Achieving net-zero pathways for Canada

Interim paper 1:
What progress are we on track to make by 2050?

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Executive Summary

In early 2022, Clean Prosperity initiated a policy-focused modelling project to explore pathways to achieving net-zero emissions across the Canadian economy by 2050.[1] Working with Navius Research, we are conducting this multi-year effort to build on the work and findings of other Canadian and international net-zero studies. Our goal is to model the broader energy-system implications of a net-zero transformation across sectors, geographies, and technologies, as well as to examine the policies and infrastructure required to achieve these outcomes.

Our objectives for the full project are to:

1. model the impact of present-day climate-policy scenarios to establish our current emissions trajectory and progress toward net-zero emissions;
2. model potential energy-system pathways for Canada to build further understanding of the challenges, opportunities, and trade-offs involved in achieving net-zero;
3. examine how various policy configurations can lead to additional emission reductions and ultimately help Canada achieve net-zero; and,
4. use mapping analysis to assess modelling outcomes against Canada's existing resource and infrastructure assets and thus further inform the scale of effort needed to meet net-zero goals.

Another aim of our work is to help foster transparency in communicating modelling approaches, assumptions, and limitations.[2] To achieve this aim, we will share our working assumptions, process, and progress over time. This interim paper is thus the first of a series that builds toward our final report. A separate modelling methodology report by Navius Research accompanies this paper.[3]

Context for interim paper 1

In this paper, we describe our modelling approach, review Canada's anticipated emissions trajectory toward net-zero emissions based on modelling current climate policy, and introduce our five net-zero energy-system pathways.

1 The Canadian Climate Institute (CCI) has defined net-zero emissions for Canada as "An energy and economic system in which Canada's total [greenhouse gas] GHG emissions from energy production and consumption, industrial processes, and land use, minus 'negative emissions' (or carbon dioxide removal) from nature-based solutions and engineered interventions results in a sum total of zero net emissions." From CCI. (2021). *Canada's Net-Zero Future: Finding Our Way in the Global Transition.* Retrieved from
https://climatechoices.ca/wp-content/uploads/2021/02/Canadas-Net-Zero-Future_FINAL-2.pdf
For an overview of Canada's net-zero target, see: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

2 As Canadian and other modelling experts have noted, such communication has been limited in net-zero modelling work to date. See: McPherson, *M. et. al.* (2022). Open-source modelling infrastructure: Building decarbonization capacity in Canada. *Energy Strategy Reviews, 44,* 100961. Also, Nikas, A. *et al.* (2021). Perspective of comprehensive and comprehensible multi-model energy and climate science in Europe. *Energy, 215,* 119153.

3 Assumptions concerning input costs, declining technology costs, and market forces such as behaviour are documented in the separate Navius methodology report.

Canada's Emissions Reduction Plan to 2050

In March 2022, the federal government released its climate plan — the 2030 Emissions Reduction Plan (ERP) — which identifies the measures and strategies needed to reach 2030 emission targets and lays the foundation for achieving net-zero emissions by 2050. In this paper, we independently analyze the effectiveness of ERP climate policies and subsequent announcements in meeting 2030 emission targets and in achieving net-zero emissions by 2050. These policies are further detailed in this report. We assume that, by 2050, 50 megatonnes of emissions per year can be removed through land use, land use change, and forestry. This 50 megatonnes is our "net-zero" target.

We also model a policy rollback scenario (RBK) to contrast ERP outcomes against those of a regressive climate policy trajectory.[4] Because we are interested in understanding the impact of current-day policy into the future, both of these scenarios are unconstrained (i.e., they are not capped or forced to meet net-zero).

Key findings

As a signatory to the global Paris Agreement, Canada has committed to establish a climate action plan to cut emissions and adapt to climate impacts, referred to as its nationally determined contribution, or NDC.[5] In the near term, we find that our ERP scenario will fall short of achieving the NDC target Canada announced in 2021, which is to reduce emissions to levels 40% to 45% below 2005 levels[6] by 2030. Our results indicate that, by 2030, Canada will instead achieve only 31% below 2005 values, even given our optimistic assumption that all legislated policy is successfully executed in a timely and optimal manner.[7,8] These findings are consistent with the results of the modelling underlying Canada's ERP, which find that all announced policies would lead to a 32% reduction in emissions, not including nature-based solutions (which would reduce emissions still further).[9]

In our extended analysis of ERP to 2050, we have also found that, although the ERP policy package[10] reduces annual emissions over time, Canada will fall significantly short of achieving net-zero emissions by mid-century. By 2050, our model projects

4 The RBK scenario includes provincial policy legislated as of November 2021, and regresses legislated federal carbon pricing and regulatory climate policies to those in place before the plan A Healthy Environment and a Healthy Economy was enacted in December 2020.

5 Each party to the Paris Agreement is required to establish a nationally determined contribution and update it every five years.

6 2005 values are reported as 741 Mt based on Canada's 2022 National Inventory Report.

7 We do not model the impact of policies such as the Canada Green Building Strategy, which, to date, has limited detail on deployment tactics. We have also included further detail from the 2022 federal budget (Budget 2022), such as the details of the investment tax credit for carbon capture, utilization, and storage and direct air capture, as well as expanded heavy-duty vehicle subsidies.

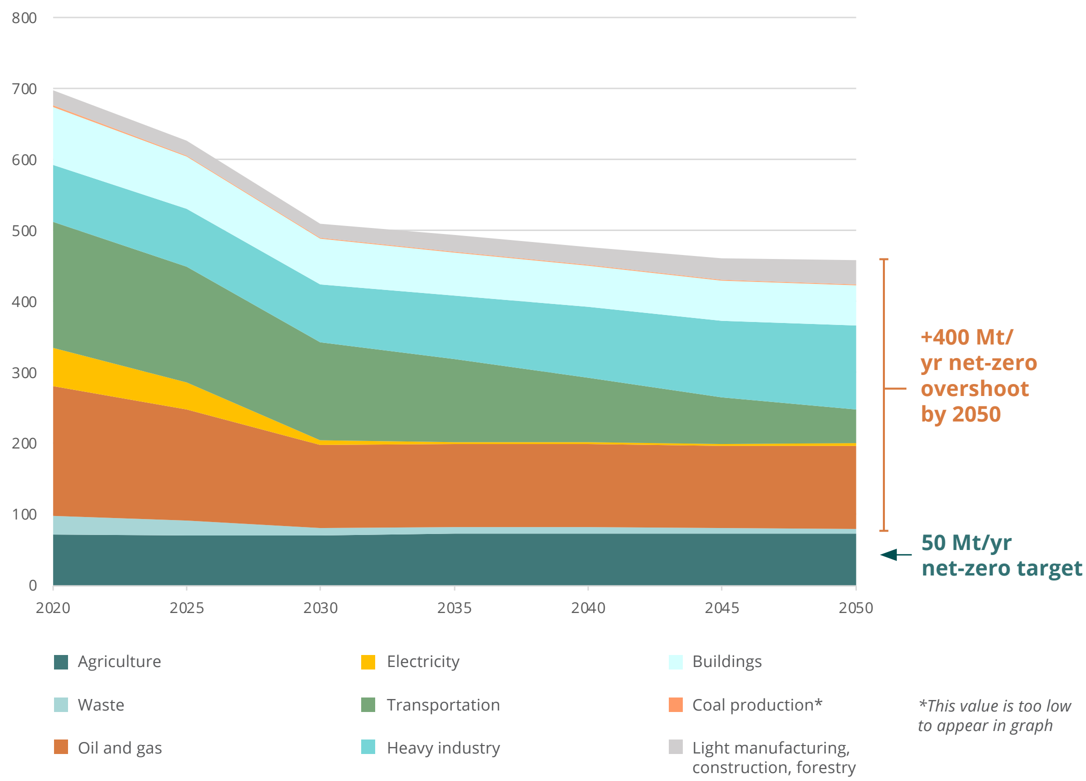
8 New information on the Clean Electricity Regulations released as of this writing state that the Regulations will now only be binding in 2035. Accounting for this development would result in higher 2025 and 2030 electricity emissions, and mean that we see less progress in reductions achieved than the 31% we report here. This update will be included in our future work.

9 Not including nature-based solutions. Government ERP modelling assumes an additional 30 megatonnes of carbon dioxide equivalent per year of reductions from agriculture, nature-based carbon solutions, land use, land-use change, and forestry by 2030, which bring the estimated reduction to 36% by 2030. See p. 193: https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf

10 The ERP policy package refers to the set of policies included in the federal ERP. See Appendix B.

459 megatonnes of emissions per year under ERP policies, which exceeds Canada's net-zero goals *(Figure E.S.1)* by 400 megatonnes per year (Mt CO_2e/yr).[11]

FIGURE ES.1: Emissions overshoot by 2050, ERP scenario, contribution of industrial sectors (Mt CO_2e/yr)



This model result suggests that our current emissions trajectory is not yet fully aligned with the *Canadian Net-Zero Emissions Accountability Act*, which legislates Canada's commitment to achieve net-zero emissions by 2050. The Act requires the federal government to have a plan to meet the 2030 target and to show how such measures will contribute to net-zero emissions by 2050. In this paper, we argue that net-zero measures need to be more thoroughly considered in planning and reporting for the Act to have a realistic chance of meeting Canada's targets.[12]

This point noted, it is worth emphasizing that by 2050, the ERP scenario does show progress over time, especially in comparison to our climate policy rollback scenario (RBK) scenario. For ERP, 2050 brings a 38% reduction in annual emissions compared to 2005 values, and additional policies that have been announced since the ERP would likely reduce emissions even further. This is in significant and sharp contrast to the RBK trajectory, which exhibits only a 6% decline in annual emissions by 2050.

11 We assume a net-zero target of 50 megatonnes of carbon dioxide equivalent per year by 2050 that can be removed by land use, land-use change, and forestry.

12 *"The Canadian Net-Zero Emissions Accountability Act*, which became law on June 29, 2021, enshrines in legislation Canada's commitment to achieve net-zero emissions by 2050. The Act ensures transparency and accountability as the government works to deliver on its targets. The Act requires public participation and independent advice to guide the Government of Canada's efforts." From: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

This RBK result clearly highlights the risk and emissions impact of even moderate regression in climate policy.

Using 2020 as the year for comparison, highlights from our extended analysis of ERP policies to 2050 include the following:

- Due to a policy focus on electrification of the economy, the ERP scenario projects a 31% rise in electricity generation by 2050, which is 9% higher than projected under the RBK trajectory in 2050. This modest rise in generation is largely met by new solar and wind power, while natural gas plants are retrofitted with carbon capture, utilization and storage (CCUS). These differences are due in part to the impact of the federal Clean Electricity Regulations.[13] The regulations support the adoption of clean energy as well as natural gas with CCUS (consistent with the government's own ERP modelling assumptions).
- Regional differences in electricity generation projections may have implications for provincial energy planning. Under both of our baseline scenarios, British Columbia exhibits growth in electricity generation of 61 terawatt-hours (in RBK) to 82 terawatt-hours (in ERP) by 2050. This growth is largely due to the anticipated electricity demand associated with liquefied natural gas development for export included in our model. This amount is equivalent to 10% to 13% of Canada's present-day electricity generation.[14]
- CCUS accounts for 33% of economy-wide emission reductions projected under the ERP scenario, capturing an estimated 79 megatonnes per year in 2050. In this scenario, CCUS becomes an economically favourable option with support of the investment tax credit for CCUS and regulatory measures included in ERP policy. The finding suggests that the ERP as modelled is influencing investment flows to specific decarbonization technologies. We also note this is a significant capture value and would require that many projects are initiated in the next 12–24 months, given the time required to design, permit, and build large decarbonization projects. The absence of direct air capture (DAC) in the results for both ERP and RBK scenarios — despite the fact DAC is also supported in the federal investment tax credit — suggests that additional policy measures are needed to facilitate adoption.[15]
- Large declines in emissions are expected in electricity generation,[16] transportation and the oil and gas sectors in the ERP scenario. The transportation sector in particular makes up a hefty 54% of the emissions decline projected by 2050.
- The oil and gas emissions cap proposed in the ERP,[17] as well as commitments to reduce upstream methane emissions, are major contributors to lowering oil and gas

13 The regulations are still under development as indicated in Footnote 8. For the Clean Electricity Regulations, our model assumes a linear stringency increase between 2025 and net-zero in 2035 for utility-generation greenhouse gas emissions, while allowing for offsets and CCUS for natural gas.

14 Equivalent to 10% to 13% of 636 terawatt-hours (Canada's current annual generation).

15 DAC technologies are currently very expensive and not well developed. In addition to adoption incentives, measures to support further research, development, and scaling of DAC may be key to unlocking the potential of these technologies.

16 This refers explicitly to a decline in emissions from generation, not to the energy required by the electricity sector to produce electricity.

17 Modelled to reach a 42% reduction by 2030 (119.94 megatonnes) and assuming no further regulated emission reductions via the cap beyond 2030.

sector emissions by about 37% under the ERP scenario by 2050. However, at 116 megatonnes of emissions per year, the sector is the second largest emitter in 2050. Approximately 40% of emissions reductions in the oil and gas sector are attributable to CCUS, which is projected to capture 27 megatonnes per year by 2050.

- Heavy industry continues to be a high-emitting sector and, by 2050, becomes the highest-emitting sector under the ERP scenario, accounting for 117 megatonnes of emissions per year. This is due, in part, to growing annual emissions contributions from chemicals and fertilizers, which becomes the highest-emitting sub-sector by 2050. This suggests that heavy industry remains a significant sector to target for further measures to reduce emissions.

Net-zero pathways

In this paper, we also introduce our five technology pathways that characterize a range of energy system futures for Canada ("net-zero pathways"). These pathways are:

- High Electrification,
- High Electrification with Renewables,
- Bioenergy,
- Hydrogen, and
- Fossil with CCUS.

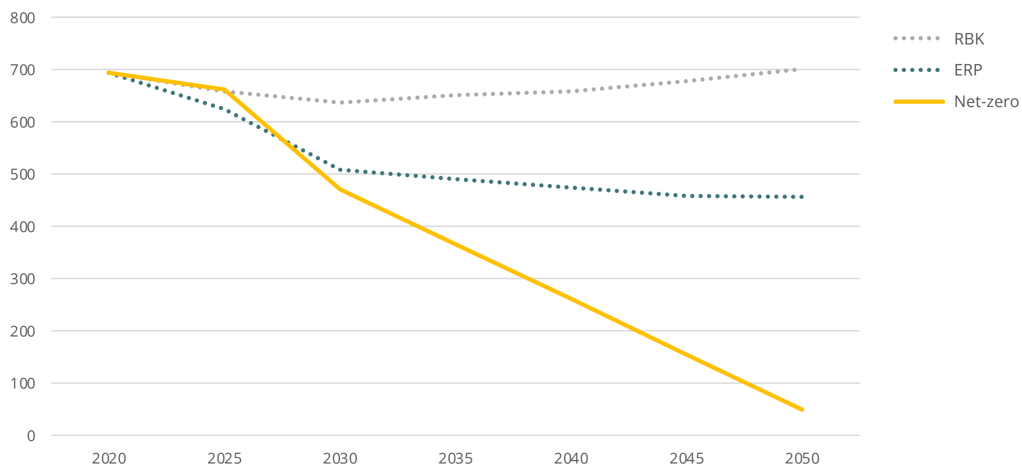
Each of these pathways is set to reach 50 megatonnes of annual emissions by 2050. As previously noted, we assume that 50 megatonnes of emissions a year by 2050 can be removed by land use, land use change, and forestry (LULUCF), thereby achieving net-zero emissions per year by mid-century.[18] Our pathways were developed to reflect a range of policy routes and technological areas of focus that can take Canada toward its net-zero objective. The pathways are defined by differing availability, input costs, and other variables associated with selected technologies, which are represented in the starting parameters of the model.

