a scenario in which oil and gas production is not constrained. However, the cost of achieving net zero is four times higher in the oil sector and 50 times higher in the gas sector when oil and gas production is explicitly phased out.

3b. Increases the negative economic impact of net zero policy.

Implementation of net zero policy leads to a reduction in Canada's GDP of $196 billion in 2050 relative to announced policy under intermediate assumptions. A net zero future where oil and gas production is explicitly phased out is more costly, lowering GDP by an additional $100 billion in 2050. In this case, the oil and gas production phaseout increases the negative GDP impact of net zero policy by 50% while providing no additional emissions reductions. The magnitude of the impact of an oil and gas production phaseout is sensitive to oil price assumptions.

3c. Guarantees a negative economic outcome for the oil and gas sector that is not guaranteed by net zero policy.

Under net zero policy, GDP in the oil and gas sector ranges from an 82% decline from 2020 to 2050 to a 226% increase, depending on the global price of oil, the availability of DAC and the cost of CCS. When an oil and gas production phaseout is implemented, however, this range is much smaller in 2050 – a 52-83% decline in GDP from 2020 levels. This suggests that an oil and gas production phaseout guarantees a negative economic outcome for the oil and gas sector, which is not guaranteed by net zero policy on its own.

3d. Leads to a reduction in Canada's net exports.

Implementation of net zero policy reduces Canada's trade balance by $36 billion in 2050 relative to announced policy. When an oil and gas production phaseout is implemented, Canada is no longer a net exporter of oil and gas products and instead becomes a net importer of these products, resulting in an additional 86% ($33 billion) decline in net exports in 2050.

Insight 4: The cost of achieving net zero emissions in Canada is uncertain and is not felt equally across regions.

4a. CCS and DAC technology are crucial to minimize the cost of achieving net zero emissions.

The cost of achieving net zero emissions in Canada ranges from $165-$678/tCO$_{2e}$ in 2050 depending on the assumptions made. If DAC technology is not commercial and CCS costs come down slowly over time, it is 76% more expensive to reduce emissions to net zero than a future in which DAC and CCS are available at low cost.

4b. Economic impacts of net zero policy depend on the future price of oil, DAC availability and the extent to which CCS costs decline over time.

Implementation of net zero policy has a smaller impact on Canadian GDP relative to announced policy if the global oil price is high or if DAC is available. In a future where there is more demand for Canadian oil (i.e., the global oil price is high) or it is less costly for the oil and gas sector to reduce emissions (i.e., DAC is available or CCS costs are low), there are greater economic consequences to constraining production of oil and gas. In this case, implementing an oil and gas production phaseout doubles the negative GDP impact of net zero policy in 2050.

On the other hand, if the future oil price is low, DAC technology is not available, and the cost for CCS technology is high, reducing oil and gas production is one of the most cost-efficient ways to achieve net zero emissions, even in the absence of a production phaseout. In this case, addition of an oil and gas production phaseout has a smaller impact on Canadian GDP.

4c. Economic impacts of net zero policy are more significant in oil and gas producing regions.

Achieving net zero emissions by 2050 has negative GDP impacts across all Canadian regions, but the impacts are most significant in oil producing provinces. Alberta, for example, accounts for a third of the total Canada-wide impact of net zero policy. The impact of an oil and gas production phaseout in addition to net zero policy doubles the negative GDP impact of net zero policy in this region, while in a non-oil producing province like Ontario, implementation of the production phaseout has a significantly smaller impact, increasing the cost of net zero policy by 11% in 2050.

5. Limitations and opportunities for future research

General limitations of forecasting

gTech is the most comprehensive model available for forecasting the techno-economic impacts of climate policy in Canada. Its representation of technological change, macroeconomic dynamics and fuels markets make it ideally positioned to simulate the impacts of achieving net zero emissions in Canada. However, no model, including gTech, can predict the future.

Despite using the best available forecasting methods and assumptions, the evolution of Canada's energy economy is uncertain. Forecasting is subject to two main types of uncertainty.

First, all models are simplified representations of reality. The gTech model is, effectively, a series of mathematical equations that are intended to forecast the future. This raises key questions: "are the equations selected a good representation of reality?" and "do the equations selected overlook important factors that may influence the future?"

The use of computable general equilibrium models (like gTech) is well founded in the academic literature. In addition, Navius undertakes significant efforts to calibrate and back-cast the model to ensure that it captures key dynamics in the energy-economic system.

However, gTech does not account for every dynamic that will influence technological change. For example, household and firm decisions are influenced by many factors, which cannot be fully captured by even the most sophisticated model. The inherent limitation of energy-economy forecasting is that virtually all projections of the future will differ, to some extent, from what ultimately transpires.

Second, the assumptions used to parameterize the model are subject to uncertainty. These assumptions include, but are not limited to, oil prices, improvements in labour productivity and a stable climate. If any of the assumptions used prove incorrect, the resulting forecast could be affected. Some of these inherent uncertainties have been explored using a sensitivity analysis, as described in Section 0. Future analysis could be conducted to investigate sensitivities that were not considered in this analysis, such as the cost of biofuels, hydrogen, renewable electricity generation and storage technologies, or the cost of electric vehicles.

Labour mobility limitations in gTech

An important limitation of this analysis is the labour mobility assumptions made in gTech. gTech disaggregates labour by wage/skill class (low, medium, high, and very high skilled labour). The model assumes that labour is fully mobile within wage classes within a province. For example, if there is a significant decline in the oil and gas sector in Alberta, that results in a decline in jobs available in this sector. gTech will assume that workers previously employed in the oil and gas sector can find a job in a different sector within the same wage class within Alberta. This may underestimate the challenges associated with a declining oil and gas sector, such as relocation costs, retraining costs, and periods of unemployment between jobs.

On the other hand, gTech also assumes that labour is immobile between provinces. If there is a significant decline in the oil and gas sector in Alberta, workers from this sector must find alternative employment within Alberta and do not have the ability relocate to a different province that may have better job prospects. This underestimates the impacts of a declining oil and gas sector on oil and gas producing regions. In reality, labour is partially mobile between provinces, so Alberta may experience a loss in labour force to other regions in Canada under a scenario in which oil and gas production declines.

More detailed representation of impacts associated with retraining, skill building, relocation, unemployment and regional migration under strong climate policy is a possible piece of future analysis. Without accounting for these impacts, this analysis is likely underestimating the economic impacts of an oil and gas production phaseout in oil and gas producing regions, and possibly Canada-wide.

Bitumen beyond combustion

Another limitation of this analysis is that it does not account for the comparative advantage of heavier grades of crude oil (like bitumen) in producing non-combustion commodities for which demand will remain in a net zero future – known as “bitumen beyond combustion”.

In a net zero future, there is a reduction in demand for lighter grades of crude oil as internal combustion engine vehicles are replaced with zero-emission vehicles. However, demand for non-combustion products like asphalt and lubricants (made from heavier ends of the barrel) is likely to remain. Heavy crudes (like bitumen) have a comparative advantage producing the heavier ends of the barrel and therefore non-combustion commodities like asphalt. When accounting for this advantage, it is likely that the oil sands sector is more resilient to net zero policy and conventional oil less resilient. If accounted for, this dynamic could impact the results of this analysis, making an explicit phaseout of oil and gas production more expensive for the oil sands sector and less expensive for the conventional oil sector in a net zero future.

Economic assumptions of note

An important assumption of note for this analysis is that all transactions between all regions in the model (including between Canada and the rest of the world, and between provinces within Canada) are balanced. This means that money transferred into a region is equal to money transferred out of a region in every scenario and every year. This means, for example, that if Canada runs a greater trade deficit (i.e., exports decrease relative to imports), another transfer will balance this deficit, such as a reduction in corporate profits transferred abroad or a reduction in Canadian savings invested outside of Canada.

Another key assumption is the calculation of GDP in a net zero future. Constant income GDP is often used as a measure of domestic income. This is calculated from the model base year, 2015. However, there are significant challenges with reporting GDP based on constant base year prices in a net zero emission future. The two main challenges are:

1. Large price changes are induced by climate policy relative to 2015 (e.g., lithium).

2. New commodities and sectors (e.g., hydrogen and offset credits produced by direct air capture) emerge in response to deep emission reductions. These commodities did not have prices in 2015 (the model base year for GDP accounting).

As such, reporting GDP based on constant 2015 prices becomes increasingly less meaningful as we move into the future. Historically, this issue has been addressed by Statistics Canada by re-basing their measure of constant and chained GDP every few years. Instead of re-basing our GDP every year, we developed an approach for calculating a “deflated” GDP so we can provide a consistent measure of real GDP until 2050. More detail about this calculation is provided in Appendix D.

