Simulating the economic impacts of the proposed Clean Electricity Regulations

Draft report prepared for the Legislative Assembly of Alberta

SUBMITTED TO

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SUBMITTED BY

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About Us

Navius Research Inc. ("Navius") is a private consulting firm in Vancouver. Our consultants specialize in analysing government and corporate policies designed to meet environmental goals, with a focus on energy and greenhouse gas emission policy. 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.

Summary of key insights

This analysis uses macroeconomic modeling to assess impacts of the proposed federal Clean Electricity Regulations (CER) on Alberta's economy. Four key insights that can be learned from this analysis are:

- **Alberta's economy grows less when the CER is implemented relative to a scenario without the CER.** Implementation of the CER leads to a 0.03% reduction in Alberta's average GDP growth rate from 2020 to 2040 relative to a Legislated Policy scenario without the CER. The effect of this lower rate of growth means provincial GDP is $1.9 billion lower in 2030 and $2.7 billion lower in 2040 than it would be without the CER.[1] Higher electricity costs and lower investment in manufacturing, services, oil, and gas contribute to a reduction in economy-wide GDP in the province.
- **Investment in Alberta's electricity sector increases in response to CER implementation.** Annual investment in Alberta's electricity sector increases when the CER is implemented (by $4.2 billion in 2030 and $0.8 billion in 2040 relative to a Legislated Policy scenario without the CER)[2]. This increase in investment in the electricity sector is partially offset by lower investment in other sectors of the economy (primarily oil and gas), though total investment in Alberta remains higher when the CER is implemented: $3.8 billion higher in 2030 and $1.2 billion higher in 2040.
- **Alberta's emissions are lower when the CER is implemented relative to a scenario without the CER.** Implementation of the CER leads to an annual reduction in emissions of 12 $MtCO_{2e}$ in 2030 and 14 $MtCO_{2e}$ in 2040 relative to a Legislated Policy scenario without the CER. This corresponds to a 5% and 6% reduction in Alberta's economy-wide emissions respectively.
- **Impacts on Alberta's economy and emissions differ depending on how the CER is implemented, including policy design and overlap.** For example, if behind-the-fence cogeneration is excluded from coverage under the CER, the policy has a smaller economic impact (12% smaller from 2020 to 2040). Similarly, if other policies announced in the ERP are implemented in addition to the CER, GDP impacts of the CER are 41% smaller from 2020 to 2040.

[1] $2015.

[2] $2015.

Contents

1. Introduction

Environment and Climate Change Canada (ECCC) is currently developing the Clean Electricity Regulations (CER), a policy intended to achieve a net-zero emission electricity system in Canada by 2035.[3] ECCC has proposed that the CER will apply to all electricity generating units that combust fossil fuels above a certain size, with an emissions performance standard declining to near-zero by 2035.

In June 2022, the Alberta Electricity System Operator (AESO) published an analysis of net-zero emission pathways for Alberta's electricity sector.[4] The AESO found the electricity sector net-zero pathways to have a cumulative incremental cost of $44-52 billion (nominal, undiscounted) between 2022 and 2041, relative to a reference case in which emissions in Alberta's electricity system do not reach net-zero.

Given the magnitude of these additional costs, the Alberta United Conservative Party (UCP) Caucus is interested in understanding the broader economic implications of the CER, including how its implementation may affect Alberta's GDP, labour supply, energy costs and investment beyond the electricity sector. In particular, the UCP Caucus is interested in understanding to what extent the increase in electricity expenditures identified by the AESO may cause macroeconomic impacts larger than the direct electricity sector expenditure required to comply with the CER.

Navius Research has extensive experience using its macroeconomic model, gTech, to assess the economic implications of climate and energy policy in Alberta. This analysis relies on the use of gTech to simulate the impacts of the CER on Alberta's economy. Results of this analysis are presented in this report, and is structured as follows:

- Section 2 summarizes the analytical approach taken.
- Section 3 provides an overview of the key findings of this analysis.
- Section 4 outlines the main conclusions from this analysis.
- Appendices outline relevant modeling and policy assumptions and provide additional detail on the gTech model.

[3] Government of Canada (2022), Clean Electricity Regulations. Available at: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/clean-electricity-regulation.html

[4] AESO (2022). AESO Net-Zero Emissions Pathways Report. Available at: https://www.aeso.ca/assets/Uploads/net-zero/AESO-Net-Zero-Emissions-Pathways-Report.pdf

2. Analytical approach

This section provides an overview of the analytical approach taken for this analysis. Assumptions outlined here cover the design of the CER, an introduction to Navius' in-house energy-economy model, gTech, and its calibration to historical data and the AESO. The section concludes with a description of the policy scenarios simulated for this analysis. More details on the gTech model can be found in Appendix A. Appendix B outlines additional modeling assumptions, and Appendix C summarizes policy assumptions.

2.1. gTech

This analysis uses gTech, Navius' in-house energy-economy 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.

gTech is a computable general equilibrium model which simulates how markets are likely to adjust due to policy-induced costs, providing insight into the effects of policy on key economic indicators such as GDP and employment. See Appendix A for a more detailed description of gTech and its capabilities.

2.2. CER assumptions

Since ECCC has not yet published the draft regulations for the CER, there is uncertainty regarding the scope, stringency, and flexibility of the policy. As a result, some assumptions are needed when simulating the policy for this analysis.

For the emissions performance standards and proposed exemptions, we have aligned our assumptions with the AESO's assumptions for how "net-zero" is defined. The AESO's scenarios achieve an ~80% reduction in GHG emissions from electricity generation, resulting in 4-5 Mt of residual emissions in 2035 in Alberta. Other key modeling assumptions are summarized in Table 1 below.

Table 1: Clean Electricity Regulations modeling assumptions

Policy	Clean Electricity Regulation
Stringency and timeline	The federal government has stated its intention to implement a Clean Electricity Regulation (CER), 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 CER will cover emissions associated with electricity generation. Two potential scopes were modeled for this analysis: 1. emissions excluding behind-the-fence industrial cogeneration 2. all electricity emissions, including cogeneration
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 there are no restrictions on generating compliance credits under the TIER program and CER for the same reduction action. We assume a national emissions cap declining linearly from present levels to an 80% reduction by 2035.

2.3. 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.[5] 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.