Key findings

For Canada to meet its net-zero objectives, our results show that all five pathways require an immediate increase in energy efficiency, fuel switching, as well as substantially increased electricity generation, storage, capture, and related infrastructure *(Figure ES.2)*. These results indicate that delaying opportunities for near-term emission reductions will likely significantly increase the technical challenges in meeting 2050 targets, as well as their costs. Given the scale of change required, this stresses the critical need to "backcast" from an intended future goal of net-zero emissions and systematically integrate this goal into present-day policy development.

18 We opt to be more conservative in our assumptions concerning land use, land-use change, and forestry (LUCUCF), and assume a target of 50 megatonnes of sequestration is achievable by LULUCF annually by 2050. The Government of Canada models 100 megatonnes in its reporting (per Canada's long-term strategy submitted to the United Nations Framework Convention on Climate Change). See: https://unfccc.int/sites/default/files/resource/LTS%20Full%20Draft_Final%20version_oct31.pdf

FIGURE ES.2: Annual emissions trajectories of ERP and RBK scenarios and net-zero pathways to 2050 (Mt CO_2/year)[19]



Further development of the net-zero pathways and related aspects such as infrastructure and policy options will be the subject of our ongoing work, however preliminary observations include that:

- We see varied contributions of emerging technologies like DAC across pathways, particularly in our fossil-based energy pathways. We also see significant use of CCUS across pathways. Combined, DAC and CCUS in our Fossil with CCUS pathway is projected to capture 415 megatonnes of emissions per year by 2050 (62% captured by DAC and 38% captured by CCUS).
- In our two electrification-based pathways, an increase in electricity generation of about 83% to 86% is anticipated by 2050 compared to 2020 model data.[20] Depending on the energy system direction, pathway requirements translate to between 66% and 215% of added wind and solar generation. All the pathways assume net new solar and wind build-out ranging from about 237 to 717 terawatt-hours by 2050, which is six to 18 times that of 2020 solar and wind generation estimates.
- All net-zero pathways show a significant increase in energy storage by 2050. The magnitude of storage currently estimated in the model ranges considerably among the pathways. For electrification-focused outcomes, storage would need to be approximately 84 to 105 times that in 2020 estimates. Storage is also prominent in our ERP-based outcomes, which also anticipate significant growth in electricity generation from renewables. This suggests the cross-cutting nature of energy storage across all pathways. This also highlights the potential importance of programs such as the Smart Renewables and Electrification Pathways Program, which received additional funding in the 2023 federal budget.[21]

19 The net-zero pathway shown here is the average emissions trajectory across our five pathways.
20 The 2020 model data represent a five-year average and should not be conflated with empirical data from 2020.
21 The program supports investments in smart renewable energy and electrical-grid modernization projects, such as energy storage.

Although our net-zero analysis is preliminary, some of these initial observations (such as the expectation for DAC, the projections for solar and wind build-out, the significant increase in electrification and cross-cutting nature of storage) suggest that much stronger measures are required and that the planning time horizon for deployment is immediate. In our next project phases, we will simulate the impact of various policies that can help us move closer to our net-zero goals as well as incorporate the new policy measures announced in the 2023 federal budget.

As a closing observation, we note the importance of considering the accumulation of emissions over time. Model estimates indicate that, by 2050, Canada's cumulative greenhouse gas contribution under the ERP trajectory will make up 4% of the remaining global carbon budget of approximately 420 gigatonnes.[22,23] This is greater than Canada's current share of annual global emissions, estimated at 1.5% in 2019.[24] This issue is complex and subject to debate, but, by most accounts, 4% of the global carbon budget is more than Canada's "fair share"[25] and makes it imperative to accelerate efforts to reduce annual emissions immediately.

22 The Intergovernmental Panel on Climate Change's (IPCC's) 2021 Special Report *Global Warming of 1.5°C* suggests a remaining global carbon budget of about 420 gigatonnes of carbon dioxide for a two-thirds chance of limiting warming to 1.5°C and of about 580 gigatonnes of carbon dioxide for an even chance of limiting warming to that goal *(medium confidence)*. However, a number of other factors significantly complicate the certainty of these estimates, including geophysical uncertainty, uncertainty in the level of historic warming, and many other factors. See: https://www.ipcc.ch/sr15/chapter/chapter-2/

23 We note that the IPCC's global carbon budget reflects carbon dioxide only, whereas our emissions estimates are in carbon dioxide equivalent (CO_2e, or total greenhouse gases). Ultimately, Canada's current estimated CO2e trajectory will still contribute carbon dioxide "equivalent" to the global carbon budget, however we recognize that several nuances to this argument remain to be considered (such as the varying residence time in the atmosphere of non-CO_2 GHGs, among other factors).

24 See: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/global-greenhouse-gas-emissions.html

25 Given that Canada's population is 0.48% of the world total and Canada contributes 1.2% of global gross domestic product. Canada also has a long history of producing industrial greenhouse gas emissions and in 2019, ranked as the 10th largest emitting country or region. See: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/global-greenhouse-gas-emissions.html

1. Introduction

In March 2022, the Canadian government released its Emissions Reduction Plan (ERP). This plan consists of a set of federal policies aimed at achieving a target of reducing emissions to 40% to 45% below 2005 levels by 2030 and laying the foundation to meet net-zero by 2050.[26,27] Spanning a broad range of sector-based policies, consumer incentives, and economy-wide measures such as carbon pricing, the plan has been touted as an ambitious roadmap to achieving Canada's climate goals.

The ERP and the accompanying accountability framework laid out in the *Canadian Net-Zero Emissions Accountability Act* are a meaningful step toward addressing climate change mitigation in Canada. However, questions still remain concerning whether ERP policies are sufficient to reach 2030 targets and consistent with 2050 ambitions, and, if they are not, what further steps may be required. In this first paper, our primary goal is to independently review the effectiveness of ERP policies in terms of meeting Canada's stated 2030 emissions targets and, especially, 2050 net-zero ambitions.

The effectiveness of ERP and prior federal climate policy to meet 2030 emission targets has been estimated by various organizations, including the Government of Canada, the Canadian Climate Institute,[28] and Clean Prosperity in 2021.[29] Our current analysis includes further updates to the ERP and extends the analysis to look at the ERP's impact to the 2050 time horizon. Recognizing that global socio-economic challenges and geopolitical shifts can result in climate policy deprioritization, we also simulate a scenario in which climate policy is "rolled back" (RBK) to a less comprehensive approach as a point of comparison.[30]

Our secondary aim in this paper is to introduce five technology pathways that align with selected themes of net-zero opportunities specific to Canada. These net-zero pathways are the main focus of research and exploration over the remaining course of this project.

26 Government of Canada. (2022). 2030 Emissions Reduction Plan: clean air, strong economy. Retrieved from https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

27 In July 2021, Canada submitted a stronger nationally determined contribution target to cut emissions by at least 40%–45% below 2005 levels by 2030, up from the previous target of 30% (including land use, land-use change, and forestry). The ERP sets out to achieve an approximately 40% reduction to 443 megatonnes (Mt) carbon dioxide equivalent (CO_2e) in 2030. See p.89 in : https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan.html

28 Sawyer D., Griffin, B., Beugin, D., Förg, F., & Smith, R. (April 2022). Independent Assessment of the 2030 Emissions Reduction Plan. Retrieved from the Canadian Climate Institute website: https://climateinstitute.ca/wp-content/uploads/2022/04/ERP-Volume-2-FINAL.pdf

29 Bernstein, M., Sawyer, D., Siebert, S., Wadland, J. & Clark, J. (2021). Assessing the 2021 Federal Liberal Climate Plan. Retrieved from the Clean Prosperity website: https://cleanprosperity.ca/wp-content/uploads/2021/10/Clean_Prosperity_LPC_Climate_Policy_Report_2021.pdf

30 The RBK scenario reverts back to the year 2020, and thus includes all federal policy in place before the release of the federal climate plan A Healthy Environment and Healthy Economy in December 2020. The "climate policy rollback scenario" applies the Pan-Canadian Framework on Clean Growth and Climate Change carbon tax schedule.

Net-zero studies to date

Much study and attention has been placed on net-zero in recent years. Significant net-zero modelling efforts in the United States include work conducted by Princeton University,[31] the Electric Power Research Institute,[32] and Energy Innovation,[33] among others. Salient Canadian efforts include the following reports, among others not cited here. Our work seeks to complement and, in some instances, extend analyses to the broader energy system and over the 2050 timescale.

- Environment and Climate Change Canada (2022)[34] has modelled the Emissions Reduction Plan and explored different approaches to achieving net-zero emissions by 2050. This analysis considered several enabling conditions that could play an important role in meeting the net-zero goal, such as widespread electrification, use of renewable fuels, and use of carbon capture, utilization, and storage.
- A report by Clean Energy Canada (2023) projects that Canadian jobs in clean energy will grow by 7% per year between 2025 and 2050 under a net-zero scenario. The report also examines possible job trends in Canada under current policy and rollback policy scenarios, given the global changes in energy policy.
- The Canadian Climate Institute's (CCI's) report Canada's Net Zero *Future: Finding Our Way in the Global Transition* (2021)[35] examines pathways to achieve a net zero economy by 2050, distinguishing between "safe bets" and "wild card" technologies on the basis of their commercial viability and associated uncertainties.
- The Electric Power Research Institute's *Canadian National Electrification Assessment Report* (2021)[36] analyzes how Canada can achieve cost-effective decarbonization by harnessing its high electrification potential and using a low-emitting electricity mix. The report considers an extended policy scenario that continues the historical trend in climate policy and a net-zero emissions scenario that incorporates a high carbon price, strict industry and vehicle standards, and carbon removal technologies, in tandem with widespread electrification and decarbonization of the electricity sector.

31 Initially issued in October 2021, this two-year effort resulted in a detailed technical examination of five pathways to net-zero emissions, including analyses of major transformations in physical infrastructure, capital mobilization, land use, energy workforce, air pollution, and public health. Princeton University. Net- Zero America: Pathways, Infrastructure, and Impacts. Retrieved from https://netzeroamerica.princeton.edu/.The recently launched REPEAT Project builds on this work by examining the evolving national policy environment and progress toward net-zero emissions. See: https://repeatproject.org.

32 See: https://www.epri.com/research/programs/109396/announcements/48WwROKcbuMMGI0frCllFo

33 See: https://energyinnovation.org/publication/a-policy-pathway-to-reach-u-s-net-zero-emissions-by-2050/

34 See: https://unfccc.int/sites/default/files/resource/LTS%20Full%20Draft_Final%20version_oct31.pdf

35 See: https://climatechoices.ca/wp-content/uploads/2021/02/Canadas-Net-Zero-Future_FINAL-2.pdf

36 Available upon request from: https://www.researchgate.net/publication/354922494_Canadian_National_Electrification_Assessment_Electrification_Opportunities_for_Canada%27s_Energy_Future

- The David Suzuki Foundation's report *Shifting Power: Zero-Emissions Electricity Across Canada by 2035* (2022)[37] uses scenario modelling to explore two net-zero pathways. These pathways integrate large increases in solar and wind electricity generation with energy storage, inter-provincial grid connections, and energy-efficiency gains.

- The Canada Energy Regulator's (CER's) *Canada's Energy Future 2021* report[38] examines an evolving policy scenario along with six net-zero energy-system scenarios to understand what net-zero emissions means for Canada's electricity sector. The authors incorporate a broad range of technological, market, and policy assumptions to project trends in energy demand, fossil fuel production, electricity generation, and macroeconomic indicators.

- The Bank of Canada and the Office of the Superintendent of Financial Institutions' (2022) report *Using scenario analysis to assess climate transition risk*[39] looks at scenarios that vary in terms of climate-mitigation goals, timing of global policy, and pace of technological change. The pilot project detailed in the report was intended as an integral step toward understanding climate-related risks to the macroeconomy and the financial system.

- A 2021 report by Institut de l'énergie Trottier *On the way to net-zero: The 2030 milestone*[40] compares three modelling exercises (by the CER, Horizon 2060 by Institut de l'énergie Trottier and e3cHub, and Environment and Climate Change Canada) to examine the transformation required to reach the sectoral emissions reductions projected in these scenarios. The authors identify policy gaps and challenges for reaching 2030 targets and long-term net-zero commitments.

In its 2022 report *Bigger, Cleaner, Smarter: Pathways for Aligning Canadian Electricity Systems with Net Zero*,[41] CCI provides a summary table on the major Canadian electrification-focused studies and their parameters.

37 See: https://davidsuzuki.org/science-learning-centre-article/shifting-power-zero-emissions-electricity-across-canada-by-2035/
38 See: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/
39 See: https://www.bankofcanada.ca/wp-content/uploads/2021/11/BoC-OSFI-Using-Scenario-Analysis-to-Assess-Climate-Transition-Risk.pdf
40 See: https://iet.polymtl.ca/en/publication-en/on-the-way-to-net-zero-the-2030-milestone/
41 See: https://climateinstitute.ca/wp-content/uploads/2022/05/Bigger-Cleaner-Smarter-May-4-2022.pdf

2. Methodology

For this work, we use a modelling approach to simulate the impact of various policy forces on Canada's coupled energy-economy system. We employ Navius Research's energy-economy model, gTech, in conjunction with their supporting electricity model, summarized below. Navius Research is releasing a separate report detailing the modelling methodology and assumptions used in this paper.

2.1 Navius gTech model

gTech is an energy-economy general equilibrium model that accounts for a range of features, such as:

- technology and consumer preferences, for example, through decision-making functions that reflect how households and firms select technologies and processes that affect their energy consumption and emissions;
- the economy at large, including how provinces and territories interact with each other and the rest of the world;
- a detailed representation of energy supply markets across Canada and the United States, including liquid fuel, gaseous fuel, hydrogen, and electricity.

Key inputs to gTech are related to characterizing the macroeconomy in the model base year, economic growth assumptions, technology availability and cost, fuel prices, and policy assumptions.