Appendix A: Introduction to gTech

Canada's energy-economy is complex. Energy consumption, which is the main driver of anthropogenic GHG 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 net zero target by mid-century will require strengthening existing policies and/or implementing new policies that result in additional emission reduction activities.

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

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

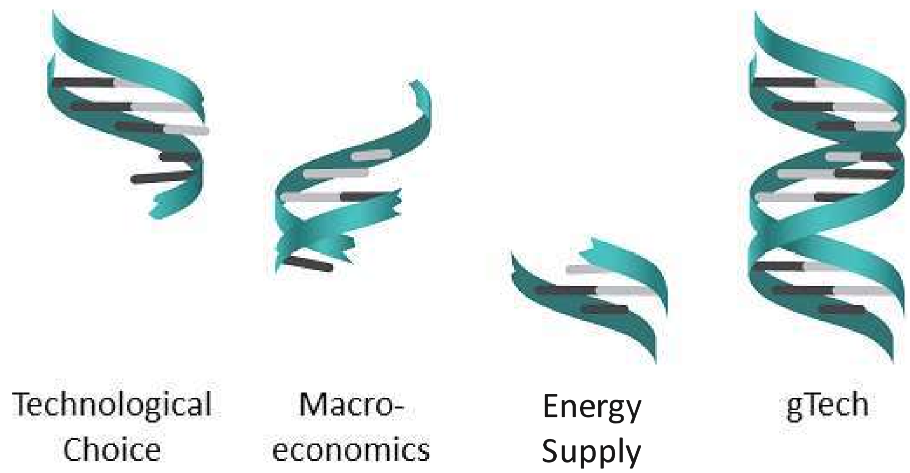
Navius' gTech model is a fully integrated macroeconomic model that combines a realistic representation of technology and consumer preferences, exhaustive accounting of the economy at large, and detailed representation of energy supply markets across Canada and the U.S.

Summary of gTech

The model used for this analysis is Navius' 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 GHG emissions;
- An exhaustive accounting of the economy at large, including how sectors, provinces and territories interact with each other and the rest of the world; and
- A detailed representation of energy supply, including liquid fuel (crude oil and biofuel), gaseous fuel (natural gas and renewable natural gas) and electricity.

Figure 25: The gTech model



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

gTech simulates technological choice

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

gTech provides a detailed accounting of the types of energy-related technologies available to households and businesses. In total, gTech includes over 95 sectors and over 300 technologies across 70 end-uses (e.g., light-duty vehicle travel, residential space heating, industrial process heat, management of agricultural manure).

Technological choice is influenced by many factors. Table 10 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 10: 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 archetype are fixed (though different archetypes allow energy efficiency improvements), but the price for energy is determined by the model.
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 these significantly higher rates.[37] The implication is that using a financial discount rate would overvalue future savings relative to revealed (i.e., real) human behaviour and would provide a poor forecast of household and firm decisions.
Technology-specific preferences	In addition to preferences around near-term and long-term costs, households (and even firms) exhibit "preferences" towards certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, buyers of passenger vehicles can be concerned about the driving range and available charging infrastructure of vehicles, some may worry about the risk of buying new technology, and some may see the vehicle as a "status symbol" that they value[38]. gTech quantifies these technology-specific preferences as "non-financial" costs, which are added to the technology choice algorithm (with the diversity of preferences addressed in the next point).

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

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

Criteria	Description
The diverse nature of Canadians	Canadians are not a homogenous group. Individuals are unique and will weigh factors differently when choosing what type of technology to purchase. For example, one household may purchase a Toyota Prius while their neighbour purchases an SUV and another takes transit. gTech uses a "market share" equation in which technologies with the lowest net-costs (including all the cost dynamics described above) achieve the greatest market share, but technologies with higher net-costs may still capture some market share[39]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.
Changing costs over time	Costs for technologies are not fixed over time. For example, the cost of electric vehicles has come down significantly over the past few years, and costs are expected to continue declining in the future[40]. Similarly, costs for many other energy efficient devices and emissions-reducing technologies have declined and are expected to continue declining. gTech accounts for whether and how costs for technologies are projected to decline over time and/or in response to cumulative production of that technology.
Policy	One of the most important drivers of technological choice is government policy. Current federal, provincial and territorial initiatives in Canada are already altering the technological choices households and firms make through various policies: (1) incentive programs, which pay for a portion of the purchasing cost of a given technology; (2) regulations, which either require a group of technologies to be purchased or prevent another group of technologies from being purchased; (3) carbon pricing, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g., whether or not to charge GST on a given technology); and (5) flexible regulations, like the federal low carbon fuel standard which will create a market for compliance credits generated from a range of defined activities. gTech simulates the combined effects of all these policies implemented together.

gTech simulates 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 11. Appendix D provides additional details on how GDP is calculated in gTech.

[39] Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047.
[40] Nykvist, B., Sprei, F., & Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. *Energy Policy*, 124, 144-155.

Table 11: 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[41]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and the transactions that occur between households, firms, and government. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income and jobs.
Full equilibrium dynamics	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply for a good or service is equal to its demand). This means that a decision made in one sector will 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 labour in construction services and ultimately leading to higher wages. The model also accounts for price effects. For example, the electricity sector can pass policy compliance costs on to households, who may alter their demand for electricity and other goods and services (e.g., by switching to technologies that consume other fuels and/or reducing consumption of other goods and services).
Sector detail	gTech provides a detailed accounting of sectors in Canada. In total, gTech simulates how policies affect over 95 sectors of the economy. Each of these sectors produces a unique good or service (e.g., the mining sector produces ore, while the trucking sector produces transport services) and requires specific inputs into production.
Labour and capital markets	Labour and capital markets must also achieve equilibrium in the model. The availability of labour 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 labour increases. The model also accounts for "equilibrium unemployment".
Interactions between regions	Economic activity in Canada is highly influenced by interactions among provinces/territories, with the United States and with countries outside of North America. Each region in the model interacts with other regions via (1) the trade of goods and services, (2) capital movements, (3) government taxation (within Canada only) and (4) various types of "transfers" between regions (e.g., the federal government provides transfers to provincial and territorial governments). gTech accounts for 10 Canadian provinces, the 3 territories in an aggregated region and the United States. The model simulates each of the interactions described above, and how interactions may change in response to policy.
Households	Households earn income from the economy at large and use this income to consume different goods and services. gTech accounts for each of these dynamics, and how policies change them.

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

gTech simulates energy supply markets

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

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

The benefits of merging macroeconomics with technological detail

By merging the three features described above (technological detail, macroeconomic dynamics, and energy supply dynamics), gTech can provide extensive insight into the effects of climate and energy policy. As such, this modeling toolkit allows for a comprehensive examination of Canada's net zero emission pathways and their impacts.

Model calibration

To characterize Canada's energy-economy, gTech is calibrated to a large variety of data sources. GHG emissions are calibrated in a 2015 base year to align with historical emissions reported by Environment and Climate Change Canada in the National Inventory Report[42]. Modeled emissions in 2020 are also calibrated to align with historical trends. The ability of gTech to replicate historical trends improves confidence in projections moving forward. Note that the model is intended to capture medium and long-term trends rather than short-term fluctuations due to business cycles and other factors. Therefore, it may not match historical data perfectly over shorter timescales.

Key calibration data sources used in this analysis include:

- Natural Resources Canada's Comprehensive Energy Use Database[43] for trends in building and transport energy consumption and efficiency.

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[42] Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
[43] Natural Resources Canada. Comprehensive Energy Use Database. Available from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

- Environment and Climate Change Canada's National Inventory Report[44] for non-combustion emissions as well as the relationship between emissions by IPCC category and NAICS (North American Industry Classification System) economic sector.
- Statistics Canada's Supply-Use Tables[45] for the structure of Canada's economy including sector activity, GDP, trade of goods and services and the financial transactions between households, firms, government and other regions.
- Statistics Canada's Annual Industrial Consumption of Energy Survey[46] for energy consumption by fuel in industry.
- Parliamentary Budget Office's Fiscal Sustainability Report[47] for GDP and labour force trends.
- Statistics Canada's Report on Energy Supply and Demand[48]
- Canada's Energy Future 2021[49]
- Statistics Canada datasets on the electricity sector[50]

Each data source is generated using different methods, so the data sources are therefore not necessarily consistent with one another. For example, expenditures on gasoline by households in Statistics Canada's Supply-Use tables may not be consistent with fuel consumption reported by Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

gTech's calibration routine places greater emphasis on some data sources relative to others. This approach means that gTech achieves near perfect alignment with data sources receiving the highest priority weight, but alignment starts to diverge from data sources that receive a lower weight.