Key calibration data sources used in this analysis include:

- Natural Resources Canada's Comprehensive Energy Use Database[6] for trends in building and transport energy consumption and efficiency.
- Environment and Climate Change Canada's National Inventory Report[7] for non-combustion emissions as well as the relationship between emissions by IPCC category and NAICS (North American Industry Classification System) economic sector.

[5] 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
[6] Natural Resources Canada. Comprehensive Energy Use Database. Available from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm
[7] 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

- Statistics Canada's Supply-Use Tables[8] 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[9] for energy consumption by fuel in industry.
- Statistics Canada's Report on Energy Supply and Demand.[10]
- Canada's Energy Future 2021 for GDP and labour force trends, and for oil and gas production and prices.[11]
- Statistics Canada datasets on the electricity sector.[12]

For this analysis, gTech was calibrated to align with the capital investment, electricity cost, and GHG impacts reported in the analysis of net-zero emission pathways for Alberta's electricity sector conducted by the AESO[13]. gTech was calibrated to a scenario in which the CER *includes* cogeneration relative to a baseline of currently legislated policy (the AESO's analysis achieves a 90% reduction in cogeneration emissions). A comparison of emissions and capital costs between gTech and the AESO are provided in Figure 1 below.

Electricity sector emissions in Alberta as simulated in gTech follow a similar trend to the scenarios in the AESO analysis. gTech's emissions are higher in 2030 and 2035 because the CER is modelled as a national cap with flexible compliance between provinces. In other words, while total electricity sector emissions in Canada need to decline by a fixed amount, we are not prescriptive about the level of emissions reductions by province. This results in a slightly lower emissions reduction (as a percentage) in Alberta compared to the country as a whole in gTech, whereas the AESO assumes an 80% reduction in electricity emissions must occur in Alberta. The needed reduction to comply with the CER is uncertain as the draft regulations for the policy have not yet been published.

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

9 Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

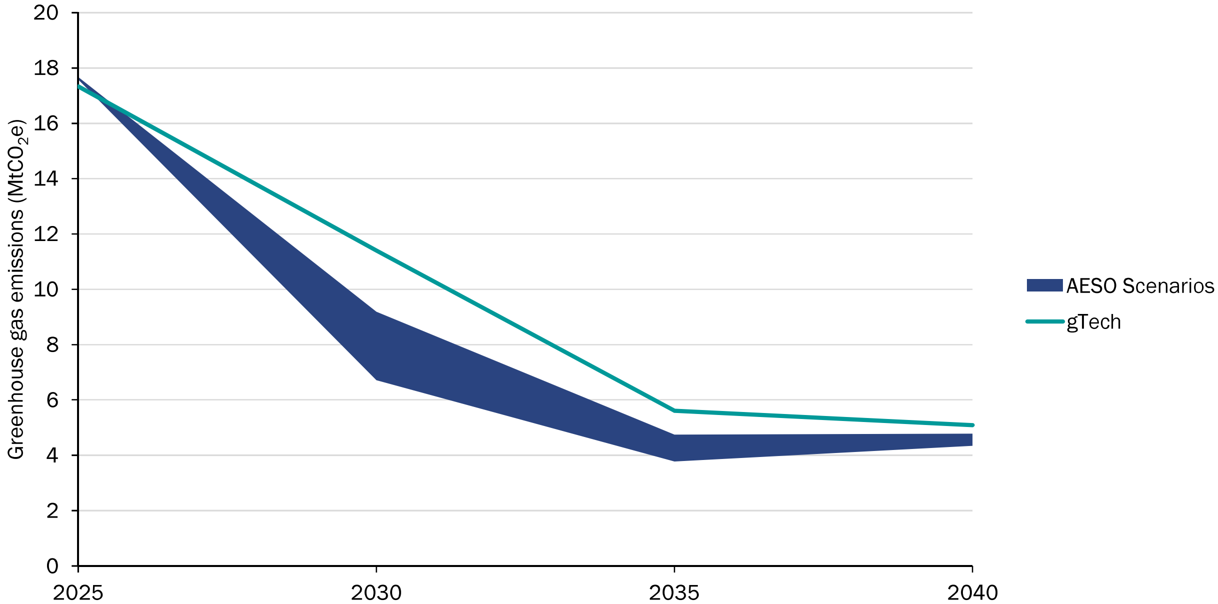
10 Statistics Canada. Report on Energy Supply and Demand in Canada. Available from: https://www150.statcan.gc.ca/n1/en/catalogue/57-003-X

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

12 Statistics Canada. (n.d.). *Data.* Available from: https://www150.statcan.gc.ca/n1/en/type/data?subject_levels=25%2C2504

13 AESO (2022). AESO Net-Zero Emissions Pathways Report. Available at: https://www.aeso.ca/assets/Uploads/net-zero/AESO-Net-Zero-Emissions-Pathways-Report.pdf

Figure 1: Comparison of Alberta's electricity sector emissions between gTech and AESO