A customized version of gTech is being developed for this project. To date, this version includes refinement of renewables, hydrogen, energy storage and transmission, direct air capture (DAC), and nuclear parameters. These are among a suite of model revisions and updates to be completed over the full project period.

2.2 Navius Integrated Electricity Supply and Demand model

Navius's Integrated Electricity Supply and Demand (IESD) model is a capacity addition and dispatch model that simulates Canadian and U.S. electricity systems under different policy and economic conditions.

Specifically, IESD addresses how utilities meet electric load, how electricity consumption varies by sector in response to the price for electricity, and the impact of decisions made by end-users on electricity demand. As a result, IESD can help estimate the impact of policy and economic conditions on characteristics of the electricity sector, such as greenhouse gas (GHG) emissions, wholesale electricity prices, generation (by source or technology), capacity (by source or technology), peak load, and electricity trade.

IESD can be linked to gTech to enhance representation of electricity-sector dynamics. These dynamics can be important in the context of climate policy, especially given the electricity sector's direct contribution to GHGs and its importance to electrification across various end-use sectors. IESD therefore complements gTech by simulating the impact of policies and economic conditions on electricity demand, supply, and prices.

2.3 Limitations to energy-economy models

As in all models, the models used in this work are subject to two main types of uncertainty:

1. **Variation from reality.** Navius's model is, in essence, a series of equations intended to forecast the future. Although the use of computable general equilibrium models (such as gTech) is well founded in literature, these models cannot account for every dynamic that will influence technological change.[42] An inherent limitation of energy-economy modelling is that virtually all projections of the future will differ, to a certain degree, from what ultimately transpires.

2. **Assumptions and parameters are subject to uncertainty.** These assumptions include changes in oil prices, improvements in labour productivity, and variations in technology cost parameters (as influenced by major breakthroughs in production processes or disruptive innovation), among others. If any of the assumptions used prove incorrect, or if unanticipated developments affect these assumptions, the resulting forecast is affected.[43]

We further note that the model is subject to assumptions specific to general equilibrium models, such as assuming identical operational cost conditions for all firms, perfect mobility of production factors between places and occupations, and inelastic labour supply. These aspects can constrain simulations of the dynamics of labour markets,[44] including estimating job decline or growth in response to green policies.[45,46] Further research is needed to understand the scope 3 emissions (indirect upstream and downstream emissions that occur along the value chain) associated with our simulated scenarios and pathways.

42 For example, household and firm decision-making is influenced by many factors that cannot be fully captured by even the most sophisticated model.

43 gTech is unable to account for disruptive technologies (e.g., the impact of companies such as Tesla on electric vehicle growth and acceptance), unanticipated events (e.g., geopolitical shifts, pandemics, armed conflicts such as the Russia-Ukraine war, natural disasters), adverse supply-chain or resource dependencies, or policies beyond the scope of energy and emissions (e.g., biodiversity regulations).

44 For gTech, as in other models, job impacts are computed as a function of sector productivity that does not always consider dependencies of labour mobility, wages, required training (and jobs associated with it), and the development of new industries from green innovation. Gross domestic product results have similar limitations. Following a perturbation (such as introduction of a policy), the model tends toward a new balance in supply and demand under similar socio-economic conditions and assumptions as before. Thus, it does not necessarily depict transformational trends in the economy (i.e., ones implying deeper changes in preferences, values, and lifestyles that pave the way for the development of new or previously marginal sectors).

45 Sue Wing, I. (2004). *Computable general equilibrium models and their use in economy-wide policy analysis.* MIT Joint Program on the Science and Policy of Global Change. Retrieved from: https://globalchange.mit.edu/sites/default/files/MITJPSPGC_TechNote6.pdf

46 Arnott, R. (2012). *Simulation models for urban economies. In International Encyclopedia of Housing and Home.*

Another acknowledged limitation of current modelling approaches for net-zero applications is that models typically assume a stable climate. This means modelling does not adequately account for the impacts and costs of climate change, which researchers have projected will grow to $35 billion by 2035 and over $100 billion by 2055 for Canada alone (not including human costs and irreversible damage to ecosystems and biodiversity).[47] Similar work by the Institute for Sustainable Finance estimates the Canadian aggregate capital losses from climate change at $2.77 to $5.52 trillion by 2100, depending on the degree of warming in the scenario employed.[48]

47 Beugin, D., & Sawyer, D. (2022). *The GDP costs of climate change for Canada.* Retrieved from the Canadian Climate Institute website: https://climateinstitute.ca/the-gdp-costs-of-climate-change-for-canada/.
Model development and technical support for this study were provided by Navius Research and can be viewed here: https://www.naviusresearch.com/publications/reducing_costs_climate_impacts/

48 Cleary, S., & Martin, S. (2022). *Partial Disclosure: Assessing the state of physical and transitional climate risk disclosure in Canada.* Retrieved from the Institute for Sustainable Finance website: https://smith.queensu.ca/centres/isf/pdfs/ISF-partial-disclosure-paper.pdf

3. Baseline policy scenarios

For this project, we use the Navius gTech and IESD models to simulate the impacts of two present-day, or baseline, policy scenarios on 2050 net-zero goals, as well as on interim emission targets for 2030:

1. Emissions Reduction Plan (ERP) scenario: Legislated and announced federal and provincial climate policy as of spring 2022, updated to include selected policy announcements made since March 2022.[49]

2. Rollback (RBK) scenario: The Rollback Scenario includes legislated federal and provincial carbon pricing and regulatory policies as of November 2021. This does not include the federal Clean Fuel Regulations and maintains carbon pricing at $50/tonne. This scenario is considered a climate policy rollback scenario.

These scenarios are further described below. Results from modelling these policy baselines to 2050 are presented in **Section 4** and are the focus of this first paper.

3.1 Emissions Reduction Plan scenario

In March 2022, the Government of Canada published the 2030 ERP, which outlines the measures Canada is taking to reach its nationally determined contribution under the Paris Agreement.[50] These measures are intended to attain a 40%–45% economy-wide reduction in emissions below 2005 levels by 2030[51] and to work toward achieving net-zero emissions by 2050.

The main intention of our ERP scenario analysis is to model how much closer the ERP policy package gets Canada to its net-zero reduction targets and identify what emission gaps may still remain. The full list of ERP policies modelled is provided in **Appendix A** and includes the following policies, both established and in development, among others:[52]

49 In particular, details announced on the carbon capture, utilization, and storage investment tax credit, as well as heavy-duty vehicle funding.
50 Building on the Pan-Canadian Framework on Clean Growth and Climate Change (2015) and A Healthy Environment and a Healthy Economy (2020). See: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/oil-gas-emissions-cap/oil-gas-emissions-cap-discussion-document-july-2022-en.pdf
51 Or a minimum goal of 443 megatonnes carbon dioxide equivalent per year by 2030. See Canada's 2030 Emissions Reduction Plan: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan.html
52 We modelled both established and developing policies. For the latter, we applied assumptions concerning how such a policy may be met, as described in Appendix A. Other policies announced since the release of the ERP, such as the carbon capture, utilization, and storage investment tax credit as well as heavy-duty vehicle funding, were also included.

- the Output-Based Pricing System (set at 2% annual tightening rate for all sectoral benchmarks after 2023);[53]
- the oil and gas emissions cap of 42% below 2019 sector levels by 2030, and a commitment to reduce methane emissions from the industry by 75% below 2012 sector levels by 2030;
- the carbon capture, utilization, and storage (CCUS) investment tax credit (ITC), updated for DAC and CCUS details announced in the 2022 federal budget;[54]
- the Clean Electricity Regulations, which assume net-zero utility generation emissions by 2035, while allowing for offsets and carbon capture for natural gas facilities; and
- vehicle emission standards, which set a sales target for zero-emission vehicles of 60% by 2030 for light-duty vehicles and 100% by 2035, and 30%–50% for medium- to heavy-duty vehicles (depending on vehicle type and class) in 2030, with the aim to reach 100% of sales in 2040 for select vehicle categories.

We excluded the Canada Green Buildings Strategy announced in the ERP owing to limited clarity on targets and detailed execution plan as of this writing. For our ERP scenario, we also included two specific project announcements on hydrogen and low-carbon steel, noted at the time of development, as well as proposed interties.[55,56,57] Our pending work with the ERP will model details from the *2022 Fall Economic Statement* as well as from the 2023 federal budget.

53 As it was uncertain when we undertook the modelling how provinces will change their carbon pricing systems to comply with the federal stringency increase, we assumed that the Output-Based Pricing System will apply to all provinces and territories, except for Québec and Alberta, and that an annual 2% tightening rate would apply to all sectoral benchmarks starting in 2023. The stringency rules recently announced in Alberta for its TIER system are consistent with this 2% assumption. All performance standard proceeds / revenue recycling has been set up so that proceeds are used to fund low-carbon industrial technologies.

54 We modelled this as an uncapped subsidy on investment, with reduced capital costs by 50% for CCUS through 2030 and 60% for DAC through 2030.

55 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. 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.

56 Two major steel companies in Ontario, ArcelorMittal and Algoma, announced that they will upgrade their plants, which will result in GHG reductions of about 3 Mt in each plant. In our model, we simulated this as a switch to less carbon-intensive forms of steel production, such as direct reduced iron steel production, which reduces GHGs by about 6 Mt from 2020 to 2030.

57 We embedded the three major interties and one proposed upgrade to interregional transmission in the ERP as part of the ERP run. The three interties currently modelled are bidirectional 500–600 MW lines linking Manitoba and Saskatchewan, Québec and Nova Scotia, and New Brunswick. British Columbia and Alberta are included as restoration of an existing line to 1200 MW. An unlimited intertie function has also been added as a sensitivity for all the pathways and will be explored in subsequent analyses.

3.2 Rollback scenario

The RBK scenario includes provincial policy legislated as of November 2021, and regresses legislated federal carbon pricing and regulatory climate policies to those in place before the plan A Healthy Environment and a Healthy Economy was enacted in December 2020. This is considered a “policy rollback” scenario, to represent a situation in which announced climate policy is largely dismantled in response to geopolitical shifts and other unanticipated global disruption.

The full list of policies included in the RBK scenario are provided in **Appendix B**, and includes the following policy differences from the ERP scenario:

- the carbon pollution pricing backstop, originally set to $50 per tonne in 2022 under the Pan-Canadian Framework on Clean Growth and Climate Change;[58]
- the Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations, which reflect the mandate to close coal-fired power plants by 2030 unless they emit less than 420 tonnes CO_2e per gigawatt-hour;
- Energy Efficiency Regulations that govern the fuel-utilization efficiency of space-conditioning equipment;
- the Incentive for Zero-Emission Vehicle Program which provides subsidies for short- and long-range alternative vehicles (e.g., hybrid, electric, hydrogen); and
- provincial measures, such as the British Columbia carbon tax and the Québec cap-and-trade system for GHG emission allowances.

58 For the carbon pollution pricing backstop, we modelled carbon pricing but not the increases past $50/t implemented later.

4. Emissions to 2050 and related findings

The following sections provide an initial analysis of ERP emission trajectories focusing on 2050 outcomes, and include supporting detail on energy use, electricity generation, and CCUS aspects. Comparison to our climate policy rollback scenario (RBK) is noted when salient. Sectors with a high impact on emissions (transportation, oil and gas, and heavy industry) are examined in more detail. Broader gross domestic product (GDP)[59] and job growth results are also included.

For this report, we use baseline (moderate) assumptions for factors such as oil prices and international (U.S.) climate-policy progress; these factors will be further examined in future project phases.

4.1 Greenhouse gas emissions

Highlights:

- The modelled ERP scenario results in an annual decline in emissions over time compared to our 2020 baseline. Emissions reach around 508 megatonnes per year (Mt/yr) by 2030 (31% reduction from 2005 levels), which is consistent with the federal government's ERP modelling.[60] Despite this progress, our ERP scenario falls short of the 2030 target to reduce emissions by 40%–45%[61] and of the accompanying notional pathway expressed by the federal government.[62]
- Our overarching assumptions are conservative in terms of the potential of agriculture and nature-based solutions, as well as land use, land use change, and forestry, to sequester carbon by 2050. Moreover, we do not model the impact of the Canada Green Building Strategy. Nonetheless, our result is likely optimistic, given our underlying assumption that all legislated ERP policies, as well as those in development, are executed, timely, and ultimately successful.[63]

59 Gross domestic product is defined as the monetary value of final goods and services produced in a country in a given period of time.

60 Estimated at 32%, not including land use, land-use change, and forestry. Government ERP modelling assumes an additional reduction of 30 $MtCO_2e$/yr from agriculture, nature-based carbon solutions, as well as land use, land-use change, and forestry by 2030, which bring the estimated reduction to 36% by 2030. See p. 193: https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

61 2005 values are reported as 741 Mt based on Canada's 2022 National Inventory Report. Our current result is directionally aligned with our previous work to evaluate the 2021 climate policy of the Liberal Party of Canada, which projected a 37%–41% shortfall.

62 The notional pathway appears on p. 83 of the 2030 Emissions Reduction Plan; see https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf. The government has estimated a pathway to achieve emissions of 443 Mt/yr by 2030 (meeting the 40% target), which also includes 30 Mt/yr in offsets from land use, land-use change, forestry, and nature-based solutions. See p. 85 of the 2030 Emissions Reduction Plan.

63 We assume this despite the complexity, magnitude, and timescale of effort associated with meeting ERP policy goals, such as augmenting or building new interprovincial transmission lines (such as those specified in the ERP); enabling widespread electric vehicle fuelling/electrification, vehicle manufacture, and availability critical to meeting sales targets for light- and heavy-duty vehicles; expediting CCUS facilities, pipeline construction, and permitting to support CCUS development; and much more.

- At 459 Mt/yr by 2050, our projected emissions under the ERP scenario are *significantly* higher than Canada's net-zero goal.[64,65] This model result suggests that our emissions planning trajectory is not yet fully aligned with the *Net-Zero Accountability Act*, which legislates Canada's commitment to achieving net-zero emissions by 2050.[66]

Modelled emissions trajectories under the RBK and ERP scenarios to 2050 are provided in *Figure 4.1*.[67] In 2030, the ERP scenario results in **508 Mt** of annual emissions, which is a 31% decrease in annual emissions compared to 2005, the baseline year used for determining Canadian climate targets.[68,69] This is more than the 443 Mt by 2030 that the federal government has committed to[70] and falls short of the revised 40%–45% reduction target set under Canada's nationally determined contribution for the Paris Agreement.[71]

Previous analysis by the Canadian Climate Institute, which independently evaluated the ERP, also projects that Canada will miss its target. The Institute's work suggests that the ERP will result in around 522 Mt/yr of emissions in 2030 under currently legislated policies and policies in development, and 452 Mt/yr if a more stringent set of announced policies is also successfully implemented.[72,73] The difference in our results (from those of the Institute) is in part due to model customization and refinement specific to this project, aspects of which have been previously noted.[74,75]

64 We assume that, by 2050, a 50 Mt target will be met by land use, land-use change, and forestry, as noted. We note that net-zero assumptions will vary across models and projects.