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44 Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
45 Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X
46 Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca
47 Parliamentary Budget Office, 2020 Fiscal Sustainability Report. Available from: https://www.pbo-dpb.gc.ca/en/blog/news/RP-1920-029-S-fiscal-sustainability-report-2020-rapport-viabilite-financiere-2020
48 Statistics Canada. Report on Energy Supply and Demand in Canada. Available from: https://www150.statcan.gc.ca/n1/en/catalogue/57-003-X
49 Canada Energy Regulator. (2021). Canada's Energy Future 2021. Available from: www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/index.html
50 Statistics Canada. (n.d.). *Data*. Available from: https://www150.statcan.gc.ca/n1/en/type/data?subject_levels=25%2C2504

For this project, the datasets that received the highest weight are:

- Environment and Climate Change Canada’s National Inventory Report
- Natural Resources Canada’s Comprehensive Energy Use Database
- Navius’ technology database
- Canada’s Energy Future 2021

Appendix B: List of all current and announced policies

This appendix describes the set of policies included in the announced policy scenario simulated in this analysis.

Legislated policy

The tables below describe the policies currently legislated in Canada.

Table 12: Legislated federal policies included in the announced policy scenario

Policy	Description
Carbon Pollution Pricing Backstop[51]	This policy includes two components: (1) a carbon levy applied to fossil fuels that reaches $50/t CO_{2e} by 2022 and is constant thereafter in nominal terms and (2) an output-based pricing system for industrial facilities emitting more than 50 kt CO_{2e} annually. This policy applies to Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, Prince Edward Island, Newfoundland and Labrador, the Yukon and Nunavut. Revenue raised by this policy is returned to households in each respective province/territory.
Energy efficiency regulations[52]	Federal standards exist for space conditioning equipment, water heaters, household appliances, and lighting products. Major standards include 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.
Green Freight Assessment Program[53]	Four-year funding program launched in 2018 with a budget of $3.4 million available for medium and heavy-duty fleet performance reviews, implementing operational best practices, installing fuel saving technologies, and purchasing alternative fuel vehicles.

[51] Government of Canada. (2020). Pricing pollution: how it will work. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

[52] Natural Resources Canada. (n.d.). Canada's Energy Efficiency Act and Energy Efficiency Regulations. Available from: www.nrcan.gc.ca/energy/regulations-codes-standards/6861

[53] Government of Canada. (2020). Green Freight Assessment Program. Available from: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/greening-freight-programs/green-freight-assessment-program/20893.

Policy	Description
Hydrofluorocarbon Controls[54]	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 GHG emissions by 15% by 2036 relative to 2011/2013 levels by revising the Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations.
Light-Duty ZEV Subsidy[55]	Light-duty vehicle subsidy available at $2,500 for short-range plug-in hybrids and $5,000 for long-range plug-in hybrids, hydrogen vehicles, and battery electric vehicles.
Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations[56]	The national government has proposed amending the Heavy-Duty Vehicle Emissions Standard to increase the vehicle emission stringency for vehicles manufactured in model years 2018 to 2027.
Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations[57]	New passenger vehicles and light-commercial vehicles/light trucks sold in Canada must meet fleet-wide GHG emission standards between 2012 and 2016, and between 2017 and 2025. Fleet targets for passenger cars are aligned with US regulation.
Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations[58]	This policy closes coal-fired power plants by 2030 unless they emit less than 420 tonnes CO_2e/GWh.
Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity[59]	This policy limits the emissions intensity of natural gas-fired electricity generation to 420 tonnes CO_2e/GWh.

54 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

55 Government of Canada. (n.d.) Zero-emission vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

56 Government of Canada. (2018). Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999: SOR/2018-98. http://gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors98-eng.html

57 Government of Canada. (2018). Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.html

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

59 Government of Canada. (2018). Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity: SOR/2018-261. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-261/index.html

Policy	Description
Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds[60]	Oil and gas facilities must adopt methane control technologies and practices.
Renewable Fuels Regulation[61]	Specifies a minimum renewable content of 5% for gasoline and 2% for diesel, by volume. This will become part of the Low carbon Fuel Regulation (CFR) once the CFR comes into force in 2022.
Zero Emission Vehicle Tax Write-Off[62]	Businesses that purchase light-, medium-, or heavy-duty ZEV vehicles (including plug-in hybrids with a battery capacity of at least 7kWh, fully electric vehicles, and hydrogen vehicles) are eligible for a 100% tax write-off. Vehicles that qualify for the federal Incentive for Zero-Emission Vehicles Program are ineligible for the tax write-off.
Zero Emission Vehicle Infrastructure Program[63]	Federal funding available (total budget of $130 million over five years from 2019 to 2024) to partially pay for various types of charging and re-fueling stations, including medium- and heavy-duty vehicle charging and re-fueling stations.

Table 13: Legislated provincial policies included in the announced policy scenario

Province	Policy	Description
Alberta	Capping oil sands emissions[64]	Limits emissions from the oil sands to 100 Mt CO_2e annually.
British Columbia	Carbon Tax[65]	Continue increasing the carbon tax by $5/tCO_2e$ annually, until it reaches $50 per tonne in 2021.

60 Government of Canada. (2020). Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector): SOR/2018-66. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.htm

61 Government of Canada (2013). Renewable Fuels Regulations: SOR/2010-189. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-189/index.html

62 Government of Canada. (2020). Zero Emission Vehicles. Tax Write-Off. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

63 Government of Canada. (2020). Zero Emission Vehicle Infrastructure Program. Available from: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/zero-emission-vehicle-infrastructure-program/21876

64 Government of Alberta (2020). Capping oil sands emissions. Available from: https://www.alberta.ca/climate-oilsands-emissions.aspx#:~:text=Alberta%20will%20transition%20to%20an,to%20oil%20sands%20GHG%20emissions.&text=A%20legislated%20emissions%20limit%20on,cogeneration%20and%20new%20upgrading%20capacity

65 Government of British Columbia. (n.d.). British Columbia's Carbon Tax. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax

Province	Policy	Description
British Columbia	Low carbon Energy Act[66]	A minimum of 93% of provincial electricity generation must be provided by low carbon or renewable sources.
British Columbia	Light-Duty ZEV subsidies[67]	Provides incentives at $1,500 for short-range plug-in hybrids and $3,000 for long-range plug-in hybrids, battery electric vehicles, and hydrogen vehicles. It is unclear how long the incentives will be available for. The province has extended the policy multiple times since funding ran out since its introduction.
British Columbia	Low Carbon Fuel Requirement Regulation (part of the Low Carbon Fuel Standard)[68]	British Columbia introduced this policy in 2008. This regulation requires a decrease in average carbon intensity of transportation fuels by 10% by 2020 and by 20% by 2030 relative to 2010. Fuel suppliers can meet the second requirement by acquiring credits generated from fueling electric vehicles.
British Columbia	PST Exemption[69]	Use of electricity in residential and industrial buildings is exempt from provincial sales tax.
British Columbia	Renewable natural gas regulation[70]	Require that 15% of natural gas consumption be provided by renewable sources by 2030.
British Columbia	Specialty Use Vehicle Incentive[71]	Rebates of up to $50,000 for plug-in hybrid, electric, and hydrogen on-road medium- and heavy-duty freight vehicles.
British Columbia	Zero Emission Vehicle Standard[72]	Requires a minimum share of light-duty vehicles sold in BC to be zero-emission. This mandate achieves 10% electric vehicles sales by 2025, 30% by 2030 and 100% by 2040.
Manitoba	Biofuels Mandate Amendment[73]	Renewable fuel content requirement at 10% for gasoline and 5% for diesel by volume.