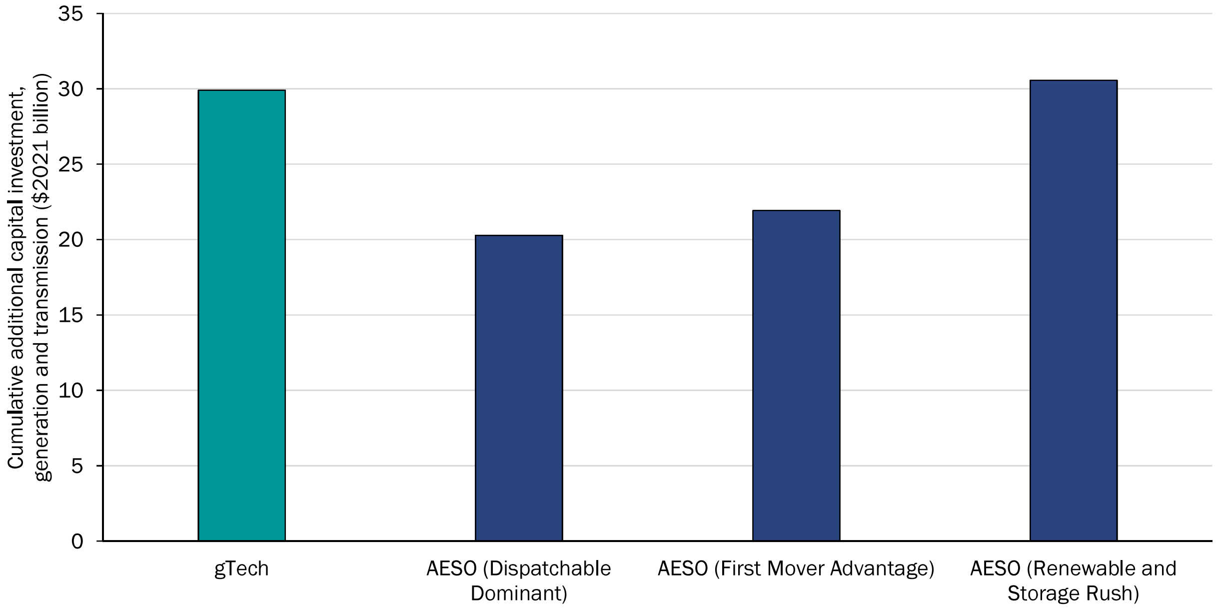


gTech's incremental capital investment under the CER aligns closely with the AESO's Renewable and Storage Rush scenario at about $30 billion[14] cumulatively over the study period.[15] This is illustrated in Figure 2 below.

[14] $2021.

[15] The AESO study presented all estimates in nominal dollars; these were converted to $2021 assuming an average of 2% inflation.

Figure 2: Comparison of capital investment in Alberta's electricity sector between gTech and AESO



The impact of the CER on the levelized cost of electricity in Alberta is consistent between gTech and the AESO's Net-Zero Emissions Pathways Report. The AESO estimated that reaching net-zero in the electricity sector would increase $/MWh costs by $20-50/MWh in nominal terms.[16] The gTech simulation resulted in a price impact of $47/MWh if assuming an average 2% inflation between now and 2040.

2.4. Policy scenarios

Six policy scenarios were simulated for this analysis:

1. **Legislated Policy**
   a. **without the CER:** A Legislated Policy scenario was simulated against which the impacts of Announced Policy (proposed *2030 Emissions Reduction Plan*) and the CER can be measured. This scenario includes currently legislated provincial and federal climate policy to 2040, including the $170/tonne carbon price, the Clean Fuel Regulation, and other currently legislated climate policies as indicated in Appendix C. This scenario excludes policies announced in the federal *2030 Emissions Reduction Plan* that have not yet been implemented.
   b. **with the CER on net-to-grid generation only**: This scenario includes implementation of the CER in addition to Legislated Policy. The CER requires an 80% reduction in emissions by 2035 and excludes emissions associated

[16] AESO (2021), AESO Net-Zero Emissions Pathways Report, figure 42 on page 71.

with behind-the-fence industrial cogeneration. This reflects the proposed approach by ECCC published in the *Proposed Framework for the Clean Electricity Regulations,* in July 2022. This scenario excludes all other policies announced in the federal *2030 Emissions Reduction Plan* that have not yet been implemented.

c. **with the CER including behind-the-fence cogeneration**: This scenario includes implementation of the CER in addition to Legislated Policy, requiring an 80% reduction in emissions by 2035 and includes emissions from behind-the-fence cogeneration. Compared to (b), this would require additional investment to decarbonize industrial electricity generation. Our understanding is that this scenario most closely aligns with modeling work conducted by the AESO, based on the public report and associated data files published by the AESO. This scenario excludes all other policies announced in the federal *2030 Emissions Reduction Plan* that have not yet been implemented.

2. **Announced Policy**[17]

a. **without the CER:** This scenario includes implementation of the federal government's proposed *2030 Emissions Reduction Plan* policies, excluding the CER. This includes a national cap on oil and gas sector emissions, sales mandates for zero-emissions vehicles, an investment subsidy for CCS, and other policies announced in this plan, as outlined in Appendix C. The CER is excluded from this scenario to allow for its impact to be measured by comparing to (b) and (c) below.

b. **with the CER on net-to-grid generation only**: This scenario includes implementation of the CER in addition to all other announced policies. The CER requires an 80% reduction in emissions by 2035 and excludes emissions associated with behind-the-fence industrial cogeneration. This reflects the proposed approach by ECCC published the *Proposed Framework for the Clean Electricity Regulations,* in July 2022.

c. **with the CER including behind-the-fence cogeneration**: This scenario includes implementation of the CER, requiring an 80% reduction in emissions by 2035 and includes emissions from behind-the-fence cogeneration. Compared to (b), this would require additional investment to decarbonize industrial electricity generation. Our understanding is that this scenario most closely aligns with modeling work conducted by the AESO, based on the public report and associated data files published by the AESO.

[17] Note that this includes policies as announced before the 2023 Federal Budget was released.

These six policy scenarios were compared to understand the impact of the CER on Alberta's economy and emissions, as discussed in the following section. Note that unless otherwise specified, we assume behind-the-fence cogeneration is included in the coverage of the CER.

3. Key findings

This section outlines key impacts of the CER in Alberta. Section 3.1 outlines economic impacts and Section 3.2 outlines greenhouse gas (GHG) emission impacts of the policy.

3.1. Economic impacts of the CER

GDP

Figure 3 presents GDP in Alberta under four policy scenarios to demonstrate the impact of the CER on Alberta's economy. When the CER is implemented[18] in addition to Legislated Policy[19], the policy leads to a reduction in Alberta's GDP growth rate, which declines by 0.03% between 2020 and 2040. This means that GDP is $1.9 billion lower in 2030 (0.5%), $3.2 billion lower in 2035 (0.7%), and $2.7 billion lower in 2040 (0.5%) when the CER is implemented, translating to a cumulative GDP impact of about $35 billion between 2020 and 2040 (undiscounted $2015[20]).

When comparing the impact of CER implementation relative to Announced Policy[21], its impact is smaller. This is because many of the actions that help comply with the CER are undergone anyway to comply with other announced policies. For example, there is adoption of CCS across Alberta's economy (for example, in response to the CCS tax credit) which helps drive down costs of the technology. Additionally, CCS is installed on cogeneration in the oil and gas sector to comply with the proposed national cap on oil and gas emissions. When the CER is implemented in addition to Announced Policy, Alberta's GDP growth rate is reduced by 0.01% between 2020 and 2040. This means that GDP is $1.9 billion lower in 2030 (0.5%), $1.8 billion lower in 2035 (0.4%) and $0.7 billion lower in 2040 (0.1%) when the CER is implemented. This translates to a cumulative GDP impact of about $21 billion between 2020 and 2040 (undiscounted $2015).