65 These results (459 Mt) project a more significant shortfall than our previous work has shown. Our 2021 evaluation estimated a reduction to 282–288 Mt/yr by 2050, whereas, in this report, we estimate around 459 Mt/yr under similar conditions. This said, we note that the modelling differs in the model used, the method, and the analytic approach, so making explicit comparisons is not advisable.

66 The *Canadian Net-Zero Emissions Accountability Act*, which became law on June 29, 2021, enshrines in legislation Canada's commitment to achieve net-zero emissions by 2050. See: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

67 GHG emissions modelling is mapped to the National Inventory Report sector breakdown and reported in Mt CO_2e. Our 2020 emissions values differ from the previous Government of Canada estimates by +25 Mt. Our model endogenously calculates 2020 values based on 2015 values.

68 2005 values are reported as 741 Mt based on Canada's 2022 National Inventory Report.

69 New information on the Clean Electricity Regulations released as of this writing state that the Regulations will now only be binding in 2035. Accounting for this development would result in higher 2025 and 2030 electricity emissions, and mean that we see less progress in reductions achieved than the 31% we report here. This update will be included in our future work.

70 See p. 85, https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf

71 Government ERP modelling assumes an additional reduction of 30 MtCO_2e/year from agricultural measures, nature-based carbon solutions, land use, land-use change, and forestry by 2030. See: https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf
Excluding this 30 Mt, our model shows that the ERP scenario will achieve 31% in annual reductions compared to 2005.

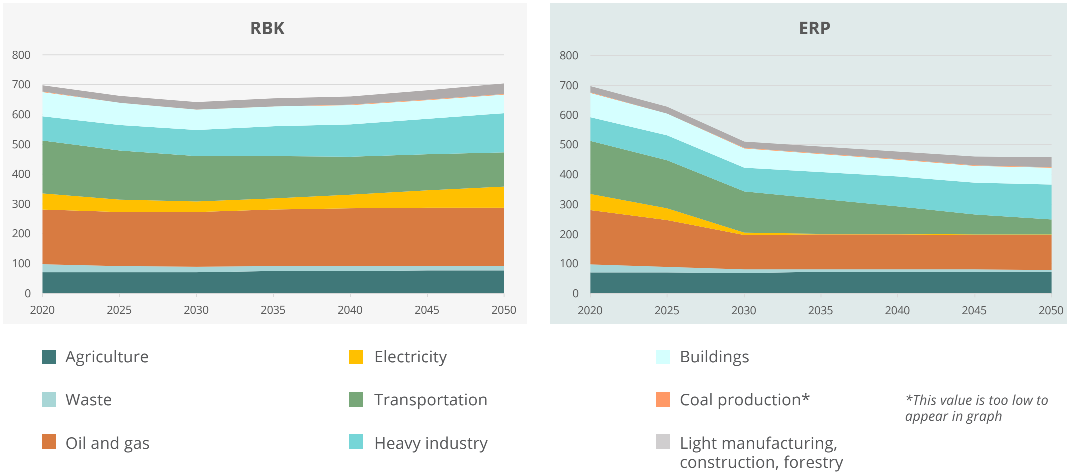
72 See: https://climateinstitute.ca/wp-content/uploads/2022/04/ERP-Volume-2-FINAL.pdf

73 Clean Prosperity's prior work to analyze the Liberal Party of Canada's policy platform (2021) estimates that the Liberal climate plan would achieve a 37%–41% drop in emissions by 2030 relative to 2005, with the results being highly dependent on fossil fuel prices and their impact on oil and gas production. Previous results apply a high fuel-price sensitivity and also account for Environment and Climate Change Canada's calculation of reductions due to land use, land-use change, and forestry (17 Mt), agricultural measures and credits purchased under the Western Climate Initiative (13 Mt), and nature-based solutions (10 Mt) from May 2021. See: https://cleanprosperity.ca/wp-content/uploads/2021/10/Clean_Prosperity_LPC_Climate_Policy_Report_2021.pdf

74 We did not include the Canada Green Building Strategy in our ERP scenario as there was limited policy detail on deployment at the time of writing. Conversely, we included more clarity on ERP policy details as they became available, such as a specified date and target amount of the oil and gas cap, announcement and details for a DAC and CCUS investment tax credit, and other policy measures, including updates announced in the 2022 federal budget.

75 We note that 2030 ERP emissions estimates cannot be easily compared without detailed comparisons of methodology, assumptions, input values, the policy package modelled, emissions baselines used, land use offset assumptions (as noted), and other variables.

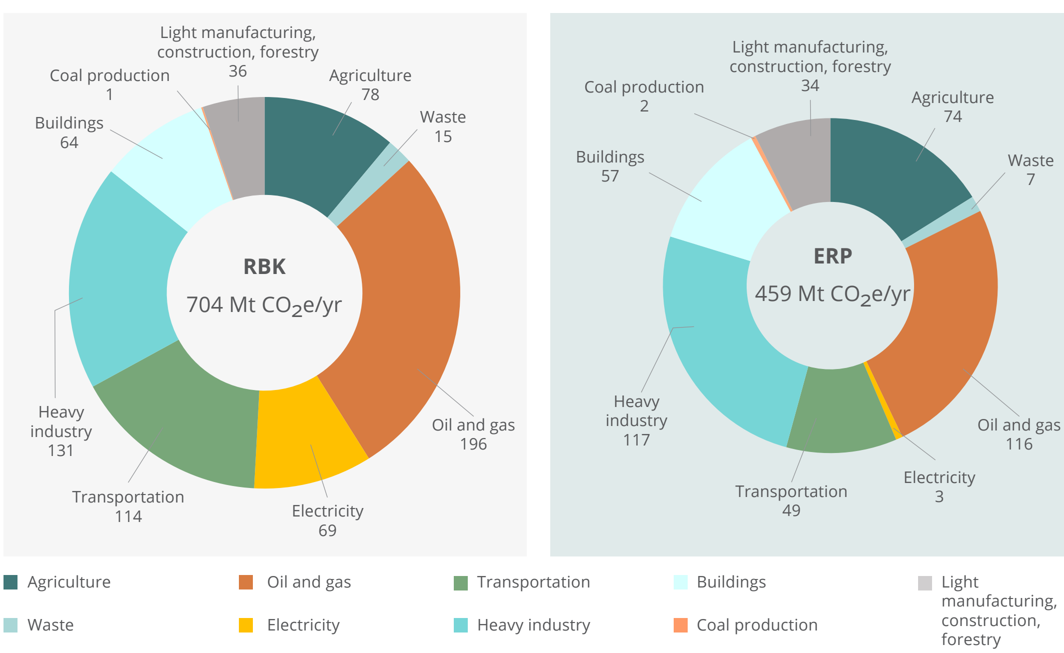
FIGURE 4.1: Annual emission trajectories to 2050 ($MtCO_2e$), RBK and ERP scenarios



Extending the picture to the year 2050 *(Figure 4.2)*, we can see that, at **459 Mt/yr**, the ERP scenario results in significantly fewer emissions compared to the RBK scenario (which anticipates 704 Mt/yr for 2050).[76] For the ERP scenario, emission declines are particularly evident in the transportation, electricity, and oil and gas sectors, which are further discussed in this section. Emissions reduction is achieved primarily through electrification across sectors, accompanied by efficiency gains. Carbon capture also plays a crucial role, especially between 2030 and 2050.

Despite this potential progress, the emissions trajectory of the modelled ERP scenario falls far short of our target of 50 Mt of emissions annually by 2050, which is assumed to be met by land use, land-use change, and forestry to reach net-zero emissions. Introducing technology pathways to help close this gap is the subject of **Section 5**.

FIGURE 4.2: Annual emissions in 2050 ($MtCO_2e$), RBK and ERP scenarios



76 This is a 38% decline in emissions compared to 2005 (vs. the RBK scenario, which shows only a 5.8% decline).

The remainder of this section examines energy use, electricity generation, and CCUS implications resulting from extending the ERP policy package to 2050. We also take a closer look at high-impact sectors (i.e., those that show either significant emissions reductions or gains over time: transportation, oil and gas, and heavy industry), and round out the analysis with discussion of GDP and job growth results.

4.1.2 Economy-wide energy system

Highlights:

- The modelled ERP scenario results in 13% (1,986 PJ) less energy use economy-wide by 2050 compared to the RBK scenario.
- A significant drop in fossil fuel use is anticipated in the ERP scenario compared to the RBK scenario. In 2050, the ERP scenario is projected to use 2,367 PJ less natural gas and petroleum than the RBK scenario.[77]

Total economy-wide energy consumption is projected to be about 13% (1,986 PJ) lower in 2050 in the ERP scenario than in the RBK scenario, largely due to efficiency gains in the transportation sector and in electricity generation.

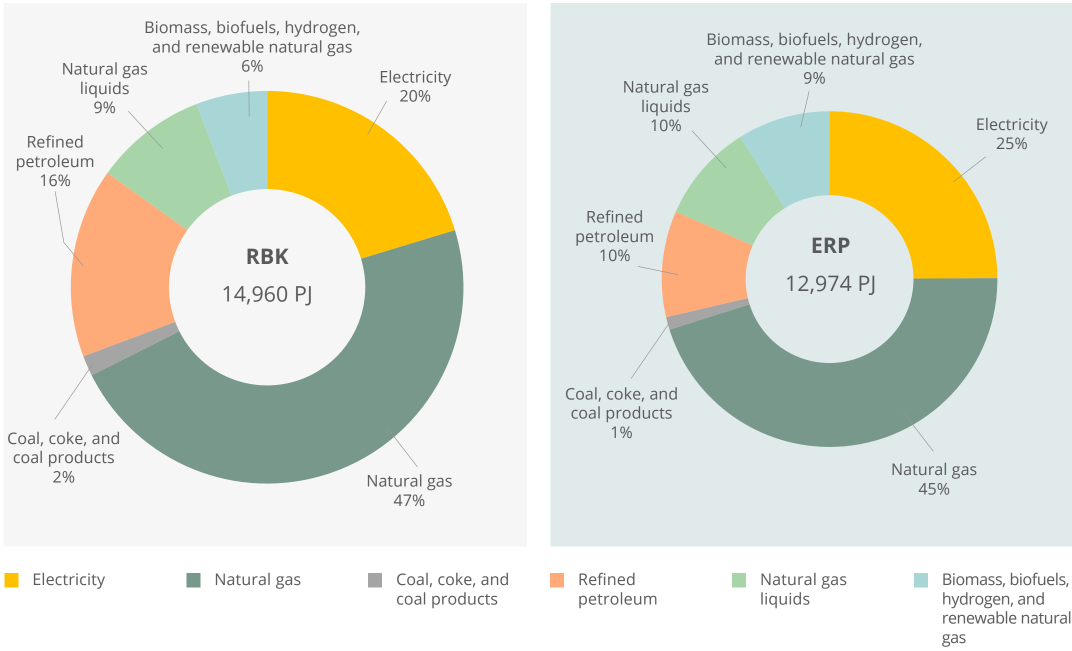
In addition, a key determinant of emissions in the model is the type of fuel being consumed, which impacts both the energy efficiency and emissions intensity of the energy system.[78] In *Figure 4.3*, we can see that the ERP policies favour a less fossil-dependent fuel mix, with electricity, biomass, biofuels, renewable natural gas (RNG),[79] and hydrogen making up 34% of the overall energy mix in 2050 (vs. 26% in the RBK scenario).

77 Not including renewable natural gas. Difference of 1,359 PJ of natural gas/natural gas liquids and of 1,010 PJ in refined petroleum between the RBK and ERP scenarios by 2050.

78 Fuel-consumption efficiency varies according to the technologies used within a sector, such as fuel-efficient natural gas furnaces or electric baseboard heaters. Switching to cleaner fuels leads to lower emissions intensity in a given sector or technology. Furthermore, shifting from fossil fuels to electricity (and other renewable fuels) in many cases results in more efficient use of energy (i.e., less energy wasted or "efficiency gains"), leading to further reduction in emissions.

79 The difference between RNG and fossil natural gas is largely due to their respective production methods and resulting environmental impacts. RNG refers to the capture of biogas (methane) already present in the environment from landfills, wastewater treatment plants, and livestock operations, which is then converted into RNG. The capture of methane (thus avoiding its release to the atmosphere) is what makes RNG more environmentally friendly than its fossil-based alternative. Both RNG and fossil natural gas can be used largely interchangeably in various applications.

FIGURE 4.3: Annual fuel mix consumed in 2050 (%), RBK and ERP scenarios[80]



In *Table 4.1*, we can observe a higher degree of electrification under our ERP scenario, as well as a marked reduction in petroleum use across the economy in response to regulations, such as aggressive zero-emission vehicle mandates. We also see greater adoption of RNG and hydrogen under ERP. Consumption of fossil natural gas increases in both scenarios, although much more under RBK. It should be noted that switching to natural gas from coal and petroleum often also yields efficiency gains, leading to less overall energy consumption and emissions.

TABLE 4.1: Annual fuel mix consumed in 2050, RBK and ERP scenarios[81]

Fuel consumed, PJ	2020	2050		Fuel consumed in ERP relative to RBK
		RBK	ERP	
Electricity	2,044	3,038	3,232	+ 194
Natural gas	5,105	7,074	5,867	–1,207
Natural gas liquids	436	1,382	1,230	–152
Hydrogen	0	35	294	+ 259
Biomass	916	739	714	– 25
Biofuels	101	51	42	–9
Petroleum	3,331	2,337	1,327	–1,010
Coal, coke and coal products	215	251	169	–82
Renewable natural gas	3	53	101	+48
Total	**12,151**	**14,960**	**12,974**	**–1,986**

80 Totals differ due to rounding.
81 Totals differ due to rounding.

4.1.3 Electricity generation

Highlights:

- Our modelled ERP scenario sees a relatively modest increase in electricity generation by 2050, about 32% higher than in 2020. This is 9% more than the RBK scenario in 2050.
- Under both our ERP and RBK scenarios, British Columbia exhibits significant growth in electricity generation by 2050 (on a scale equivalent to 10%–13% of Canada's present-day generation),[82] largely to meet the anticipated electricity demand associated with liquefied natural gas (LNG) development for export included in our model.
- Combined, solar and wind make up between 24% and 30% of generation in both baseline scenarios by 2050, which reflects the growing maturity and cost-competitiveness of this sector.
- The increase in electricity and renewables generation anticipated is supported by a significant increase in energy storage capacity by 2050 for both scenarios (from 50 to 90 times that of present-day estimates). This suggests that accelerating energy storage capability in Canada can be a cost-effective way to meet peak demand in a net-zero scenario, especially in regions such as Alberta that are particularly responsive to ERP policies in the energy sector.