66 Government of British Columbia. (2010). Clean Energy Act. Available from: http://www.bclaws.ca/civix/document/id/lc/statreg/10022_01

67 Government of British Columbia. (2020). Go Electric Passenger Vehicle Rebates. Available from: https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/passenger-vehicles

68 Government of British Columbia. (2020). Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act, SBC 2008, c. 16. Available from: https://www.bclaws.ca/civix/document/id/complete/statreg/08016_01

69 Government of British Columbia. (2017). Provincial Sales Tax (PST). Tax Rate. Available from: https://www2.gov.bc.ca/gov/content/taxes/sales-taxes/pst

70 Government of British Columbia. (2019). CleanBC. Available from: https://cleanbc.gov.bc.ca/

71 Plug In BC. (n.d.). Specialty Use Vehicle Incentive. Available from: http://pluginbc.ca/suvi/

72 Government of British Columbia. (2019). Zero-Emission Vehicle Act. SBC 2019, Chapter 29. Available from: https://www.bclaws.ca/civix/document/id/complete/statreg/19029

73 Government of Manitoba. (2020). Biofuels Mandate and Renewable Fuels in Manitoba. Available from: https://reg.gov.mb.ca/detail/3340256

Province	Policy	Description
Manitoba	Coal phaseout[74]	Manitoba Hydro phased out its last coal-fired generating unit in 2018.
Manitoba	Efficient Trucking Program (ETP)[75]	Provincial and federal fund of jointly $11.8 million for heavy-duty vehicle efficiency retrofits. Applications closed April 2020.
Manitoba	Keeyask Hydro-electricity Project[76]	Ongoing construction of the 695-megawatt (MW) hydro generating station with expected completion in 2021.
New Brunswick	Renewable Portfolio Standard[77]	The renewable portfolio standard requires NB Power to ensure that 40% of in-province electricity sales are from renewable energy by 2020. Imports of renewable energy from other jurisdictions qualify for compliance, as do energy efficiency improvements.
Newfoundland and Labrador	Freight Transportation Fuel Efficiency Program (FTFEP)[78]	Joint federal and provincial fund of $3.2 million with rebates available over three years (2019-2021) for heavy-duty truck retrofits to reduce fuel consumption and GHG emissions.
Newfoundland and Labrador	Muskrat Falls Hydro Project[79]	A hydro project with a capacity of 824 MW.
Nova Scotia	Cap-and-Trade Program[80]	Annual caps on certain activities in Nova Scotia, including fuel suppliers, electricity importers and large final emitters.
Nova Scotia	Cap on GHG emissions from electricity generation[81]	This policy requires emissions from the electricity sector to decline to 4.5 Mt by 2030.
Nova Scotia	Renewable Portfolio Standard[82]	This renewable portfolio standard requires that 25% of electricity consumption be provided from renewable resources in 2015, increasing to 40% by 2020.

[74] Manitoba Hydro. (n.d.). Generation Stations. Available from: https://www.hydro.mb.ca/corporate/facilities/generating_stations/

[75] Red River College. (2020). Vehicle Technology & Energy Centre. Efficient Trucking Program. Driving sustainability forward in Manitoba. Available from: https://www.rrc.ca/vtec/efficient-trucking-program/

[76] Manitoba Hydro. (n.d.). Keeyask Generating Station. Available from: https://www.hydro.mb.ca/projects/keeyask/

[77] Government of New Brunswick. (2015). New Brunswick Regulation 2015-60 under the Electricity Act (O.C. 2016-263). Available from: www.gnb.ca/0062/acts/BBR-2015/2015-60.pdf

[78] Government of Newfoundland and Labrador. (n.d.). Freight Transportation Fuel Efficiency Program. Available from: https://www.gov.nl.ca/mae/occ/low-carbon-economy-programs/freighttransportation/.

[79] Naclor Energy. (2019). Muskrat Falls Project: Project Overview. https://muskratfalls.nalcorenergy.com/project-overview/

[80] Government of Nova Scotia. (n.d.). Nova Scotia's Cap-and-Trade Program. Available from: https://climatechange.novascotia.ca/nova-scotias-cap-trade-program.

[81] Government of Nova Scotia. (2013). Greenhouse Gas Emissions Regulations made under subsection 28(6) and Section 112 of the Environment Act. Available from: www.novascotia.ca/JUST/REGULATIONS/regs/envgreenhouse.htm

[82] Government of Nova Scotia. (2020). Renewable Electricity Regulations made under Section 5 of the Electricity Act. Available from: https://novascotia.ca/just/regulations/regs/elecrenew.htm

Province	Policy	Description
Nova Scotia	Maritime Link[83]	This transmission line will connect Nova Scotia to hydroelectric generation from Newfoundland Labrador (and in particular, to the Muskrat Falls hydroelectric project).
Ontario	Coal Phaseout[84]	Ontario phased out its last coal-fired generating unit in 2014. In 2019, about 94% of Ontario's electricity generation was emissions free.
Ontario	Greener Diesel Regulation[85]	Specifies a minimum renewable fuel content of 4% for diesel, by volume. Renewable diesel life cycle GHG emissions are required to be at least 70% lower than standard petroleum diesel.
Ontario	Greener Gasoline Regulation[86]	Specifies a minimum renewable fuel content of 10% for gasoline, by volume. Renewable gasoline must have an average of 45% less life cycle GHG emissions than standard petroleum gasoline.
Ontario	Nuclear Power Plant Refurbishment[87]	Ontario will refurbish 10 nuclear power plants which together will provide more than 9,800 MW emissions-free capacity.
Québec	Biofuels mandate[88]	In 2019, Québec released a draft regulation that would require a minimum blend of 10% renewable fuel in gasoline and 2% in diesel by volume starting in 2021 and rising to 15% for gasoline and 4% for diesel by 2025.
Québec	Cap and Trade System for Greenhouse Gas Emissions Allowances[89]	Cap and trade for industrial and electricity sectors as well as fossil fuel distributors. Revenue raised by the policy is invested in low carbon technologies.
Québec	Electric Vehicle Incentives[90]	Provides incentives between $4,000 and $8,000 for the purchase of a zero-emission vehicle.

83 Emera Newfoundland & Labrador. (2014). Maritime Link. Available from: http://www.emeranl.com/en/home/themaritimelink/overview.aspx

84 Government of Ontario. (2020). The End of Coal. Available from: https://www.ontario.ca/page/end-coal#:~:text=Ontario%20enshrined%20its%20commitment%20in,to%20generate%20electricity%20in%20Ontario

85 Government of Ontario. (2020). Greener Diesel. Available from: https://www.ontario.ca/page/greener-diesel-regulation

86 Government of Ontario. (2020). Greener Gasoline. Available from: https://www.ontario.ca/page/greener-gasoline

87 Government of Ontario. (2018). Chapter 2. Ensuring a Flexible Energy System. Available from: https://www.ontario.ca/document/ontarios-long-term-energy-plan-2017-order-council-21202017/chapter-2-ensuring-flexible-energy-system#section-8

88 Gouvernement du Québec. (2019). Projet de règlement. Volume minimal de carburant renouvelable dans l'essence et le carburant diesel. Available from: https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/energie-ressources-naturelles/publications-adm/lois-reglements/allegement/PR_Volume_minimal_carburant_renouvelable_MERN.pdf?1570737693.

89 Gouvernement du Québec. (2020). The Carbon Market, a Green Economy Growth Tool! Available from: http://www.environnement.gouv.qc.ca/changementsclimatiques/marche-carbone_en.asp.

90 Gouvernement du Québec. (2019). Discover electric vehicles. Available from: http://vehiculeselectriques.gouv.qc.ca/english/

Province	Policy	Description
Québec	Renewable Natural Gas Regulation[91]	This regulation requires a minimum renewable fuel content of 1% in distributed natural gas in Québec as of 2020, rising to 2% in 2023, and 5% in 2025.
Québec	Zero Emission Vehicle Standard[92]	Automakers that sell over 4,500 vehicles in the province are required to meet a minimum zero-emission vehicle credit quota. The credit requirement is set to rise from 3.5% in 2018 to 22% of non-ZEV sales by 2025. The government's own impact assessment estimates that the policy will result in zero-emission vehicles accounting for 9.9% of new sales in 2025.
Saskatchewan	Boundary Dam Carbon Capture Project[93]	This project stores and captures CO2 emissions from a 115 MW coal plant.
Saskatchewan	Ethanol Fuel (General) Regulations[94]	Requires a minimum renewable fuel content of 7.5% for gasoline, by volume.
Saskatchewan	Renewable Diesel Act[95]	Specifies a minimum renewable fuel content of 2% for diesel, by volume.

Announced policy

The tables below describe policies that have been announced in Canada. These policies are simulated in addition to legislated policies to form the announced policy scenario.