In addition to the GDP impacts of the CER,

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[18] Note that unless otherwise specified when results are presented, behind-the-fence cogeneration is included in the characterization of the CER.

[19] This scenario includes currently legislated provincial and federal climate policy to 2040, including the $170/tonne carbon price, the Clean Fuel Regulation, and other currently legislated climate policies as indicated in Appendix C.

[20] Note that gTech solves in 5-year increments. GDP impacts between model timesteps were interpolated using a linear trajectory to calculate the cumulative GDP impact.

[21] This scenario includes implementation of the federal government's proposed *2030 Emissions Reduction Plan* policies, excluding the CER.

Figure 3 presents the GDP impact of Announced Policy (i.e., the ERP) relative to Legislated Policy. The complete set of proposed federal policies in the ERP leads to a $6.4 billion reduction in Alberta's GDP in 2030 (1.5%), a $7.5 billion reduction in 2035 (1.6%), and a $4.7 billion reduction in 2040 (0.9%) relative to Legislated Policy. Of this total economic impact of announced policy, the CER impacts (presented above) are a small portion.

Figure 3: GDP in Alberta under four policy scenarios

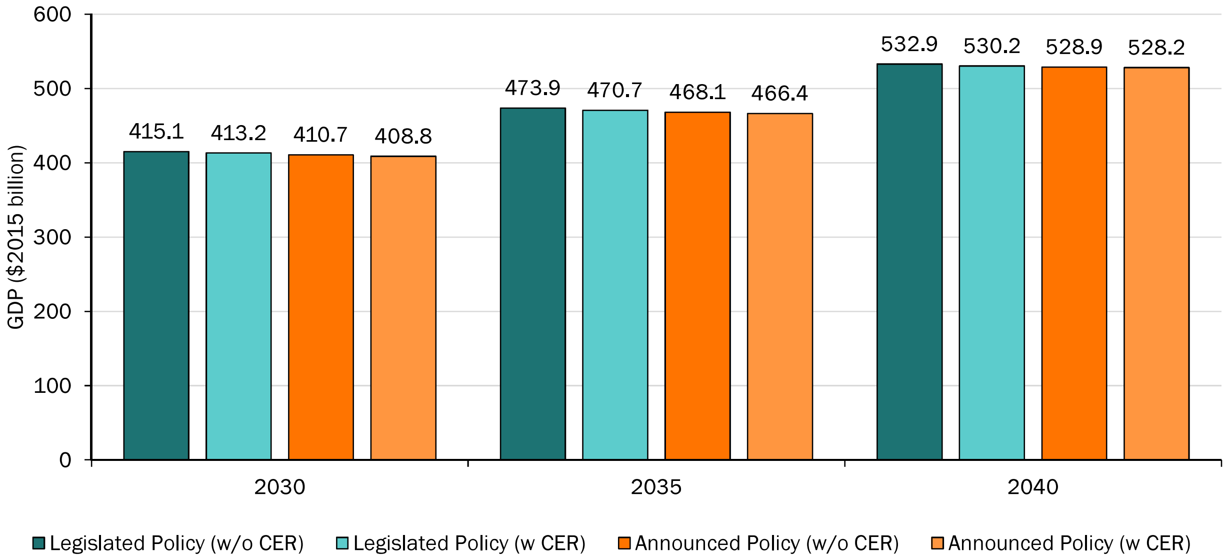
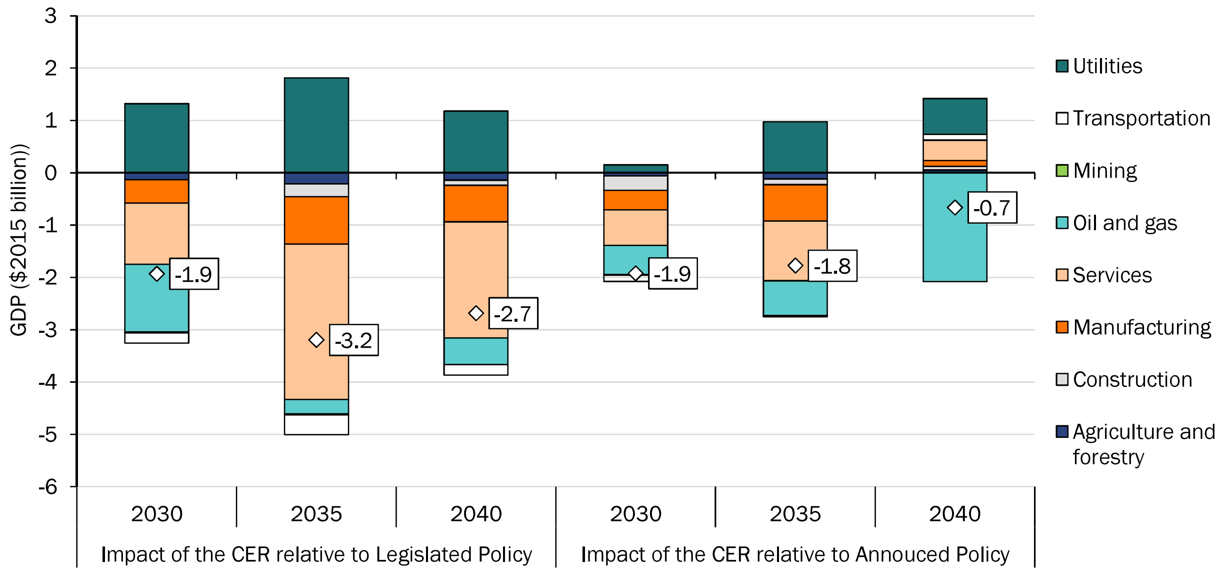


Figure 4 presents GDP impacts by sector of implementing the CER in Alberta. While GDP in Alberta's utility sector is greater when the CER is implemented ($1.8 billion greater relative to Legislated Policy, and $1.0 billion greater relative to Announced Policy in 2035), GDP is lower across most other sectors of the economy when the CER is implemented. The overall negative GDP impact of implementing the CER is driven by GDP reductions in the oil and gas, services, and manufacturing sectors, due to higher electricity costs.