For both scenarios, annual electricity generation increases over time. By 2050, annual electricity generation under the ERP scenario rises by 32%, or by an added 213 terawatt-hours (TWh) compared to 2020. In 2050, electricity generation under ERP (891 TWh/yr) is about 9% greater than RBK (821 TWh/yr). Notable changes for ERP include greater adoption of electricity generation from natural gas combustion with CCUS (+79 TWh in 2050), which allows natural gas facilities to meet the net-zero requirement set forth under our interpretation of ERP's Clean Electricity Regulations.[83] We also refer to natural gas without CCUS as "unabated" natural gas.

In both scenarios, there is an observable dip in total electricity generation in 2030, reflecting the mandated phase-out of coal by 2030[84] and reduced natural gas generation, partly in response to existing federal energy-efficiency and emissions-intensity legislation. This policy-driven temporary decrease in electricity generation (in particular to meet the Clean Electricity Regulations by 2035 in the ERP scenario) is offset in the model by an increase in electricity imports to support growing demand.[85]

82 Equivalent to 10%–13% of Canada's current annual generation of 636 terawatt-hours (TWh).

83 The scenario which we adopt for the Clean Electricity Regulations (which are still under development) assumes a linear stringency increase between 2025 and net-zero in 2035 for utility-generation GHG emissions, while allowing for offsets and CCUS for natural gas.

84 This is a result of the coal phase-out legislation, which is also included in the RBK scenario. See: https://www.canada.ca/en/services/environment/weather/climatechange/canada-international-action/coal-phase-out.html#toc6

85 We note here the opportunity for our downscaling work to identify other alternatives to electricity import, such as the potential for domestic renewable electricity generation to meet demand. Downscaling allows us to further consider existing resource potential and can help complement and build on modelling outcomes.

The dip is followed by a steady upward trend, with some differences in the energy mix between the two scenarios. A key difference is the persistence of unabated natural gas generation in the RBK scenario, while in the ERP scenario, unabated natural gas generation is almost entirely replaced by natural gas with CCUS *(Figures 4.4, 4.5)*. Natural gas generation offers grid flexibility to meet generation demand during times of peak load and fluctuation due to weather events, maintenance of aging infrastructure, and times of low resource availability in high-renewable energy systems (especially if energy storage is limited). At the same time, the rise in base demand for electricity under ERP is largely met by added wind and solar, as well as cogeneration.[86]

FIGURE 4.4: Annual electricity generation to 2050 (TWh), RBK and ERP scenarios

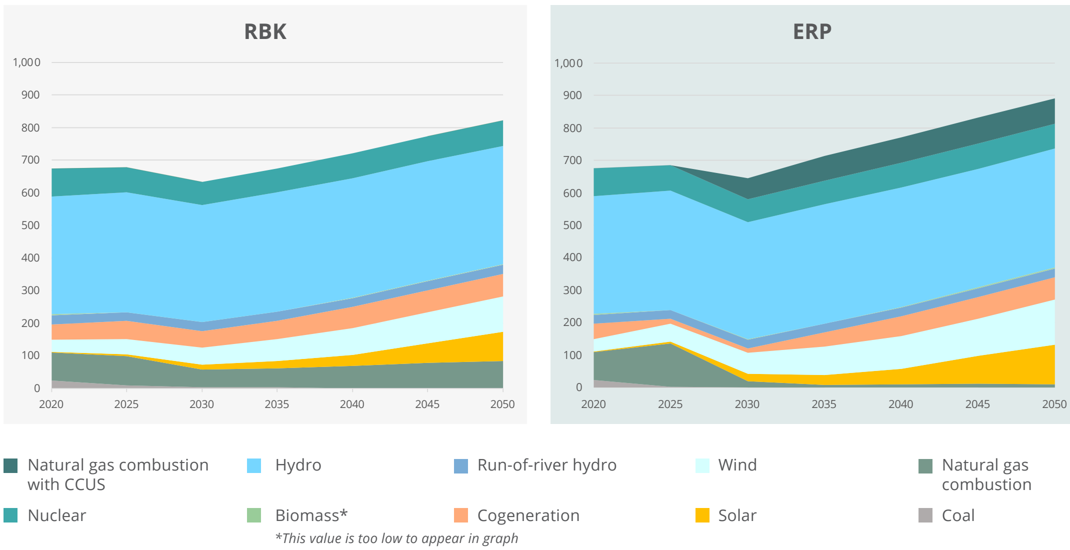
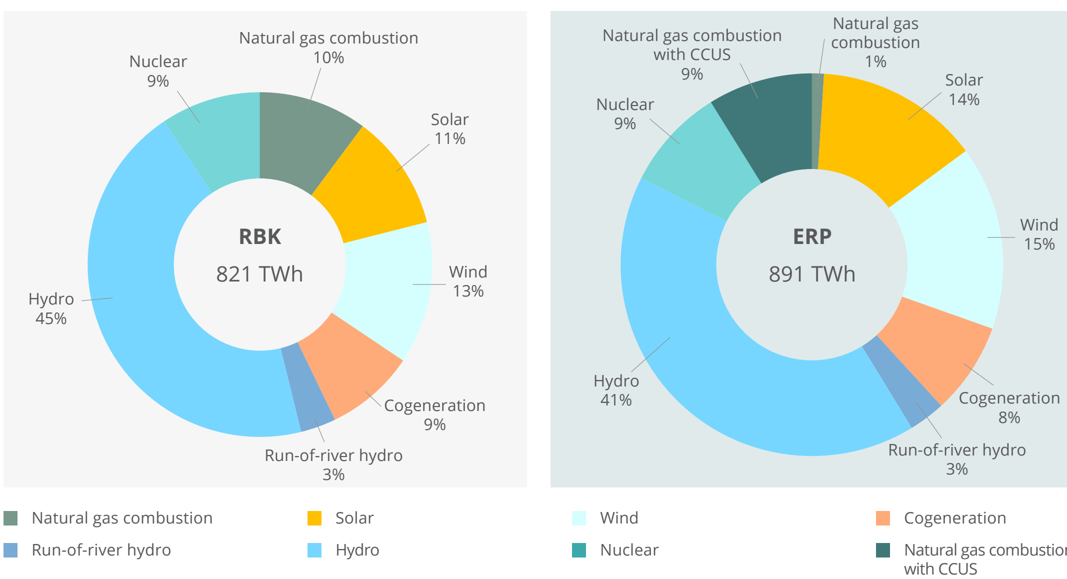


FIGURE 4.5: Annual electricity generation in 2050 (%), RBK and ERP scenarios[87]

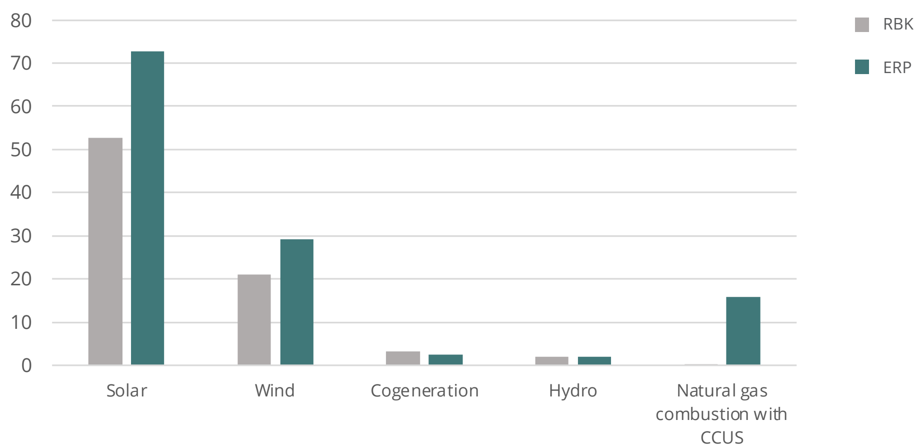


86 Cogeneration is the combined generation of electricity and usable heat. Within the various categories, cogeneration refers to any cogeneration, including biomass and coal, that is used to produce electricity in the industrial sector.

87 We note here that the 2023 federal budget suggests that Canada's electricity demand is expected to double by 2050 and that its electricity capacity must increase by 2.2 to 3.4 times compared to current levels (based on CCI's analysis for achieving net-zero). Our ERP scenario shows generation (in terawatt-hours) increasing 1.3 times between 2020 and 2050 and generation capacity (in megawatts) increasing by 1.7 times.

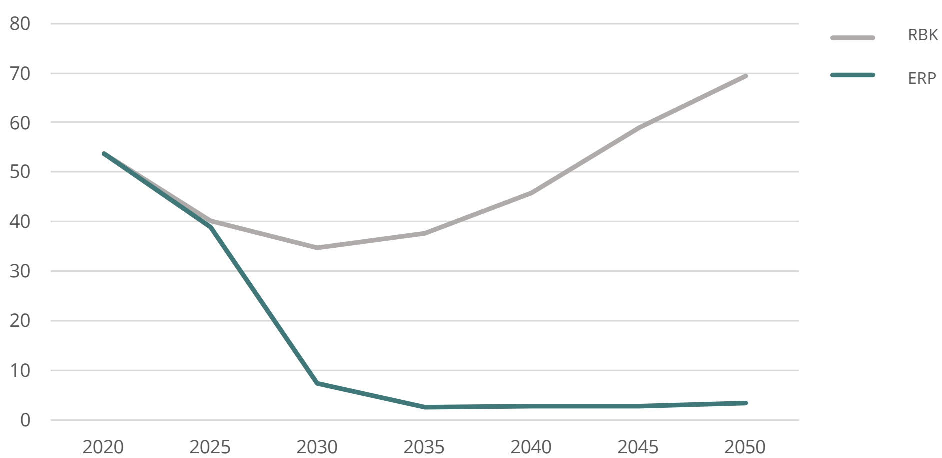
From 2020 to 2050, a net increase of 222 TWh in wind and solar electricity generation is projected under ERP. This is met through almost 73 GW of added solar and 29 GW of added wind capacity across Canada *(Figure 4.6)*, which is concentrated in certain provinces. An addition of 159 TWh (between 2020 and 2050) of annual wind and solar electricity generation is also projected in the RBK scenario, to compensate for the phase–out of coal and slight reduction of natural gas generation, as well as to meet increasing electricity demand. The increased generation in the RBK scenario is supported by capacity build-out of about 53 GW of solar and 21 GW of wind.[88]

FIGURE 4.6: Added capacity (GW) from 2020 to 2050, RBK and ERP scenarios



The rise in renewables in the energy mix results in a steep decline in emissions from the electricity sector in the ERP scenario (54 Mt/yr in 2020 to 7 Mt/yr in 2030) *(Figure 4.7)*, with Clean Electricity Regulations incentivizing renewables and CCUS offsets for natural gas. In RBK, we also see emissions decline to 35 Mt/yr in 2030 due to the phase-out of coal in the sector. However, continued unabated natural gas generation in RBK pushes emissions upwards after 2030, to reach approximately 70 Mt/yr in 2050.[89]

FIGURE 4.7: Emissions by the electricity sector to 2050 (Mt CO_2e/yr), RBK and ERP scenarios

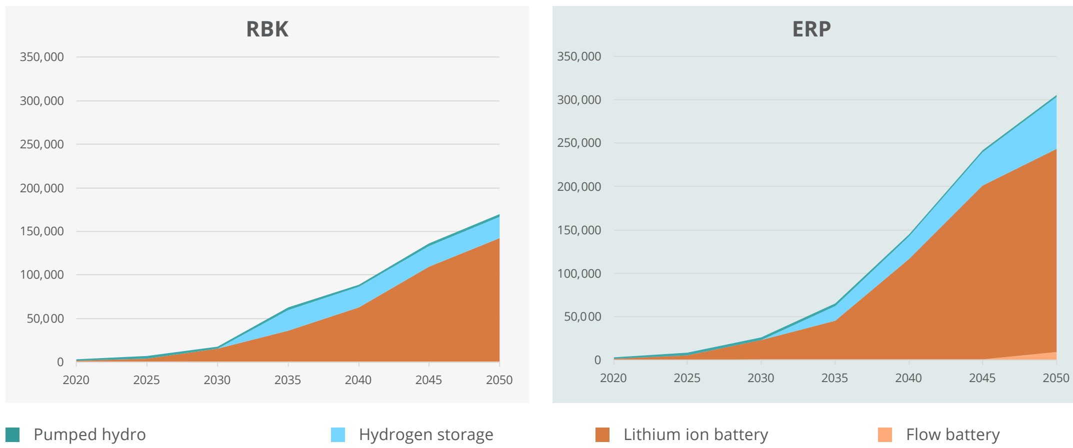


88 Overall, the percentages shown across both scenarios in Figure 4.7 are, in part, influenced by the varying fuel mix contributions. For example, the amount of hydroelectricity in both scenarios is largely similar in terms of overall terawatt-hours produced; however, the percent expressed varies based on the contribution of other sources for each scenario, such as wind and solar electricity generation.

89 Under the RBK scenario, natural gas generation makes up 97% of the energy consumed by the electricity sector in 2050.

As shown in *Figure 4.8*, peak load electricity generation in ERP is also served by a 90-fold growth in capacity of storage systems[90] between 2020 and 2050 (vs. a 50-fold growth in RBK during the same period), almost entirely from lithium-ion battery systems.[91] As shown by the grey shaded area, some growth in hydrogen storage capacity is also anticipated, reaching approximately 60,000 MWh in ERP and approximately 24,000 MWh in RBK by 2050. Energy storage is an important consideration for designing renewables-based energy grids, as storage can help supplement periods of low resource availability and/or high demand.[92]

FIGURE 4.8: Energy storage capacity to 2050 (MWh), RBK and ERP scenarios[93]



Looking at results regionally, the added electricity generation between 2020 and 2050 under the ERP scenario is primarily in British Columbia (+82 TWh/yr, 98% of which is met by solar, wind, and large hydro/run-of-river sources in our model results), Ontario (+55 TWh/yr), and Alberta (+47 TWh/yr) *(Figure 4.9)*. Increases in generation in these provinces are also significantly larger under the ERP scenario than under the RBK scenario (a difference of +21 TWh/yr in British Columbia, +24 TWh/yr in Alberta, and +16 TWh/yr in Ontario by 2050).[94,95]

90 Energy storage capacity in grid-scale energy systems refers to the maximum amount of power that can be stored (in megawatt-hours).

91 Lithium-ion and flow batteries are short-term (approximately four to 10 hours) storage systems that are typically used to meet peak demand. Pumped hydro and hydrogen storage systems are used for longer-term storage, for example, to ameliorate seasonal reduction in solar/wind resources.

92 The ERP scenario has more intermittent energy capacity than the RBK scenario, which would drive a need for more storage capacity.