Table 14: Federal Fuel Charge

Policy	Federal Fuel Charge[96]
Stringency and timeline	The federal fuel charge is a backstop policy that applies a tax on fossil fuels in provinces that do not have an equally stringent carbon pricing system. The federal government announced that the federal fuel charge will be annually

[91] Gouvernement du Québec. (2019). Québec encadre la quantité minimale de gaz naturel renouvelable et met en place un comité de suivi. Available from: https://mern.gouv.qc.ca/quebec-encadre-quantite-gaz-naturel-2019-03-26/

[92] Gouvernement du Québec. (2018). The zero-emission vehicle (ZEV) standard. Available from: http://www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm

[93] SaskPower. (2019). Boundary Dam Carbon Capture Project. Available from: https://www.saskpower.com/our-power-future/infrastructure-projects/carbon-capture-and-storage/boundary-dam-carbon-capture-project

[94] Government of Saskatchewan. (2020). Ethanol Fuel (General) Regulations (E-11.1 Reg 1). Available from: https://publications.saskatchewan.ca/#/products/1064.

[95] Government of Saskatchewan. (2012). Renewable Diesel Act (R-19.001). Available from: https://publications.saskatchewan.ca/#/products/64461.

[96] Government of Canada. (2021). The federal carbon pollution pricing benchmark. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information.html

	increased by \$15/tCO_{2e} after 2022 until the tax reaches \$170/tCO_{2e} in 2030 and stays constant at that level thereafter.
Sectors	All sectors except large industrial emitters
Emissions covered	Emissions-intensive trade- exposed industries are excluded from the fuel charge. Fuel charge proceeds are returned to the province in which they were collected and 90% of proceeds are returned to households. The remaining 10% are returned to the rest of the covered sectors.
Assumptions	As it is uncertain how provinces will change their carbon pricing systems to comply with the federal stringency increase, we assume that the federal fuel charge backstop applies to all provinces and territories, except for Québec. Québec's cap is assumed to be sufficiently stringent in its current design.

Table 15: Output-Based Pricing System

Policy	Output-Based Pricing System[97]
Stringency and timeline	The Output-Based Pricing System (OBPS) is a tradable emissions performance standard that puts a price on industrial emissions if a facility's emissions intensity exceeds the sectoral benchmark. The federal government announced that the OBPS carbon price will be annually increased by \$15/tCO_{2e} until it reaches \$170/tCO_{2e} in 2030. Furthermore, sectoral OBPS benchmarks will be annually increased in stringency by 2 percentage points starting in 2023. Electricity benchmarks will not be increased in stringency as the federal government intends to address this sector's emission intensity through a low carbon electricity standard.
Sectors	Large industrial emitters
Emissions covered	The OBPS applies to industrial facilities emitting more than 50 kilotonnes of CO_{2e} annually in provinces that do not have an equally stringent performance standard or carbon price for industrial emitters.
Assumptions	As it is uncertain how provinces will change their carbon pricing systems to comply with the federal stringency increase, we assume that the OBPS will apply to all provinces and territories, except for Québec, and that an annual 2% tightening rate will apply to all sectoral benchmarks starting in 2023. OBPS proceeds are assumed to be used to fund low-carbon industrial technologies.

Table 16: Greenhouse Gas Emissions Cap on the Oil and Gas Sector

Policy	Greenhouse Gas Emissions Cap on the Oil and Gas Sector[98]
Stringency and timeline	The federal government has announced its intention to cap greenhouse gas emissions from the oil and gas extraction sector.
Sectors	Oil and gas extraction (upstream and downstream sectors)

[97] Government of Canada. (2021). Review of the OBPS Regulations: Consultation paper. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/2022-review-consultation.html

[98] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Emissions covered	The ERP does not provide details on the policy mechanism that will be used to implement an emissions cap on oil and gas extraction. It also does not specify the level at which emissions will be capped but references a modelling analysis which projects that oil and gas sector emissions would decline to 110 Mt in 2030 under the most economically efficient pathway to achieving Canada's 2030 target.
Assumptions	We simulate this policy as a tradable performance standard in which the oil and gas sector is required to reduce its emissions intensity. Carbon intensity benchmarks are calculated to be consistent with the emissions cap. In line with the modeling analysis referenced in the ERP, we assume that the emissions cap will apply to total oil and gas extraction sector emissions, including direct combustion and non-combustion emissions in the upstream and downstream oil and gas sector. We assume that there are no restrictions to generating compliance credits under the OBPS and oil and gas emissions cap for the same reduction action, such as implementation of carbon capture and storage.

Table 17: 75% Reduction in Oil and Gas Methane Emissions

Policy	75% reduction in oil and gas methane emissions[99,100,101]
Stringency and timeline	The federal government announced its commitment to implement regulations that will reduce methane emissions from the oil and gas sector by at least 75% below 2012 levels by 2030. This builds on the federal government's current methane regulations, which seek to achieve a 40% to 45% reduction in methane emissions in the upstream oil and gas sector below 2012 levels by 2025.
Sectors	Oil and gas extraction (upstream sectors)
Emissions covered	The current methane regulations cover upstream oil and gas emissions. To our knowledge, it has not yet been announced if the 75% reduction will apply to upstream oil and gas emissions or both upstream and downstream (including refineries, natural gas distribution, and LNG production) emissions.
Assumptions	The 75% methane reduction requirement is simulated as a regulatory requirement requiring increased uptake of abatement actions and technologies for surface casing vent flows, leaking, and venting, such as increased monitoring, flaring, and well reworking, in the upstream oil and gas sector.

99 Government of Canada. (2021). Canada confirms its support for the Global Methane Pledge and announces ambitious domestic actions to slash methane emissions. Available from: https://www.canada.ca/en/environment-climate-change/news/2021/10/canada-confirms-its-support-for-the-global-methane-pledge-and-announces-ambitious-domestic-actions-to-slash-methane-emissions.html

100 Government of Canada. (2018). Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector). Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/page-1.html#h-858529

101 Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Table 18: Low carbon Electricity Standard

Policy	Low carbon Electricity Standard[102,103]
Stringency and timeline	The federal government has stated its intention to implement a Low carbon Electricity Standard (CES), which will achieve net-zero emissions from electricity generation by 2035. The policy mechanisms that will be used to achieve this target have not yet been announced.
Sectors	Electricity generation
Emissions covered	The CES will cover electricity generation sold to the electricity grid. It is uncertain whether the CES will cover cogeneration providing electricity to the grid.
Assumptions	This policy is simulated as a national cap in form of a tradable performance standard with regional benchmarks for the emissions intensity of utility electricity generation. Emissions intensity benchmarks are calculated to be consistent with the emissions cap. We assume that cogeneration is excluded from the CES and that there are no restrictions on generating compliance credits under the OBPS and CES for the same reduction action.

Table 19: Waste Methane Capture

Policy	Waste Methane Capture[104]
Stringency and timeline	The ERP states the federal government's intention to create landfill methane regulations with the goal of reducing waste emissions through waste methane capture and treatment.
Sectors	Landfills
Emissions covered	Landfill methane emissions
Assumptions	We simulate a regulatory policy which requires the uptake of abatement actions and technologies such as flaring and methane capture and utilization in landfills.

[102] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[103] Government of Canada. (2022). A clean electricity standard in support of a net-zero electricity sector: discussion paper. Available from: https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/achieving-net-zero-emissions-electricity-generation-discussion-paper.html

[104] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Table 20: Low carbon Fuel Regulations

Policy	Low carbon Fuel Regulations[105,106,107]
Stringency and timeline	The federal government is developing a performance-based fuel supply standard requiring liquid fossil fuel suppliers to reduce the lifecycle greenhouse gas intensity of their fuels. The Canada Gazette Part I required a carbon intensity reduction of 2.4 g CO_{2e} /MJ in 2022, increasing to 12 g CO_{2e} /MJ in 2030. In the ERP, a potential increase in stringency to 14 g CO_{2e} /MJ in 2030 has been stated. The CFR creates a credit-based compliance market which allows regulated liquid fuel suppliers and voluntary credit generators to trade compliance credits. At the end of each compliance period, regulated suppliers must present sufficient credits to comply with the reduction requirement. Credits can be produced by reducing upstream emissions associated with liquid fossil fuel production, blending low carbon fuels such as ethanol into the liquid stream, or end-use fuel switching in transport. To our knowledge it has not yet been specified if instream trading with gaseous credits, generated through supplying renewable gaseous fuels, will be a proposed compliance option in the soon to be updated policy design.
Sectors	Transportation
Emissions covered	Under the currently proposed CFR standard (as of March 2022) the following fuels will be regulated under the CFR: gasoline, diesel, kerosene, and jet fuel (note that the GHG intensity reduction requirement is not planned to increase in stringency for jet fuel).
Assumptions	We simulate this policy as outlined in the Canada Gazette Part I and with the following policy updates: 1) Only liquid fuels will be regulated under the CFR. There are no emissions intensity reduction requirements for solid and gaseous fuels. 2) Light and heavy fuel oils are excluded from the list of regulated liquid fuels.