Figure 4: GDP impacts of the CER by sector in Alberta



An important uncertainty explored in this analysis is whether the CER coverage includes behind-the-fence cogeneration or not. Results presented in

Figure 3 and Figure 4 above include scenarios in which CER does include cogeneration. However, if the CER only covers grid generation, the GDP impact of the policy is smaller because it is less stringent. In this case, the cumulative GDP impact of the policy from 2020-2040 is 12% smaller relative to Legislated Policy and 9% smaller relative to Announced Policy (undiscounted $2015[22]).

3.1.1. Investment

Figure 5 presents investment impacts by sector of implementing the CER in Alberta. When the CER is implemented[23] in addition to Legislated Policy[24], investment in Alberta is $3.8 billion higher in 2030, $1.6 billion higher in 2035, and $1.2 billion higher in 2040[25]. Most of the additional investment occurs in Alberta's utilities sector to achieve the GHG reductions required to comply with the CER. Investment in Alberta's

[22] Note that gTech solves in 5-year increments. GDP impacts between model timesteps were interpolated using a linear trajectory to calculate the cumulative GDP impact.

[23] Note that unless otherwise specified when results are presented, behind-the-fence cogeneration is included in the characterization of the CER.

[24] This scenario includes currently legislated provincial and federal climate policy to 2040, including the $170/tonne carbon price, the Clean Fuel Regulation, and other currently legislated climate policies as indicated in Appendix C.

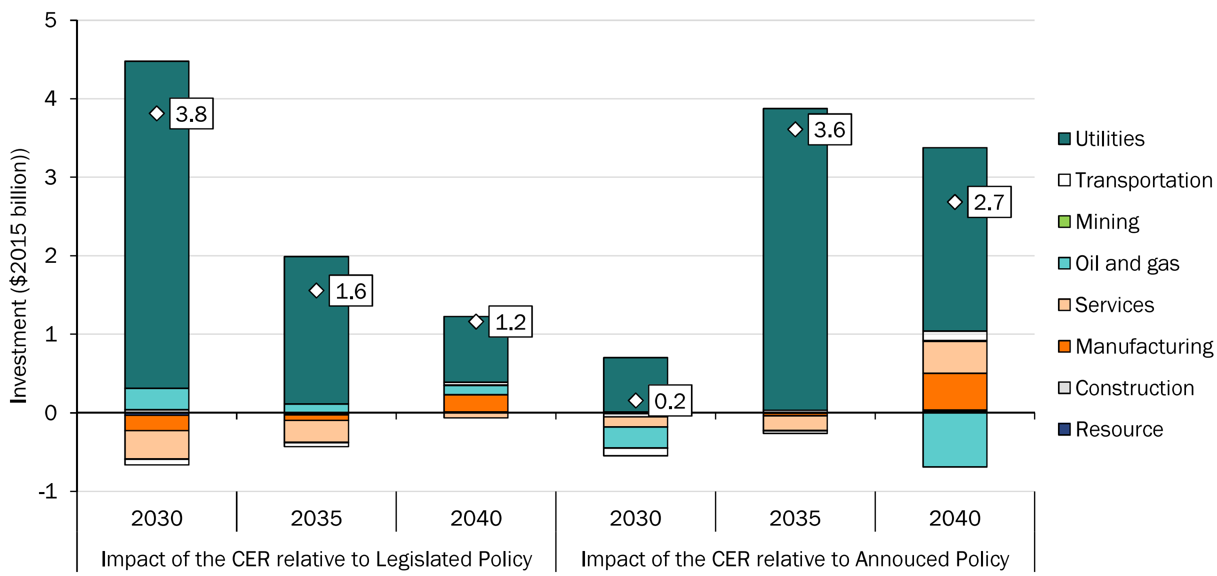
[25] $2015.

utilities sector is $4.2 billion higher in 2030, $1.9 billion higher in 2035, and $0.8 billion higher in 2040 when the CER is implemented in addition to Legislated Policy.

When comparing the impact of CER implementation to Announced Policy[26], the relative increase in investment in response to the policy is greater in 2035 and 2040 than its impact relative to Legislated Policy. This is because Announced Policy leads to greater electricity demand in the province, and as a result greater investment is required to decarbonize the electricity system. Implementing the CER leads to $0.2 billion more investment in 2030, $4.1 billion more investment in 2035, and $2.7 billion more investment in 2040 relative to Announced Policy without the CER.

Increased investment in the electricity sector in response to CER implementation is partially offset by a reduction in investment in other sectors of the economy, including in oil and gas, manufacturing, and services. Total investment in Alberta remains higher in policy scenarios that include the CER.

Figure 5: Investment impacts of the CER by sector in Alberta



3.2. Emission impacts of the CER

Figure 6 presents GHG emissions in Alberta under four policy scenarios to demonstrate the impact of the CER on Alberta's emissions. When the CER is implemented in addition to Legislated Policy[27], the policy leads to a reduction in Alberta's emissions of

[26] This scenario includes implementation of the federal government's proposed *2030 Emissions Reduction Plan* policies, excluding the CER.

[27] This scenario includes currently legislated provincial and federal climate policy to 2040, including the $170/tonne carbon price, the Clean Fuel Regulation, and other currently legislated climate policies as indicated in Appendix C.

12 $MtCO_{2e}$ in 2030, 15 $MtCO_{2e}$ in 2035, and 14 $MtCO_{2e}$ in 2040, translating to a cumulative GHG impact of about 158 $MtCO_{2e}$ between 2020 and 2040. When comparing the impact of implementing the CER relative to Announced Policy[28], its impact is slightly smaller due to overlap with other policies in the ERP which target the same emissions (such as the proposed oil and gas emissions cap). In this case, the CER leads to a reduction in emissions of 5 $MtCO_{2e}$ in 2030, 13 $MtCO_{2e}$ in 2035 and 16 $MtCO_{2e}$ in 2040. This translates to a cumulative GHG impact of about 130 $MtCO_{2e}$ between 2020 and 2040.