93 We recognize that storage and discharge dynamics are of interest when it comes to detailed treatment of storage. However, the current model is limited in terms of outputs (to storage capacity build-out) and prioritizes economically optimal storage. As of this writing, we refer readers to analysis by the Electric Power Resource Institute for more detailed and granular treatment of storage parameters. See: https://lcri-netzero.epri.com/en/results-comparison-supply-electricity.html

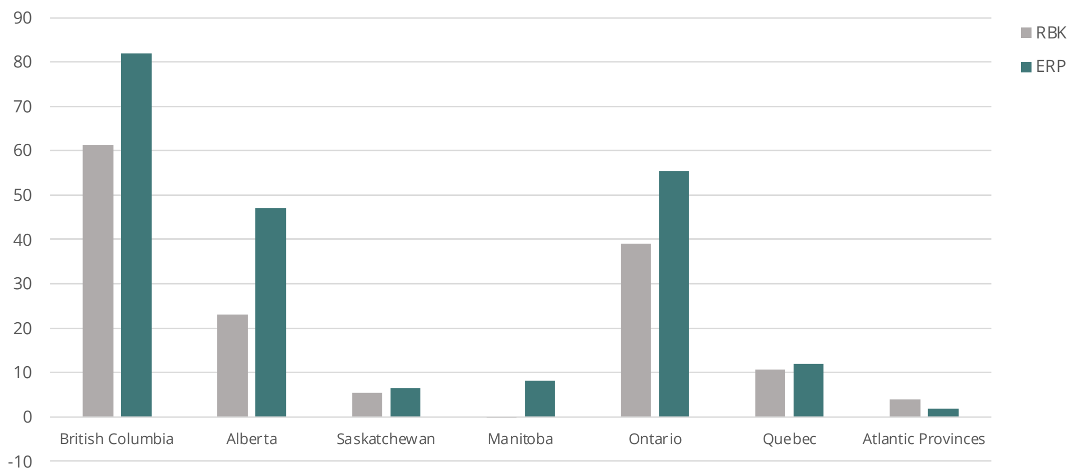
94 Each of the subsequent values is expressed in terms of the relative amount of generation in 2050 under the ERP modelled scenario vs. the RBK scenario. For the following provinces, the significant differences are in:

- British Columbia: +12 TWh/yr solar, +6 TWh/yr wind
- Alberta: +34 TWh/yr natural gas with CCUS, +24 TWh/yr solar, +7 TWh/yr wind, −38 TWh/yr natural gas (no CCUS), −5 TWh/yr cogeneration
- Ontario: +12 TWh/yr natural gas with CCUS, +10 TWh/yr wind

95 Generation is also expected to increase by 12 TWh/yr in Québec by 2050 under the ERP scenario. However, a similar increase is expected under the RBK scenario. In this instance, the model currently anticipates reduced electricity exports from Québec to retain electricity for use within the province to meet increasing electricity consumption over time, which merits further investigation.

The large increase in generation anticipated in British Columbia under both scenarios is due in part to the anticipated electricity demand required for the development of facilities for LNG export.[96] The planned electrification of such large-scale facilities suggests added generation equivalent to 10%–13% of Canada's current generation of 636 TWh. This works at cross-purposes to the provincial government's focus on electrification to meet the needs within the province.

FIGURE 4.9: Added electricity generation (TWh/yr) between 2020 and 2050, RBK and ERP scenarios



Preliminary results show that storage capacity increases primarily in Ontario, British Columbia, and Alberta. ERP policies are particularly consequential in Alberta, where storage capacity is approximately 140% higher under the ERP scenario than under the RBK scenario by 2050. Further exploration of regional generation and storage implications will be the subject of our ongoing research, including downscaling analysis.

4.1.4 Carbon capture, utilization, and storage

Highlights:

- Modelling results suggest that CCUS can play an important role in decarbonization, with potentially 44 $MtCO_2e$ captured annually by 2030 under the ERP scenario. This is a significant capture value and would require that many projects are initiated in the next 12–24 months, given the time required to design, permit, and build large decarbonization projects.
- By 2050 and at 79 Mt/yr, CCUS accounts for 33% of the total emission reductions achieved since 2020 under the ERP scenario. This result indicates that the sector is highly responsive to the ITC included in this scenario, among other regulatory measures such as the Clean Electricity Regulations and industrial carbon pricing.[97] In contrast, only about 8 Mt/yr of CCUS is expected in the RBK scenario by 2050.

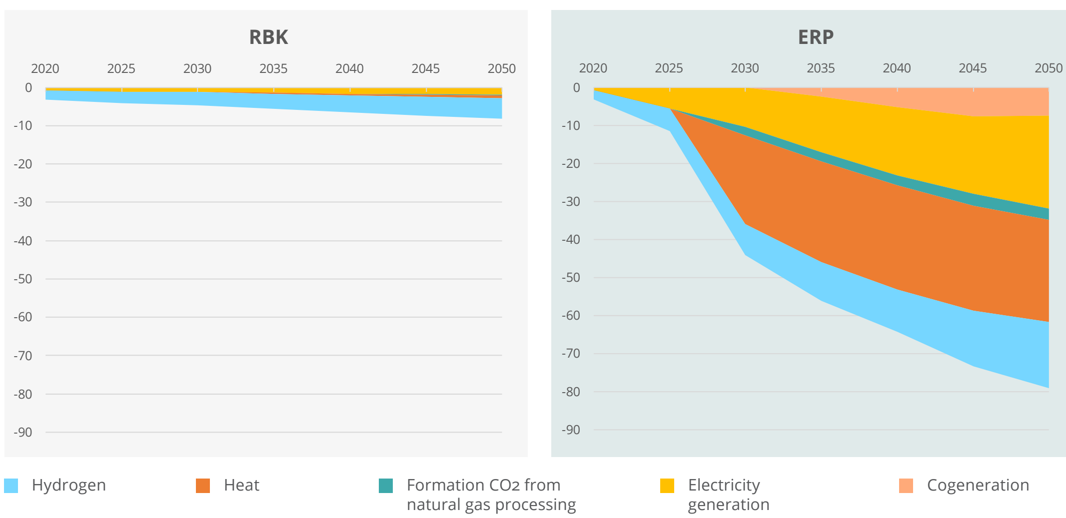
96 For the LNG Canada project, we align with assumptions in the 2021 version of Canada's Energy Future, in which LNG exports reach 7 billion cubic feet a day by 2050 under current policies. Their assumptions are based on LNG Canada Phase 1 and additional volumes that are not specific to a particular project. The model uses this as an upper bound for production and export.
97 697 Mt in 2020 vs. 458 Mt in 2050 (–238 Mt). At 79 Mt, CCUS is 33% of this total.

- Although the ITC is also in place for DAC, the model shows no DAC adoption in the ERP or RBK scenarios. This suggests that additional policy measures and/or development of more inexpensive DAC technologies are required for DAC adoption to prove economical.

CCUS technology can be adopted in various sectors to reduce, remove, or use carbon emissions that would otherwise be released into the atmosphere. In some cases, the implementation of CCUS requires additional energy, increasing the total energy (and fuel) consumed in the given sector, but overall is anticipated to yield a net reduction in emissions. In our model, CCUS is applied mainly in fossil-fuel based electricity generation[98] and in the industrial sector.[99]

The model results show a significant uptake of CCUS in Canada, projecting around 44 Mt/yr by 2030 and nearly double that (79 Mt/yr) by 2050 with ERP policies, which include the ITC for CCUS announced in April 2022.[100] In the ERP scenario, CCUS is used mainly in electricity generation (24 Mt/yr), process heat for the oil and gas sector (27 Mt/yr), hydrogen production (17 Mt/yr), and cogeneration (8 Mt/yr).[101] Combined, these form the bulk of the total 79 Mt/yr of CCUS expected by 2050, as shown in *Figure 4.10*. In contrast, CCUS in RBK is much lower at 8 Mt/yr of uptake by 2050. CCUS is shown as a negative capture value as it mitigates the release of emissions, however should not be considered the same as negative emissions.

FIGURE 4.10: Carbon capture, utilization, and storage uptake to 2050 ($MtCO_2e/yr$), RBK and ERP scenarios



98 CCUS applied to combined-cycle and simple-cycle natural-gas or coal-generating plants that are the primary generating source for the electric grid.
99 Burning fossil fuels to generate heat for industrial processes, such as oil and gas extraction and refining. CCUS can also be used for hydrogen production, oil and gas production, and cogeneration.
100 The ITC for CCUS is modelled as an uncapped subsidy on investment, with reduced capital costs by 50% for CCUS and 60% for DAC through 2030.
101 CCUS for **electricity generation** is applied to combined-cycle and simple-cycle natural gas or coal generating plants that are the primary generating source for the electric grid; for **process heat** (resulting from burning fossil fuels), CCUS is coupled with natural-gas-fired industrial boilers, and furnaces. Almost all industrial sectors require heat production for their processes. Electrifying industrial boilers is costly; thus, using CCUS to mitigate these emissions is an alternative abatement strategy. **Hydrogen production** paired with CCUS refers predominantly to the carbon dioxide captured from the steam methane reformation process of blue hydrogen. For **cogeneration**, this refers to facilities that produce both heat and power while offsetting emissions using CCUS (much the same way that the electricity generation and industrial sectors use CCUS).

Our projection of CCUS adoption departs from some of the more conservative projections, which (as of this writing) anticipate that CCUS will capture from 4 to 15 Mt/yr by 2030,[102] up from the current 3.2[103] to 4.8 Mt currently captured.[104] The federal government has estimated 30.8 Mt/yr as a target for emissions reduction via CCUS by 2030,[105] focusing on oil sands facilities, gas plants, and refineries. The government expects between 20 and 40 CCUS facilities to be in operation within the decade. Some sources estimate even more CCUS capacity to become available, given the right policy incentives.[106] However, even with sizable CCUS capacity, uncertainty remains regarding the economics of industry uptake, time to scale, and timelines of project approval, building, and operation.

In looking at regional CCUS adoption for 2050 *(Table 4.2)*, we can see that the majority of CCUS is slated for Alberta (49 Mt/yr), Ontario (20 Mt/yr), Saskatchewan (5 Mt/yr), and British Columbia (4 Mt/yr) under ERP policies by 2050.[107] Our future research will expound these model outcomes and include resource mapping to better understand how and where the modelled CCUS could occur, and what infrastructure may be required.

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102 Industry estimates range from 4 to 15 Mt/yr, based on project specific estimates as well as sector-wide estimates. See: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/oil-gas-emissions-cap/Oil%20and%20Gas%20Emissions%20Cap%20Discussion%20Document%20-%20July%2018%202022_EN.pdf
https://www.naviusresearch.com/wp-content/uploads/2021/07/CCS-net-zero-opportunity-2021-06-30.pdf
https://www.snclavalin.com/~/media/Files/S/SNC-Lavalin/download-centre/en/report/net-zero-canada-2030-report.pdf
https://www.csis.org/analysis/canadas-carbon-capture-industrial-strategy https://www.canada.ca/en/natural-resources-canada/news/2022/07/canada-opens-call-for-carbon-capture-research-development-and-demonstration-projects.html
https://natural-resources.canada.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/shell-canada-energy-quest-project/18168

103 See the Canada Energy Regulator (CER): https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2022/market-snapshot-new-projects-alberta-could-add-significant-carbon-storage-capacity-2030.html

104 Per Clean Prosperity's internal analysis, C. Noyahr. In 2021, Quest reported 1.05 Mt (Canada Energy Regulator [CER] reports 1.05). Alberta Carbon Trunk Line reports 1.2 Mt (CER reports 1.9, which incorporates recycled CO_2). "Other Enhanced Oil Recovery": reports 0.11 Mt (CER reports 0.21). For Alberta, this suggests that 2.4 Mt is sequestered via carbon capture and storage currently, whereas CER reports 3.2 Mt total.
For Saskatchewan in 2021: (1) Sask BD3 sequestered 0.4 Mt (it was offline for 3 months but normally averages between 0.6 and 0.7 Mt) (reported by SaskPower); (2) Aquistore sequestered approximately 0.1 Mt (estimated from Aquistore press reports); (3) Whitecap resources Weyburn field sequestered 1.77 Mt (reported from their own environmental, social, governance documents); and (4) Husky Lashburn EOR sequestered 0.09 Mt (from environmental, social, governance reports). This suggests approximately 2.4 Mt of sequestration via CCUS for Saskatchewan, and 4.8 Mt of sequestration overall when also including CP's estimates for Alberta.

105 See p. 194 (Table 6.8) in Government of Canada 2030 Emissions Reduction Plan. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf. CCUS makes up 12.9% of approximately 239 Mt total anticipated from 2005 to 2030, not including land use, land-use change, and forestry.

106 Based on the Alberta Major Projects Inventory, G. Bishop estimates that around 60 Mt/yr CCUS capacity could come into operation by 2030 in Alberta alone. However, Bishop notes that this potential may not be fully realized unless the current Technology Innovation and Emissions Reduction Regulation (TIER) system is tightened to encourage further investment in the technology. Bishop, G. (May 20, 2022). Looming oversupply risk for emission offsets in Alberta's TIER carbon pricing market. Retrieved from https://www.linkedin.com/pulse/looming-oversupply-risk-emission-offsets-albertas-tier-grant-bishop/

107 CCUS deployment is a plant-scale decision. We are not modelling decisions at this scale but rather at the broader industry scale, tied to the economics of carbon pricing and CCUS policy incentives. Therefore, we are suggesting that it would be more economical for a given point-source emitter to deploy CCUS rather than pay emissions-associated costs (however this does not mean that the emitter will necessarily make that decision). Since we are not using an agent-based model, we are limited in how much we can represent actors at a granular scale. Also, we note that the model we are using does not show the final destination of the captured carbon. Some of it is utilized in industrial processes (e.g., as heat) rather than being wasted (as it otherwise would be). CCUS, as defined here, is therefore not, strictly speaking, a measure of carbon sequestration but a measure of avoided emissions.