Table 21: Light-Duty Vehicle Emissions Standard

Policy	Light-Duty Emissions Standard[108]
Stringency and timeline	The ERP states that the federal government plans to implement a light-duty zero emissions vehicle (ZEV) sales mandate. The ZEV mandate will require at least 20% of all new light-duty vehicle sales to be ZEVs by 2026, 60% by 2030, and 100% by 2035.
Sectors	Light-duty transportation
Emissions covered	We expect this policy to apply to light-duty vehicle manufacturers

[105] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[106] Government of Canada. (2020). Canada Gazette, Part I, Volume 154, Number 51: Clean Fuel Regulations. Available from: http://www.gazette.gc.ca/rp-pr/p1/2020/2020-12-19/html/reg2-eng.html

[107] Government of Canada. (2021). Canada's Climate Actions for a Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

[108] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Assumptions	As there are currently no details on policy design available, we assume that a policy similar to Québec's ZEV mandate will be implemented. After a recently announced stringency increase, Québec 's ZEV mandate will require at least 17.5% low-carbon (plug-in hybrids) and zero-emission (battery electric and fuel cell electric) vehicle sales in 2026, rising to 65% in 2030 and 100% in 2035. Each year, vehicle manufacturers need to retire a certain number of credits in compliance with these targets. Credits are generated through the sale of low-carbon and zero-emission vehicles. Vehicles with a wider electric range are thereby awarded more credits.

Table 22: Medium- and Heavy-Duty Vehicle Emissions Standard

Policy	Medium- and Heavy-Duty Emissions Standard[109],[110],[111],[112],[113],[114]
Stringency and timeline	The ERP announced plans to develop a medium- and heavy-duty ZEV sales mandate with the goal of achieving 35% ZEV sales by 2030 and 100% by 2040 in selected medium- and heavy-duty categories, based on feasibility. Furthermore, interim targets for pre-2030 years will be explored.
Sectors	Medium- and heavy-duty transportation
Emissions covered	There are currently no details on policy design available but the federal government previously expressed interest in developing a policy similar to California's Advanced Low Carbon Trucks Regulation, which also aims to achieve 100% ZEV sales by 2040 in selected vehicle categories. California's regulation applies to manufacturers of on-road medium- and heavy-duty vehicles, excluding transit buses.
Assumptions	We assume that Canada will implement a medium- and heavy-duty emissions standard aligned with California's Advanced Low Carbon Trucks Regulation. California's medium- and heavy-duty emissions standards require that 7% to 11% of new vehicle sales be ZEVs in 2025 and 30% to 50% in 2030, depending on vehicle weight class. Each year, vehicle manufacturers need to retire a certain number of credits in compliance with these targets. Credits are generated through the sale of low-carbon emission vehicles. For full battery electric and fuel cell electric vehicles, the number of credits generated depends on the vehicles' weight class. For plug-in electric vehicles, credit generation also depends on electric range.

109 Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

110 Government of Canada. (2021). Canada's Climate Actions for a Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

111 Government of Canada. (2021). Discussion paper for heavy-duty vehicles and engines in Canada: transitioning to a zero-emission future. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/cepa/21199_HDV%20Discussion%20Document_Dec%2016_MinO%20Approved_Final_EN.pdf

112 Government of Canada. (2021). Government launches consultations on commitment to require all new cars sold in Canada be zero emission by 2035. Available from: https://www.canada.ca/en/environment-climate-change/news/2021/12/government-launches-consultations-on-commitment-to-require-all-new-cars-sold-in-canada-be-zero-emission-by-2035.html

113 California Air Resources Board (CARB). (2019). ZEP Cert FSOR. Available From: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/zepcert/fsor.pdf

114 California Air Resources Board (CARB). (2019). Advanced Clean Trucks Regulation. Available From: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/30dayatta.pdf

Table 23: National Net-Zero Emissions Building Strategy

Policy	National Net-zero Emissions Building Strategy[115,116,117]
Stringency and timeline	The ERP mentions that $150 million will be invested to develop the Canada Green Buildings Strategy, a national net zero by 2050 buildings strategy. As part of the strategy, regulatory standards to phaseout fossil-fuel heating in buildings will be developed. The Liberal Party also included the following statements on the 2021 Election Platform: "Launch a National Net-zero Emissions Building Strategy, which will chart a path to net-zero emissions from buildings by 2050 with ambitious milestones along the way" and "accelerate the development of the national net-zero emissions model building code for 2025 adoption." To our knowledge, there is currently no further information available regarding timelines and the policy mechanisms that will be used.
Sectors	Buildings
Emissions covered	To our knowledge, there is currently no information available regarding the buildings and technologies that will be covered under this policy.
Assumptions	There is little information on this policy available

Table 24: Investment Tax Credit for Carbon Capture Utilization and Storage

Policy	Investment tax credit for CCUS[118]
Stringency and timeline	Budget 2022 introduces an investment tax credit for carbon capture utilization and storage capital investments. The target of this measure is to reduce emissions by at least 15 Mt of CO_{2e} per year. Budget 2022 states that a total of 2.6 billion dollars will be invested in direct air capture and carbon capture utilization and storage between 2022 and 2026, and 1.5 billion annually from 2027 to 2030.
Sectors	Large industrial emitters
Emissions covered	We expect that the tax credit would be available to all new carbon capture and storage or use facilities.
Assumptions	This is simulated as a $2.6 billion subsidy over five years starting in 2022, and a $1.5 billion annual subsidy from 2027 to 2030.

115 Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

116 Liberal Party of Canada. (2021). Liberal Party 2021 platform. Available from: https://liberal.ca/our-platform/a-retrofit-economy-that-cuts-pollution-and-creates-jobs/

117 Office of the Prime Minister. (2021). Minister of Natural Resources Mandate Letter. Available from: https://pm.gc.ca/en/mandate-letters/2021/12/16/minister-natural-resources-mandate-letter

118 Government of Canada. (2022). Budget 2022: Chapter 3. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont

Table 25: Canada Infrastructure Bank Spending

Policy	Canada Infrastructure Bank Spending[119,120]
Stringency and timeline	The Healthy Environment and Healthy Economy federal climate plan states that the Canada Infrastructure Bank (CIB) has a long-term investment target of $5 billion for low carbon power projects. It further outlines that the CIB has committed $1.5 billion for zero emission buses, $2.5 billion for low-carbon power projects, including storage, transmission and renewables, over 3 years, and $2 billion for commercial building retrofit upfront costs. The ERP mentions that CIB will receive a total of $35 billion with priorities to invest in green infrastructure ($5 billion), public transit ($5 billion) and low carbon power ($5 billion).
Sectors	Transit, electricity generation, commercial buildings
Emissions covered	Buildings and other infrastructure, transit, electricity generation
Assumptions	CIB spending is simulated as a $1.5 billion subsidy for zero-emission buses, $500 million for electric charging and hydrogen refueling infrastructure. Funding for charging stations" policy), a $5 billion subsidy for renewable electricity generation and storage, and $2 billion for commercial high efficiency building shells and heating technologies over three years.

Table 26: Net Zero Accelerator

Policy	Net Zero Accelerator[121,122]
Stringency and timeline	A Healthy Environment and a Healthy Economy announced an investment of $3 billion over 5 years for the Net Zero Accelerator, which provides funding for development and adoption of low-carbon technologies in all industrial sectors. Budget 2021 provided an additional $5 billion over seven years for the Net Zero Accelerator.
Sectors	Large industrial emitters
Emissions covered	Funding is available to low-carbon industrial technologies.
Assumptions	The Net Zero Accelerator is simulated as an $8 billion subsidy over seven years for industrial low-carbon technologies, including carbon capture and storage technologies, electrification of industrial heat production and compression, fuel switching to wood waste and hydrogen for industrial heat production, efficient electric motors, and direct air capture.

[119] Government of Canada. (2021). Canada's Climate Actions for a Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

[120] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[121] Government of Canada. (2022). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html

[122] Government of Canada. (2021). Canada's Climate Actions for a Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

Table 27: Zero Emission Vehicle Tax Write-Off

Policy	Zero Emission Vehicle Tax Write-Off[123],[124]
Stringency and timeline	Businesses can receive a 100% tax write-off when purchasing a zero-emission vehicle before 2024. The tax write-off rate declines to 75% in 2024, 25% in 2025, and 0% in 2028.
Sectors	Transportation
Emissions covered	The increased tax write-off rate is available to businesses purchasing light-, medium-, or heavy-duty on-road zero emission vehicles, including plug-in hybrids, battery electric and fuel cell electric vehicles. Vehicles that received subsidies from the iZEV program are not eligible for the tax write off.
Assumptions	The increased tax write-off for businesses is simulated as a per vehicle subsidy for medium- and heavy-duty ZEVs. Businesses purchasing light-duty ZEVs are assumed to use the federal iZEV incentive and forgo the tax write off.