Figure 6: Economy-wide emissions in Alberta in four policy scenarios

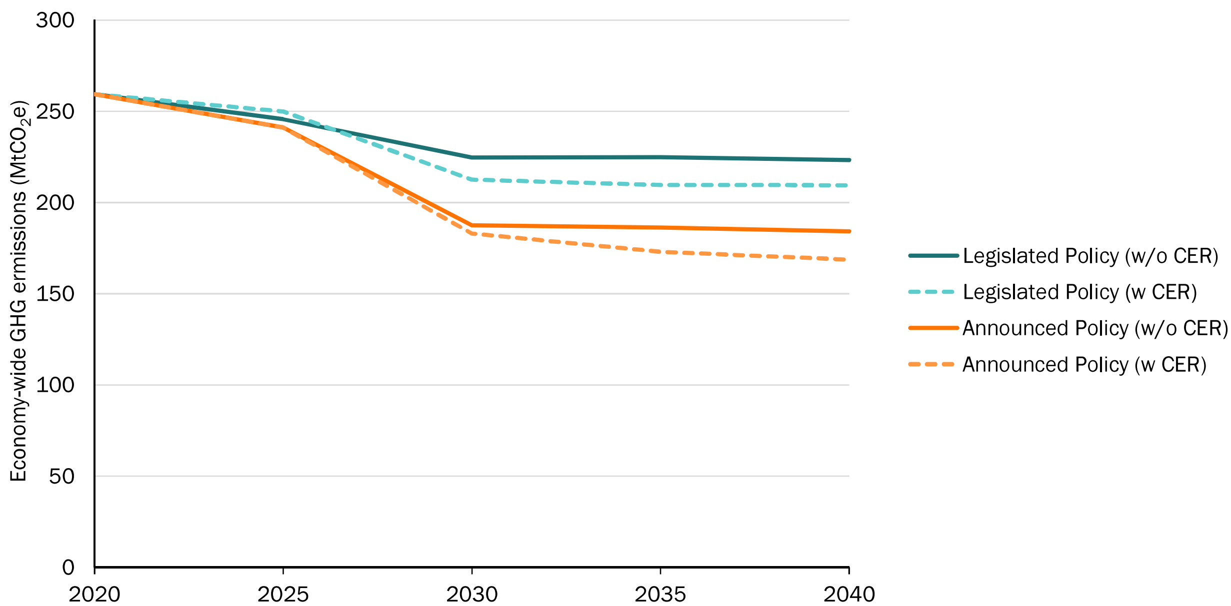
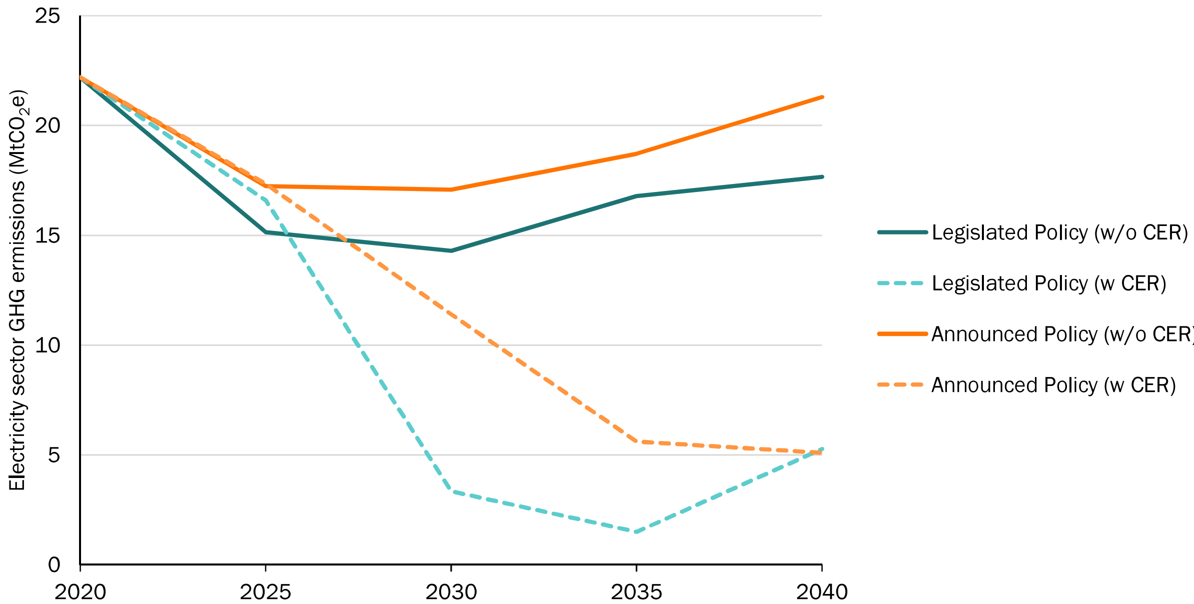


Figure 7 presents electricity sector GHG impacts of implementing the CER in Alberta. Implementation of the CER leads to a significant reduction in electricity sector emissions in the province. Emissions are 11 $MtCO_{2e}$ lower in 2030 and 12 $MtCO_{2e}$ lower in 2040 when the CER is implemented relative to Legislated Policy, and 6 $MtCO_{2e}$ lower in 2030 and 16 $MtCO_{2e}$ lower in 2040 when the CER is implemented relative to Announced Policy.

[28] This scenario includes implementation of the federal government's proposed *2030 Emissions Reduction Plan* policies, excluding the CER.

Figure 7: Electricity sector emissions in Alberta in four policy scenarios



An important uncertainty explored in this analysis is whether the CER coverage includes behind-the-fence cogeneration or not. Results presented in Figure 6 and Figure 7 above include scenarios in which CER includes behind-the-fence cogeneration. However, if the CER covers grid generation only, the GHG impact of the policy is smaller because it is less stringent. In this case, the cumulative emissions impact of the policy from 2020-2040 is 30% smaller relative to Legislated Policy and 16% smaller relative to Announced Policy.

4. Conclusions

Results of this analysis suggest that implementation of the CER leads to smaller GDP growth in Alberta. This is driven by higher electricity costs and lower investment in non-electricity sectors of the economy. However, the economic impact of the CER is a minor portion of the overall cost of policies announced in the ERP, with other policies, such as a cap on oil and gas sector emissions, having a larger economic impact in the province. Implementation of the CER also leads to a significant reduction in emissions from Alberta's electricity sector.

Impacts of the CER on Alberta's economy and emissions differ depending on assumptions about coverage (i.e., whether it includes behind-the-fence cogeneration) and policy overlap (i.e., whether it is implemented in addition to currently legislated policy or in addition to all policies announced in the ERP). If the CER coverage is less stringent by excluding cogeneration or if the CER is implemented in addition to other overlapping policies announced in the ERP, its emissions and economic impacts are smaller.

There are a few uncertainties and limitations of this analysis that are important to note.