TABLE 4.2: Annual CCUS anticipated by province by 2050, RBK and ERP scenarios*

Carbon capture, utilization, and storage by sector ($MtCO_2e/yr$) in 2050	Alberta		British Columbia		Ontario	
	RBK	ERP	RBK	ERP	RBK	ERP
Cement CO_2	0	0	0	0	0	0
Cement heat	0	0	0	0	0	0
Cogeneration	0	−7	0	0	0	0
Electricity generation	−1	−6	0	0	0	−16
Formation of CO_2 from natural gas processing	−0	−2	0	−2	0	0
Heat	0	−24	0	−2	0	0
Hydrogen	−4	−10	0	0	−1	−4
Low-temperature industrial heat	0	−0	0	0	0	0
Grand total	**−5**	**−49**	**0**	**−4**	**−1**	**−20**

Carbon capture, utilization, and storage by sector ($MtCO_2e/yr$) in 2050	Québec		Saskatchewan		Manitoba	
	RBK	ERP	RBK	ERP	RBK	ERP
Cement CO_2	0	0	0	0	0	0
Cement heat	0	0	0	0	0	0
Cogeneration	0	0	0	0	0	0
Electricity generation	0	0	−1	−3	0	0
Formation of CO_2 from natural gas processing	0	0	0	0	0	0
Heat	0	0	0	−1	0	0
Hydrogen	0	−2	0	−1	0	0
Low-temperature industrial heat	0	0	0	0	0	0
Grand total	**0**	**−2**	**−1**	**−5**	**0**	**0**

* **Cement CO_2** is the capture of process emissions; **Formation CO_2** is separate from vented gases from the natural gas sector; **Hydrogen CCUS** is predominantly the CO_2 captured in the production of blue hydrogen; **Heat CCUS** refers to abated emissions from industrial boilers and furnaces, particularly in natural-gas processing and upstream oil and natural gas, but also in other industrial sectors, such as chemicals and various types of manufacturing; **Low-temperature industrial heat** is used in sectors such as food and beverages, wood processing, electronics, and other types of manufacturing, which can also be abated through CCUS; **CCUS in electricity generation** is applied to single-cycle or combined-cycle natural-gas or coal-generation plants; CCUS can be added to **Cogeneration** (electricity and heat production) facilities in a similar way as it is added to other electricity or industrial plants.

As previously noted, the model shows no to negligible DAC adoption for either scenario, despite the inclusion of DAC in the ITC for CCUS that is modelled in the ERP scenario. Our modelling assumes an optimistic levelized starting cost for DAC in both of our reference scenarios, which is in line with current cost estimates for this nascent technology.[108] However, the lack of DAC adoption indicates the need for additional policy measures to make the economics of DAC more attractive in Canada. Support for research, development, and production scaling of DAC would enable wider and more cost-effective adoption.

As of this writing, the U.S. *Inflation Reduction Act* CCUS credit value has increased to US$85 per tonne, which is anticipated to cover nearly two-thirds of a project's total capital and operating costs in the United States. In response, some analysts have suggested that this will result in a more attractive investment environment for CCUS projects[109] and consequently incentivize widespread adoption in the United States. In our proposed future policy simulation phase, we aim to test the impact of a similar tax credit (among other policy configurations) to assess its impact on CCUS uptake in Canada.

4.2 High-impact sectors

Highlights:

- Large emission reductions between 2020 and 2050 are expected in the transportation (72%) and oil and gas (37%) sectors as a result of targeted policies for these sectors in the ERP scenario. For oil and gas, CCUS is expected to capture 27 Mt of emissions annually in 2050, which equates to 40% of the emissions reductions from 2020.
- Heavy industry is anticipated to have continued output growth, paired with increased emissions. Although ERP policies, such as the Output-Based Pricing System, reduce 2050 emissions by about 10% compared to RBK, this sector still charts an overall emissions increase of approximately 45% since 2020, and becomes the highest-emitting sector by 2050 under ERP.

Over the 2020 to 2050 period, we see a notable decline in annual emissions for transportation (–128 Mt) and oil and gas (–67 Mt) sectors in the ERP scenario. In contrast, annual emissions increase in heavy industry (+36 Mt, an increase of approximately 44%) and in light manufacturing (+13 Mt).

The following explores model outputs relating to transportation, oil and gas, and heavy industry, as these three sectors show the greatest absolute changes in emissions over time for both of our scenarios.

108 We apply a "reference" (middle of the road) cost for DAC, where the levelized cost of capture in a DAC plant starts at $734/tCO_2e$ (pre-commercialization abatement cost) and declines with experience to a potential price floor of $164/tCO_2e$ ($354/tCO_2e$ for 1 Mt capture). The reference-case sensitivity is based on an average of the peer-reviewed literature and, for DAC, is applied to the two reference scenarios as well as the Fossil with CCUS pathway. We also note that some industry estimates show a cost range from US$300–$425/t (C$400– $566/t) for the first phase of a 500,000 t plant. See p. 24: https://www.oxy.com/investors/stockholder-resources/lcv-investor-update/
Conversely, other studies, including those by the Electric Power Research Institute, indicate much higher costs, in the range of US$1500/$tCO_2$ to US$3000/$tCO_2$. See: https://us-regen-docs.epri.com/v2021a/assumptions/direct-air-capture.html#technology-cost-and-performance

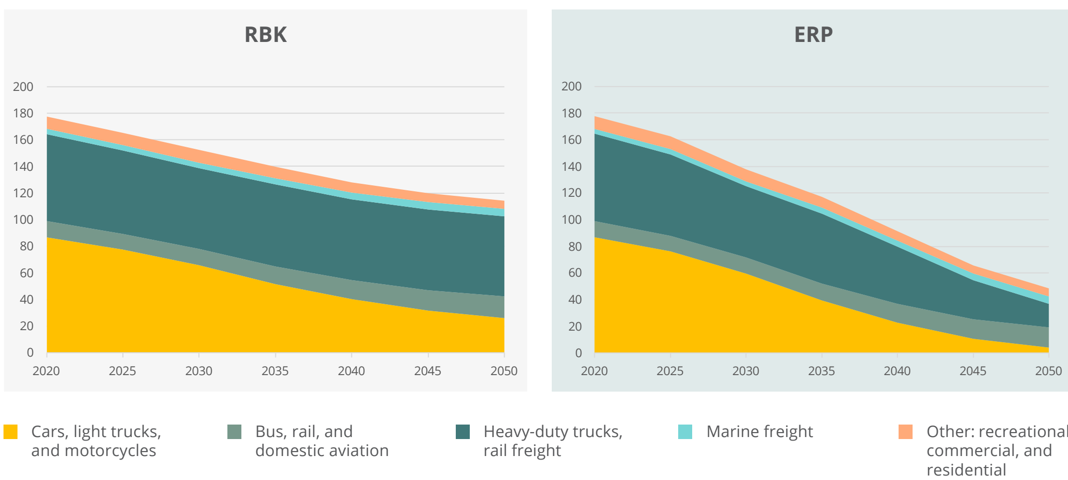
109 The ITC is estimated to cover less than 25% of total projected costs for CCUS facilities approved by 2030 in Canada. See: https://financialpost.com/commodities/energy/oil-gas/us-carbon-capture-incentives-investment-canada

4.2.1 Transportation

Gains made in this sector are responsible for a hefty 54% of the total emissions decline from 2020 to 2050 in the ERP trajectory.[110] We also observe some declines under the RBK scenario, partly due to the inclusion of prior federal and current provincial policy. However, the emissions reductions in the ERP scenario are far more significant in comparison — these decline from 178 Mt/yr in 2020 to 48 Mt/yr by 2050 (vs. to 114 Mt/yr by 2050 for RBK). Generally, we find that the modelled policies are effective in driving technological change, including the shift to electric vehicles (EVs) and alternative fuels.[111]

The largest reduction over time is observed in cars, light trucks and motorcycles, followed by heavy-duty trucks and rail freight (83 Mt and 47 Mt decline in annual emissions, respectively, from 2020 to 2050; *Figure 4.11*). These results are directly related to ERP transportation policies, which include aggressive sales targets for light-, medium-, and heavy-duty vehicles;[112] subsidies, tax write-offs, and business incentives for zero-emission vehicles; as well as additional programs to help fund charging infrastructure and truck retrofits.

FIGURE 4.11: Greenhouse gas emissions in transportation to 2050 ($MtCO_2e$/yr), RBK and ERP scenarios



110 A significant decline in transportation emissions by 2050, on the order of –128 Mt/yr for the sector, results from sector-targeted ERP policies. Overall, our modelling of the ERP scenario shows 697 Mt in 2020 vs. 459 Mt in 2050 (–238 Mt). At –128 Mt, the transportation sector accounts for 54% of these gains.

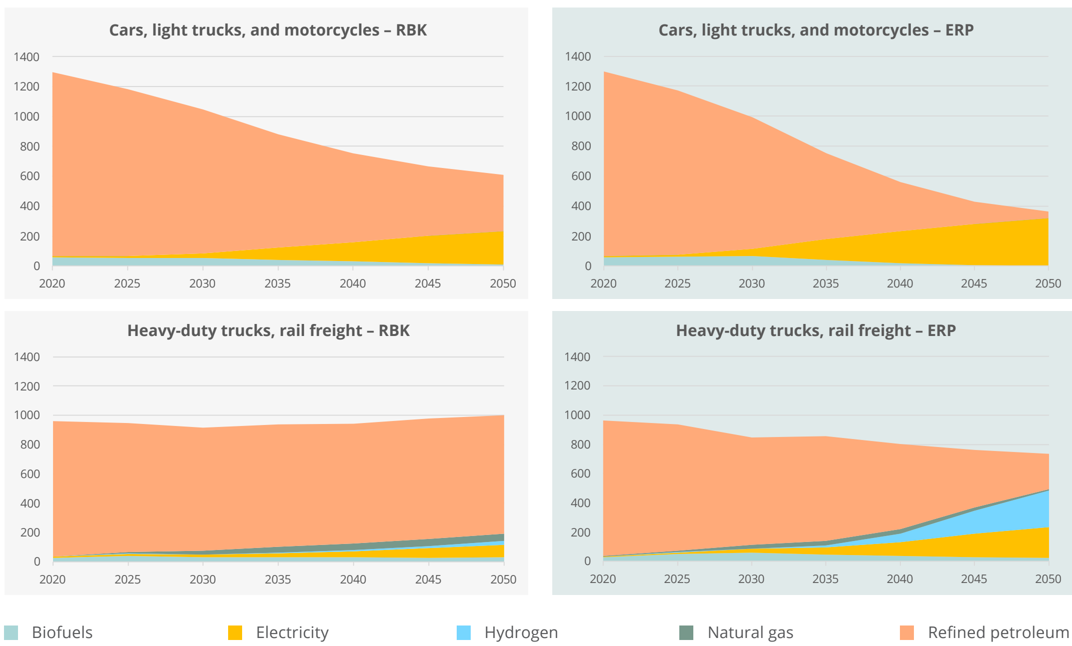
111 Further emissions reductions in this sector are possible as a result of changes in consumer travel behaviour; for example, moving away from use of single-occupancy vehicles toward shared-mobility modes and public transit. In our modelling, we assume continued statistical behavioural trends, including rising consumer preference for sport utility vehicles over smaller vehicles.

112 We included the light-duty vehicle sales target and we assumed the 60% sales target would be achieved in 2030 and the 100% target by 2035. The ERP also features a medium- and heavy-duty emissions standard, which was modelled as a target for new sales of zero-emission vehicles of 7% to 11% in 2025 and 30% to 50% in 2030, depending on vehicle weight class. As the policy includes the goal of 100% zero-emission vehicle sales by 2040 in selected medium- and heavy-duty categories, we have interpreted this as achieving 95% of the sales target around 2040. This may be a generous interpretation given the current unavailability of electric options for the higher weight classes, and we may adjust this expectation in future work.

The decline in emissions corresponds to (1) overall reduced energy consumption in the sector and (2) a transition to cleaner fuel types in vehicle sub-sectors, which is mainly the case for ERP. By 2050 under the ERP scenario, 87% of fuel energy consumed by light-duty vehicles (cars, light trucks, and motorcycles) shifts to electricity (317 PJ/yr of 363 PJ/yr consumed by this sector in total; *Figure 4.12*). This is a substantial increase in electrification (especially compared to the 36% uptake we see in RBK for that same year for the same vehicle class).

Compared to the medium- and heavy-duty vehicle segment, light-duty vehicles also show a faster decline in emissions due to Canada's zero-emission vehicle sales targets,[113] which we model as starting sooner and being stricter for the light-duty vehicle class. In heavy-duty trucks and rail (freight), we observe that by 2050 hydrogen constitutes 34% of fuel energy consumed,[114] while electricity makes up 29%.

FIGURE 4.12: Energy consumption by fuel type to 2050 in PJ, RBK and ERP scenarios



Our results suggest the significant influence of achieving targeted policies in driving transformation toward low-carbon technologies. However, despite assuming this progress in the light-, medium-, and heavy-duty vehicle segments, the broader transportation sector remains far from carbon-neutral in 2050. Even in ERP, refined petroleum continues to account for over 53% of energy consumed by the sector in 2050. Significant opportunities for decarbonization are evident in the bus, rail, and domestic aviation and domestic air and marine (freight) sub-sectors, given that our results show petroleum still makes up more that 92% of energy consumption for both of these sub-sectors in 2050.

113 See: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/canada-s-zero-emission-vehicle-zev-sales-targets

114 For heavy-duty vehicles, the hydrogen contribution under the ERP scenario is approximately 10 times that seen under the RBK scenario by 2050 (248 PJ vs. 25 PJ).

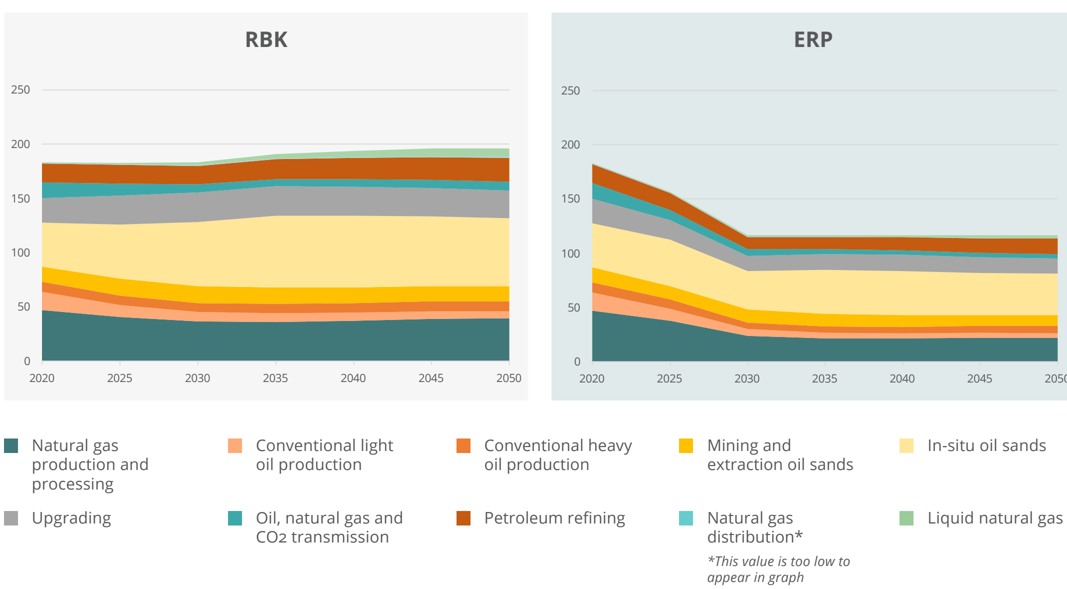
Notably, support for multi-modal and rail in the ERP remains relatively limited as of this writing. To date, Canadian climate policy continues to prioritize the use of single-occupancy vehicles (including through mandated sales targets for such), which overlooks the potentially greater opportunity inherent in higher-occupancy options, such as high-speed rail, public transport innovation and shared mobility. Work to date also does not consider the opportunity in autonomous vehicles, which have potential to significantly disrupt single- and high-occupancy modes of personal transport, as well as freight.