Table 28: Incentives for Zero-Emission Vehicle Program

Policy	Incentives for Zero-Emission Vehicles Program[125],[126],[127]
Stringency and timeline	The ERP announced an additional $1.7 billion to extend the iZEV program for another three years. The iZEV program provides rebates of up to $5,000 for light-duty zero emission vehicles.
Sectors	Light-duty transportation
Emissions covered	The rebate program provides subsidies to on-road light-duty plug-in hybrids, battery electric vehicles, and fuel cell electric vehicles.
Assumptions	We simulate this as a 1.7 billion subsidy, additional to historic and remaining iZEV funds for zero emission light-duty vehicles, including battery electric vehicles, plug-in hybrids, and fuel cell electric vehicles, over three years. Subsidy values are assumed to be nominal.

123 Government of Canada. (2020). Zero-Emission Vehicle Taxes. Available from: https://www.canada.ca/en/revenue-agency/services/tax/individuals/topics/about-your-tax-return/tax-return/completing-a-tax-return/deductions-credits-expenses/line-22900-other-employment-expenses/capital-cost-allowance/classes-depreciable-properties/zero-emission-vehicles.html

124 Government of Canada. (2022). Incentives for purchasing zero-emission vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/incentives-purchasing-zero-emission-vehicles

125 Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

126 Government of Canada. (2021). Economic and Fiscal Update 2021. Available from: https://www.budget.gc.ca/efu-meb/2021/report-rapport/EFU-MEB-2021-EN.pdf

127 Government of Canada. (2022). Zero-emission vehicles Program statistics. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/program-statistics

Table 29: Funding for Charging Stations

Policy	Funding for Charging Stations[128,129,130]
Sectors	Transportation
Emissions covered	Funding is available for electric charging and hydrogen fuel cell refueling network improvements.
Assumptions	This is simulated as a $900 million subsidy for light-, medium-, and heavy-duty zero emission vehicles, including plug-in hybrids, battery electric and fuel cell electric vehicles, over five years. Subsidy values are assumed to be nominal.

Table 30: Large Truck Retrofits

Policy	Large Truck Retrofits[131]
Stringency and timeline	The ERP includes a $199.6 million subsidy for retrofitting large trucks currently on the road.
Sectors	Medium- and heavy-duty transportation
Emissions covered	To our knowledge, there is currently little information regarding the retrofit actions that would qualify for funding under this policy.
Assumptions	This is simulated as a $199.6 million subsidy for efficient heavy-duty vehicles. Subsidy values are assumed to be nominal.

Table 31: Interest-Free Home Retrofit Loan

Policy	Interest-free home retrofit loan[132,133]
Stringency and timeline	Budget 2021 allocated $4.4 billion on a cash basis ($778.7 million on an accrual basis over five years, starting in 2021-22, with $414.1 million in future years), to the Canada Mortgage and Housing Corporation to provide interest-free loans up to $40,000 to low-income homeowners for home retrofits. The ERP announced an additional investment of $458.5 million into the low-income loan program.
Sectors	Residential buildings

[128] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[129] Government of Canada. (2021). Canada's Climate Actions for a Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/actions-healthy-environment-economy.html

[130] Government of Canada. (2022). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html

[131] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[132] Government of Canada. (2022). Canada 2030 Emissions Reduction Plan (ERP). Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

[133] Government of Canada. (2021). Budget 2021 A Healthy Environment for a Healthy Economy. Available from: https://www.canada.ca/en/department-finance/news/2021/04/budget-2021-a-healthy-environment-for-a-healthy-economy.html

Emissions covered	Funding is available to low-income households for efficiency upgrades of residential building shells and heating technologies.
Assumptions	This is simulated as a $1.2 billion subsidy ($778.7 million + $458.5 million) over seven years for efficient residential building shells and heating technologies. Subsidy values are assumed to be nominal.

Table 32: Residential Efficiency Retrofits

Policy	Residential Efficiency Retrofits[134]
Stringency and timeline	Budget 2021 included $2.6 billion for residential energy efficiency improvements over seven years.
Sectors	Residential buildings
Emissions covered	Funding is available to households for efficiency upgrades of residential building shells and heating technologies.
Assumptions	This is simulated as a $2.6 billion subsidy for efficient residential building shells and heating technologies over seven years. Subsidy values are assumed to be nominal.

Table 33: Replace Home-Heating Oil

Policy	Replace Home-Heating Oil[135]
Stringency and timeline	The Liberal Party stated on its 2021 Election Platform that it aims to accelerate electrification in home-heating and would invest $250 million to help low-income homeowners replace heating oil.
Sectors	Residential buildings
Emissions covered	Funding available to low-income households for replacing home heating with heating oil.
Assumptions	This is simulated as a $250 million subsidy over five years for electric heating technologies. Subsidy values are assumed to be nominal.

Table 34: Community Buildings Upgrade

Policy	Community Buildings Upgrade[136]
Stringency and timeline	Budget 2021 proposed to invest $1.5 billion over three years for repairs and efficiency upgrades in community buildings and for building new energy efficient community buildings.
Sectors	Community buildings
Emissions covered	Funding is available for efficiency upgrades of building shells and heating technologies in community buildings.

134 Government of Canada. (2022). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html

135 Liberal Party of Canada. (2021). Liberal Party 2021 platform. Available from: https://liberal.ca/our-platform/a-retrofit-economy-that-cuts-pollution-and-creates-jobs/

136 Government of Canada. (2022). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html

Table 37: Hydrogen Projects

Policy	Hydrogen Projects[141,142]
Stringency and timeline	There are two major hydrogen projects planned in Alberta. The Suncor and ATCO plant will become operational in 2028 and produce more than 300,000 tonnes of low-carbon hydrogen per year of which 20% could be used in Alberta's natural gas distribution system. Most of the remainder will be used by refineries. The Air Products project will come online in 2024 and produce 30 tonnes of liquid low-carbon hydrogen per day which will be available for the merchant market. Air products will further produce low-carbon hydrogen for refineries and electricity generation for its own operations and the grid.
Sectors	Hydrogen production
Emissions covered	n/a
Assumptions	We assume that by 2030, 24 PJ of low-carbon hydrogen, available for the merchant market and electricity production, would be produced through Air Products' project and an additional 13.5 PJ through Suncor and ATCO's project.

Table 38: Ontario Steel Plant Upgrades

Policy	Ontario Steel Plant Upgrades[143,144]
Stringency and timeline	Two major steel companies in Ontario, ArcelorMittal and Algoma, announced that they will upgrade their steel plants, which will result in greenhouse gas reductions of about 3 Mt in each plant.
Sectors	Steel production
Emissions covered	Steel production
Assumptions	This is simulated as a switch to less carbon intensive forms of steel production, such as direct reduced iron steel production, and achieves about a 6 Mt reduction in GHG emissions in 2030 relative to 2020.

141 Air Products Announces Multi-Billion Dollar Net-Zero Hydrogen Energy Complex in Edmonton, Alberta, Canada

142 Suncor and ATCO partner on a potential world-scale clean hydrogen project in Alberta | Suncor

143 Globe News Wire. (2021). Algoma Steel Announces Final Investment Decision for Electric Arc Steelmaking. Available from: https://www.globenewswire.com/news-release/2021/11/11/2332532/0/en/Algoma-Steel-Announces-Final-Investment-Decision-for-Electric-Arc-Steelmaking.html

144 Arcelor Mittal. (2021). ArcelorMittal and the Government of Canada announce investment of CAD$1.765 billion in decarbonisation technologies in Canada. Available from: https://corporate.arcelormittal.com/media/press-releases/arcelormittal-and-the-government-of-canada-announce-investment-of-cad-1-765-billion-in-decarbonization-technologies-in-canada

Appendix C: Key technology assumptions

gTech simulates over 300 technologies, including many low carbon technology options. This appendix provides assumptions for two technologies important for this analysis – CCS and DAC.