- **Ability of industry to deploy CCS:** all the scenarios examined in this report rely heavily on CCS to decarbonize both utility electricity generation and the oil and gas sector. Given the lead times required for large infrastructure projects, this would require rapid deployment of CCS.

- **Policy design of the CER and interactions with other uncertain policies:** this analysis has examined several proposed policies, which do not yet have details about their design announced. For example, in all Announced Policy scenarios, national oil and gas sector emissions are capped at 110 $MtCO_2e$ in 2030, resulting in large-scale decarbonization of cogeneration. Implementation of the CER above-and-beyond these announced policies results in a smaller incremental cost of the CER if implemented with other ERP policies, because there are numerous overlapping pricing, regulatory, and subsidy policies.

- **Electricity price impacts:** Alberta's deregulated electricity system is unique in that it ensures supply adequacy by allowing generators to mark up their bids as high as the market will bear. The introduction of regulations to reach net-zero electricity generation, incentivizing the introduction of additional wind and solar generation, may reduce opportunities to exercise market power, reducing generator margins in the long-term. This has the potential to mitigate some of the upwards pressure on costs associated with decarbonization.

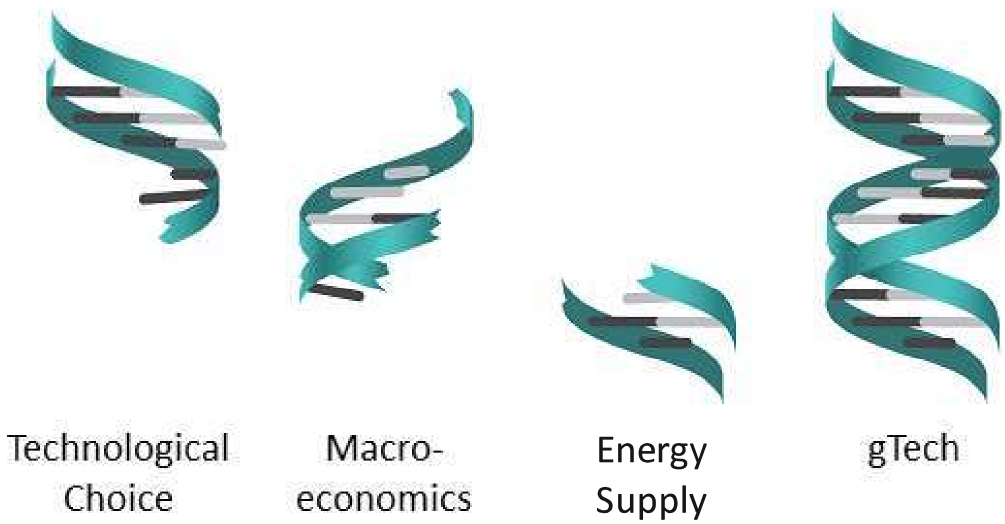
- Sensitivity analysis: this analysis has taken a deterministic approach to assessing the CER's cost. Considering scenarios in which key technologies, such as CCS and renewable electricity generation, are more or less expensive, as well as alternative designs for overlapping policies, would result in higher or lower costs of the policy. We aligned the cost of reaching net-zero in the electricity sector in gTech with the AESO's analysis. However, if the realized post-2030 costs of emerging technologies are lower than the AESO's assumptions, the broader economic impacts would also be smaller.

Appendix A: Introduction to 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 8: 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 over 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 2 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 2: 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.[29] 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.

[29] 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.

Criteria	Description
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[30]. 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).
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[31]. 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[32]. 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.

[30] 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.

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

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

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 3.

Table 3: 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[33]. 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).

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

Dynamic	Description
	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.

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.

Appendix B: Key modeling assumptions

This section outlines key modeling assumptions, including commodity prices, carbon capture and storage technology costs, and the renewable electricity supply curve.

Commodity prices

Oil and natural gas prices are exogenous[34] inputs to the model (i.e., based on an assumed global price). The Henry Hub natural gas price and the WTI oil price are calibrated to the 2021 version of Canada's Energy Future[35] and are summarized in Table 4 below.

Table 4: Oil and gas price assumptions in gTech

Commodity price	2020	2025	2030	2035	2040
Henry Hub Natural Gas (2021 USD/mmBTU)	2.53	3.00	3.18	3.42	3.65
WTI Oil (2021 USD/barrel)	48.5	63.0	63.0	63.0	63.0

Carbon capture and storage

Carbon capture and storage (CCS) technologies are parameterized in gTech based on studies from the Global CCS Institute[36] and the International Energy Agency[37]. Table 5 presents current costs of CCS (first of a kind) and Table 6 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[38]. Additionally, we

[34] An exogenous input refers to an input that is not solved for by gTech but is instead set from an external source.
[35] 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
[36] Global CCS Institute. (2017). Global Costs of Carbon Capture and Storage: 2017 Update.
[37] International Energy Agency. (2011). Cost and Performance of Carbon Dioxide Capture from Power Generation.
[38] 2020 CAD.

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 reduced. A capture rate of 90% is assumed for all CCS technologies.

Table 5: Current (first of a kind) levelized cost of CCS (2020 CAD/tCO_2 reduced)

CCS application	Reference
Utility electricity generation (coal with CCS)	146
Utility electricity generation (natural gas with CCS)	215
Co-generation (natural gas with CCS)	215

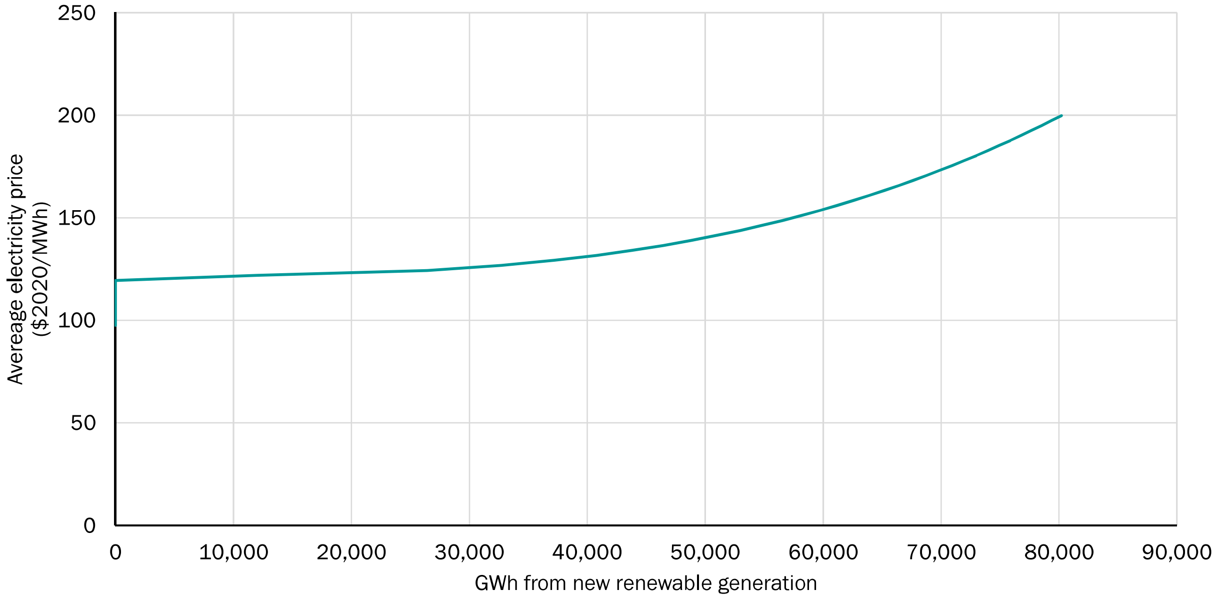
Table 6: Future minimum (n^{th} of a kind) levelized cost of CCS (2020 CAD/tCO_2 reduced)

CCS application	Reference
Utility electricity generation (coal with CCS)	106
Utility electricity generation (natural gas with CCS)	150
Co-generation (natural gas with CCS)	128

Renewable electricity supply curve

The electricity sector in the gTech model is parameterized with a supply curve for renewable electricity. Because generation sources such as wind and solar are intermittent, the cost of incorporating additional supply tends to increase with quantity. This relationship for the Alberta electricity sector is shown in Figure 9 below.

Figure 9: Renewable electricity supply curve in Alberta



Appendix C: Summary of policy characterization by scenario

Table 7 summarizes the federal and provincial policies that are included in the scenarios in this report. While the gTech model includes a representation of all Canadian provinces, provincial policy inputs outside of Alberta (e.g., Ontario's renewable fuel regulations) are held constant across scenarios and not discussed here for conciseness. Note that Announced Policy includes policies as announced before the 2023 Federal Budget was released.

Table 7: Summary of policy inputs

Policy input	Scenario			
	Legislated Policy (w/o CER)	Announced Policy (w/o CER)	CER with net-to-grid generation only	CER including behind-the-fence cogeneration
Carbon price	Rising to $170/t in 2030, held constant thereafter.	Same as Legislated Policy.	Same as Legislated Policy.	Same as Legislated Policy.
TIER high-performance electricity benchmark	370 kgCO2e/MWh, held constant.	Declining to zero by 2035.[39]	Declining to zero by 2035.	Declining to zero by 2035.

39 This modification of the TIER benchmarks is needed to ensure the $170/t price signal remains binding in spite of the federal government's proposed cap on oil and gas emissions. The AESO's net-zero analysis used the assumption that the electricity benchmarks would decline to zero by 2035 in a net-zero policy scenario. This same

Clean electricity regulation	None.	None.	Modeled as a performance standard, with national electricity emissions declining to 80% below present levels by 2035, covering emissions from public electricity generation and net-to-grid cogeneration.	Same as the "+CER" scenarios but achieving the same emissions reduction *including* behind-the-fence cogeneration.
Coal-phaseout[40]	Phase-out of coal-fired power plants by 2030 unless they emit less than 420 tonnes CO_2e/GWh.	Same as Legislated Policy.	Same as Legislated Policy.	Same as Legislated Policy.
Alberta Renewable Electricity Act[41]	Alberta achieves 30% renewable electricity generation by 2030.	Same as Legislated Policy.	Same as Legislated Policy.	Same as Legislated Policy.

assumption was used in the Announced Policy scenario; if benchmarks are held constant at 370 $kgCO_2$/MWh while the rest of the ERP is implemented, this results in a net surplus of TIER credits and a carbon price much lower than $170/tonne.

40 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

41 Government of Alberta (2023). Renewable energy legislation and reporting. Available from: https://www.alberta.ca/renewable-energy-legislation-and-reporting.aspx#:~:text=The%20Renewable%20Electricity%20Act%20outlines,30%25%20renewable%20electricity%20by%202030.

Federal cap on oil and gas emissions[42]	None.	Emissions capped at 110 MT starting in 2030, held constant thereafter. Revenue recycled to industry as a per-barrel/per-bcf output-based subsidy.		
Investment Tax Credit for Carbon Capture Utilization and Storage[43]	None.	45% of project capital expenditures until 2030, 20% thereafter. Based on the assumption that 10-15% of capital expenditures are design costs, ineligible for the credit.		
Methane regulations[44]	Achieves 75% reduction in emissions intensity of methane from oil and gas sector by 2030.	Same as Legislated Policy.	Same as Legislated Policy.	Same as Legislated Policy.

[42] Government of Canada. (2022). Oil and gas emissions cap. Available from: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap.html

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

[44] 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

Clean fuel regulation[45]	14 gCO2e/MJ reduction requirement by 2030, held constant thereafter.	Same as Legislated Policy.	Same as Legislated Policy.	Same as Legislated Policy.
Light-duty zero emissions vehicle sales mandate[46]	None.	60% by 2030 and 100% by 2035		
Medium/heavy duty zero emissions vehicle sales mandate[47]	None.	Achieving 30-35% of medium duty sales by 2030 as zero-emissions, and 70% by 2040. Achieving about 15% of heavy-duty sales in 2030 and 20% in 2040.		
Budget 2023 investment and	Not included (modeling work conducted prior	Not included.	Not included.	Not included.

[45] Government of Canada. (2022). Clean Fuel Regulations (SOR/2022-140). Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2022-140/index.html

[46] 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

[47] 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

production tax credits[48]	to the release of the budget).

[48] Government of Canada. (2023). Budget 2023, Chapter 3: A Made-In-Canada Plan: Affordable Energy, Good Jobs, and a Growing Clean Economy. Available at: https://www.budget.canada.ca/2023/report-rapport/chap3-en.html

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