Carbon capture and storage

Carbon capture and storage (CCS) technologies are parameterized in gTech based on studies from the Global CCS Institute[145] and the International Energy Agency[146]. Table 39 presents current costs of CCS (first of a kind) and Table 40 presents future minimum costs (n^{th} of a kind). All costs are presented as levelized incremental costs for carbon capture for each technology using a 15% discount rate, 30-year life, electricity price of $27.6/GJ, coal price of $2.2/GJ, and natural gas price of $2.8/GJ[147]. Additionally, we assume emissions of 0.05 tCO_2e/GJ of natural gas combusted and 0.09 tCO_2e/GJ of coal combusted for the purpose of the tables below. Costs are presented per tCO_2 captured for three sensitivities.

Table 39: Current (first of a kind) levelized cost of CCS (2020 CAD/tCO_2 captured)

CCS application	Low cost	Intermediate cost	High cost
Co-generation (natural gas with CCS)	151.0	221.2	252.3
Cement heat (coal with CCS)	103.3	151.3	172.5
Cement heat (natural gas with CCS)	128.1	221.2	262.5
Industrial heat (coal with CCS)	96.8	141.7	161.6

145 Global CCS Institute. (2021). *Technology Readiness and Costs of CCS*. Available from: https://www.globalccsinstitute.com/wp-content/uploads/2022/03/CCE-CCS-Technology-Readiness-and-Costs-22-1.pdf

146 International Energy Agency. (2021). *Is carbon capture too expensive?* Available from: https://www.iea.org/commentaries/is-carbon-capture-too-expensive

147 2020 CAD.

CCS application	Low cost	Intermediate cost	High cost
Industrial heat (natural gas with CCS)	128.1	221.2	262.5
Low-temperature industrial heat (coal with CCS)	96.8	141.7	161.6
Low-temperature industrial heat (natural gas with CCS)	128.1	221.2	262.5
SMR hydrogen production (with CCS)	65.6	100.5	135.5
Formation CO_2 (with CCS)	36.5	49.0	61.5
Electricity generation (new coal with CCS)	106.4	146.4	164.1
Electricity generation (new combined cycle gas turbine with CCS)	142.5	215.6	248.0

Table 40: Future minimum (n^{th} of a kind) levelized cost of CCS (2020 CAD/tCO_2 captured)

CCS application	Low cost	Intermediate cost	High cost
Co-generation (natural gas with CCS)	86.7	127.0	144.8
Cement heat (coal with CCS)	59.5	87.2	99.4
Cement heat (natural gas with CCS)	61.8	106.7	126.6
Industrial heat (coal with CCS)	51.3	75.1	85.6
Industrial heat (natural gas with CCS)	73.2	126.4	149.9
Low-temperature industrial heat (coal with CCS)	51.3	75.1	85.6
Low-temperature industrial heat (natural gas with CCS)	73.2	126.4	149.9

CCS application	Low cost	Intermediate cost	High cost
SMR hydrogen production (with CCS)	63.0	96.5	130.0
Formation CO_2 (with CCS)	20.1	27.0	33.8
Electricity generation (new coal with CCS)	77.2	106.2	119.0
Electricity generation (new combined cycle gas turbine with CCS)	99.6	150.7	173.4

Direct air capture

Direct air capture (DAC) technology differs from CCS in that, rather than capturing CO_2 at a point source of emissions to prevent it from entering the atmosphere, DAC removes CO_2 directly from the atmosphere, effectively producing negative emissions.

Figure 26 provides the levelized cost of DAC used in this analysis. DAC techno-economic parameters are based on Fasihi (2019)[148], Larsen et al. (2019)[149] and Keith et al. (2018)[150]. The intermediate case sensitivity is based on an average of the literature reviewed. The high-cost sensitivity represents the highest value reported in the literature. The low-cost sensitivity is a revised version of the lowest value reported in the literature, based on consultation with experts in the field.

Costs were harmonized using a 15% discount rate, 30-year life, $27.13/GJ electricity price, and $2.64/GJ natural gas price[151].

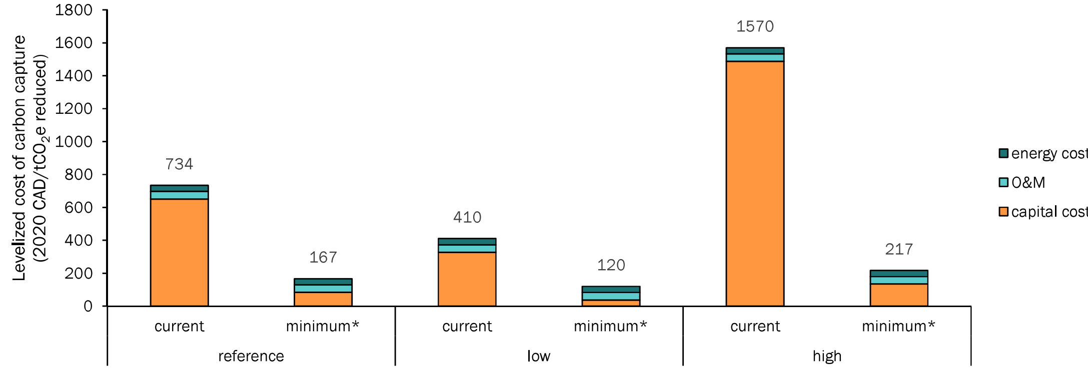
[148] Fasihi et al. (2019). Techno-economic assessment of CO2 direct air capture plants. Journal of Cleaner Production, 224, 957-980.

[149] Larsen et al. (2019). Capturing Leadership, Policies for the US to Advance Direct Air Capture Technology. Rhodium Group.

[150] Keith et al. (2018). A process for Capturing CO2 from the Atmosphere. Joule, 2, 1-22.

[151] 2020 CAD.

Figure 26: Levelized cost of carbon capture from DAC



*Future minimum costs are based on 1557 Mt CO_2 of capture.

Appendix D: GDP accounting in gTech

To address the challenges with reporting constant GDP in scenarios with stringent climate policy, we developed a method for reporting GDP in which we undertake three steps described below.

1. Calculate a Chain Fisher Price Index[152] for expenditure GDP, based on 2015$. This is calculated as follows:

$$LAS\_P_t^C = LAS\_P_{t-1}^C \times \frac{\sum_I \sum_E (P_{t,i} \times E_{t-1,i,e})}{\sum_I \sum_E (P_{t-1,i} \times E_{t-1,i,e})}$$

$$PAA\_P_t^C = PAA\_P_{t-1}^C \times \frac{\sum_I \sum_E (P_{t,i} \times E_{t,i,e})}{\sum_I \sum_E (P_{t-1,i} \times E_{t,i,e})}$$

$$FIS\_P_t^C = \sqrt{LAS\_P_t^C \times PAA\_P_t^C}$$

Where LAS_P^C is the Chain Laspeyres Price Index; PAA_P^C is the Chain Paasche Price Index; FIS_P^C is the Chain Fisher Price Index; P is the price of commodity i in year t; and E is expenditure on commodity i in year t and expenditure category e (e.g., consumption, investment, government expenditure, exports and imports).

2. We then measure both income- and expenditure-based current GDP from gTech using prices determined by the model. This is calculated as follows:

$$\text{"NOMINAL"}\ \ INC\_GDP_{t,j} = \sum_I (P_{t,i} \times O_{t,i,j} - P_{t,i} \times II_{t,i,j})$$

$$\text{"NOMINAL"}\ \ EXP\_GDP_{t,e} = \sum_I (P_{t,i} \times E_{t,i,e})$$

Where P is the price of commodity i in year t; O is the output in physical units of commodity i in year t and sector j; II is intermediate inputs by commodity i in year t and sector j; E is expenditure on commodity i in year t and expenditure category e.

[152] https://www150.statcan.gc.ca/n1/pub/13-605-x/2003001/concept/fisher/metho/index-eng.htm

3. We then deflate both income- and expenditure-based GDP by the Fisher Price Index. This is calculated as follows:

$$\text{REAL INC\_GDP}_{t,j} = \text{"NOMINAL"} * \text{INC\_GDP}_{t,j}/\text{FIS\_P}_t^C$$

$$\text{REAL EXP\_GDP}_{t,e} = \text{"NOMINAL"} * \text{EXP\_GDP}_{t,e}/\text{FIS\_P}_t^C$$

The outcome of this approach, which we call “deflated” GDP, is that:

- Total real expenditure GDP is equal to total chained expenditure GDP in 2015$.
- Value-added from the production of new commodities that do not exist in 2015, do not exist the absence of climate policy, or undergo large price changes induced by policy (e.g., hydrogen, carbon offset credits produced by direct air capture) is more accurately accounted for.

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