4.2.2 Oil and gas

Under the ERP scenario, emissions due to energy consumption by the oil and gas sector decline by about 37% between 2020 and 2050 and reach 116 Mt/yr by 2050 (compared to 196 Mt/yr in RBK, as seen in *Figure 4.13*). As can be clearly seen in the figure, the bulk of the decline for the modelled ERP is expected to occur by 2030. This reflects the initial target year for the federally proposed oil and gas emissions cap, which also includes the announced commitment to reduce upstream methane emissions by 75%.[115]

As the modelling assumes no regulated emission reductions via the cap beyond 2030, emissions from the oil and gas sector remain steady, which signals a need to further tighten regulation to continue to support decarbonization of the sector. This said, we also acknowledge that the emission reductions anticipated by 2030 are likely ambitious, given the depth of reductions from present-day levels required in short order.

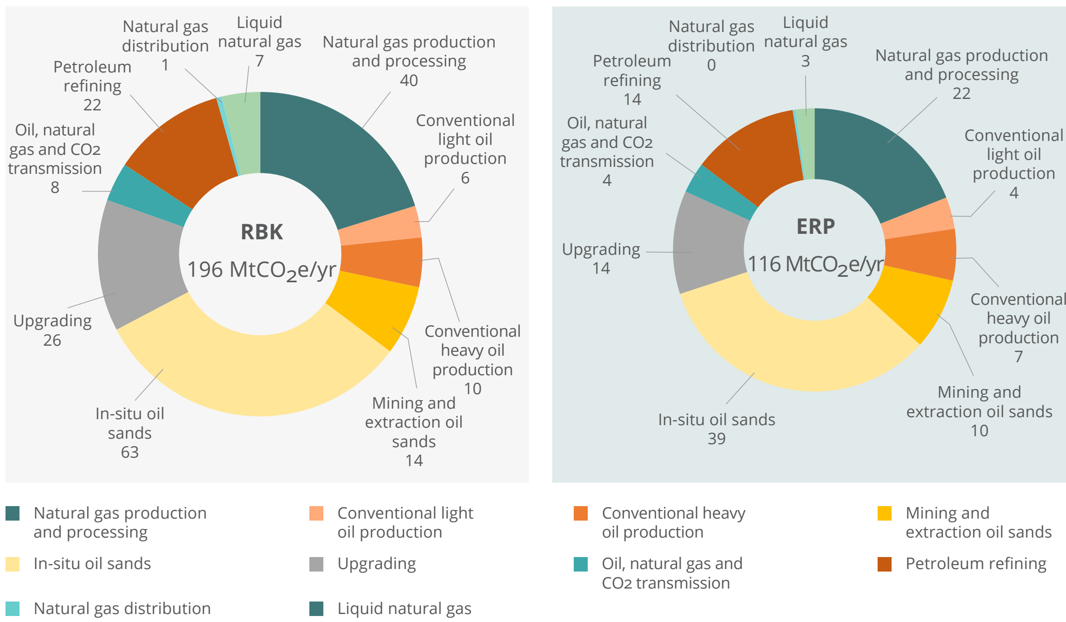
FIGURE 4.13: Oil and gas sector emissions (Mt CO_2e/yr) to 2050, RBK and ERP scenarios



115 On methane, current federal regulations require the oil and gas sector to reduce methane emissions by 40%–45% below 2012 levels by 2025. The 75% methane reduction commitment is simulated as a regulatory requirement demanding an increased uptake of abatement actions and technologies for surface case vent flows, leaks, and venting, such as increased monitoring, flaring, and well reworking, in the upstream oil and gas sector.

Figure 4.14 compares the anticipated 2050 emissions for the oil and gas sector by respective sub-sectors. Here we can see that, although the ERP scenario projects lower total emissions, the relative distribution of emissions by sub-sector remains very similar between the two scenarios. Oil sands emissions still constitute the most significant share of emissions across both RBK (39%) and ERP (41%) scenarios in 2050, which is consistent with the current emissions contribution of this sub-sector.[116] This finding also indicates the limited direct impact of current policies beyond the broad-scope planned cap and methane management regulations.[117]

FIGURE 4.14: Oil and gas sector emissions ($MtCO_2e/yr$) in 2050, RBK and ERP scenarios



As indicated in *Table 4.3*, modelled ERP policies promote a transition toward lower-emitting energy sources that are used for production in the oil and gas sector. This transition is seen through the increased contribution of electricity, hydrogen, and RNG to the energy consumption mix, as well as the 23% decline in refined petroleum use between 2020 and 2050. Still, electricity, hydrogen, and renewables together make up less than 13% of total energy consumption in 2050 under the ERP scenario, with 82% of energy consumed being natural gas.

116 Absolute GHG emissions from oil sands operations have more than doubled since 2005, from 35 Mt to 81 Mt in 2020 - this is 45% of the total emissions released by the sector in 2020. Approximately 88% of oil sands emissions come from burning fossil fuels (natural gas) to extract bitumen during mining or in-situ operations and to upgrade bitumen to transform it into synthetic crude oil. See: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap/options-discussion-paper.html

117 In July 2022, the federal government released a discussion paper on the design of the proposed cap for the sector: *Options to cap and cut oil and gas sector greenhouse gas emissions to achieve 2030 goals and net-zero by 2050 — discussion document.* In addition to input on upstream activities, the government is seeking input on whether the cap should apply to natural-gas transmission pipelines and petroleum refineries. See: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap/options-discussion-paper.html

TABLE 4.3: Change in energy consumption over time (PJ/yr) for oil and gas, RBK and ERP scenarios

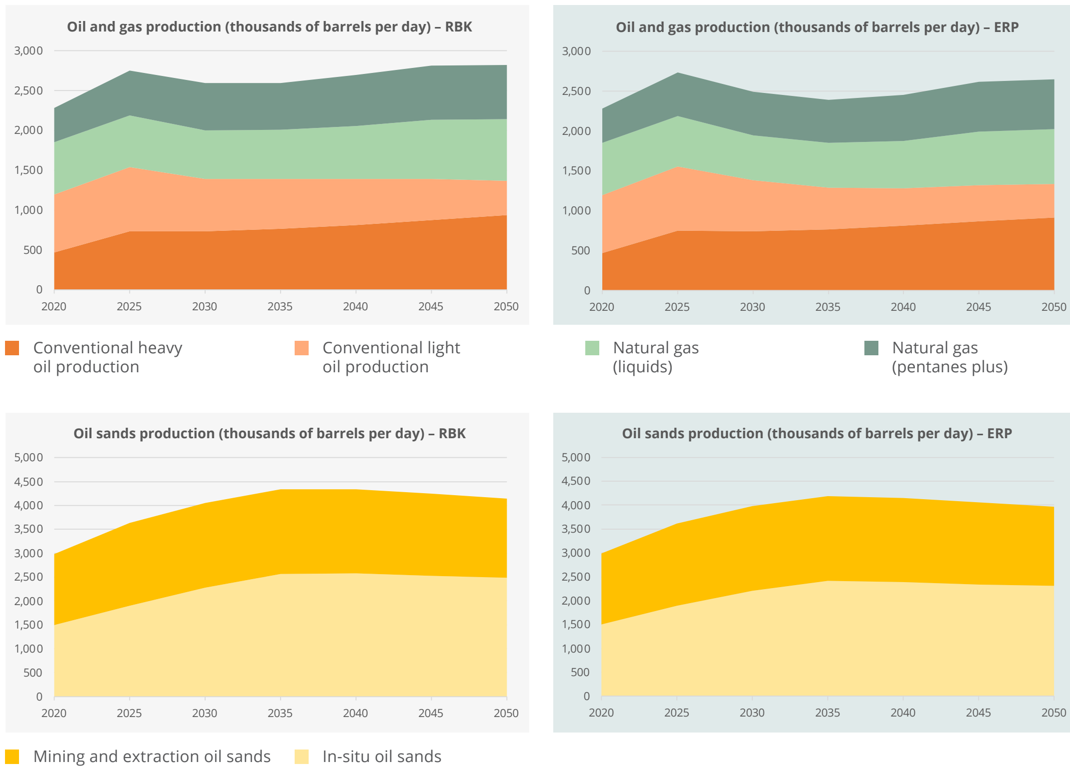
Energy consumption (PJ/yr)		RBK		ERP	
Oil and gas sector	**2020**	**2050**	**Difference from 2020**	**2050**	**Difference from 2020**
Biofuels	1	1	0	1	0
Electricity	182	269	87	379	197
Hydrogen	0	0	0	9	9
Natural gas	2,533	3,038	505	2,648	115
Refined petroleum	225	212	−13	174	−51
Renewable natural gas	0	7	7	11	11
Coal, coke, coal products	1	4	3	2	1
Natural gas liquids	8	26	18	6	−2
Total	**2,950**	**3,557**	**607**	**3,230**	**280**
GHGs emissions ($MtCO_2e$/yr)					
Oil and gas sector total	**183**	**196**	**+13**	**116**	**−67**

CCUS plays a significant role in this traditionally hard-to-decarbonize sector, which is in large part responsible for the reduction in oil and gas emissions despite little reduction in productivity and a rise in overall energy consumption.[118] Most types of oil and gas production volumes hold relatively steady through 2050, with few differences between the ERP and RBK scenarios *(Figure 4.15)*. In 2050, the largest differences in production are in natural gas (about 10% less natural gas pentanes and liquids produced in ERP compared to RBK) followed by oil sands in-situ operations (approximately 7% less in ERP compared to RBK), while the difference in oil sands mining and extraction is less than 1%. Overall, oil sands production (combined in-situ operations and mining and extraction) rises by 33% between 2020 and 2050 under the ERP scenario. The application of CCUS is instrumental in offsetting emissions resulting from sector growth, with approximately 27 Mt of CO_2 set to be captured in 2050. Adoption of CCUS in oil and gas thus makes up 40% of the total annual decline in emissions in the sector by 2050.[119]

118 The rise in energy consumption does not translate into higher emissions under the ERP scenario for two main reasons: (1) reduced contribution from petroleum and increased contribution from electricity, biofuels, and hydrogen in some sub-sectors, and (2) a portion of the added energy consumption comes from implementation of CCUS technologies (such as using waste heat from natural gas plants), which require additional energy but result in a net decline in emissions.

119 The sector drops from 183 Mt/yr in 2020 to 116 Mt/yr in 2050, or a difference of 67 Mt/yr by 2050. The oil and gas sector uses 99% of the process heat-related CCUS in the ERP scenario, which is estimated to be approximately 27 Mt/yr by 2050. This capture volume is just over a third of the total CCUS anticipated across the economy by 2050 under ERP (79 Mt).

FIGURE 4.15: Oil and gas sector production between 2020 to 2050, RBK and ERP scenarios



Our results suggest that ERP policies result in significant progress in reducing emissions in the oil and gas sector, including by tightening methane management and incentivizing the use of lower-emitting energy sources, such as electrification and RNG. Furthermore, adoption of carbon capture technologies stands out, as CCUS currently accounts for the majority of emissions reduction in the sector. Nevertheless, at 116 Mt/yr, emissions from the oil and gas sector remain among the largest for any sector in 2050, even under ERP.

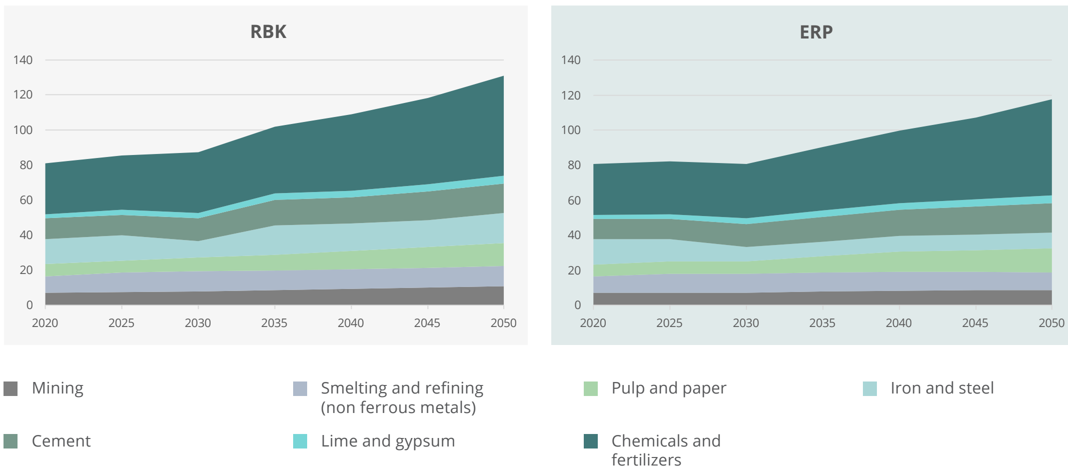
4.2.3 Heavy industry

As seen in *Figure 4.16*, heavy industry emissions grow steadily through to 2050 in both ERP and RBK scenarios. In ERP, we anticipate an overall increase in annual emissions of 36 Mt between 2020 and 2050, with growth in all sub-sectors, except for iron and steel which sees a 5 Mt decline. The decline in iron and steel is overshadowed however by the 26 Mt increase in annual emissions expected in the chemical and fertilizers sub-sector and in other areas by 2050.[120] In the RBK scenario, total annual emissions from heavy industry rise by over 50 Mt between 2020 and 2050, with no sub-sector declines.

120 Typically, about half or more of the emissions from the chemical sector in a given country are from making hydrogen to make ammonia to make urea for ammonia fertilizers. Such fertilizer production is categorized under emissions from the chemicals industry (Pers. Comm: C. Bataille). In 2015, this constituted about 22% of emissions from the sector (Pers. Comm: Navius). This area bears further exploration.

The largest growth overall is in chemicals and fertilizers, which is the highest-emitting sub-sector in both scenarios. For ERP, this becomes the highest-emitting sub-sector across the economy in 2050, at 12% of annual emissions. This sub-sector depends heavily on the consumption of natural gas as well as natural gas liquids, which are used to produce various chemical-based products.

FIGURE 4.16: Emissions ($MtCO_2e$/yr) associated with the heavy industry sector to 2050, RBK and ERP scenarios



Despite the ERP policies to address emissions from heavy industry, such as the Output-Based Pricing System (which targets industrial emissions) as well as DAC and CCUS ITCs, significant opportunity for abatement remains. At 117 Mt/yr projected by 2050, this sector's emissions are approximately equivalent to those of the oil and gas sector,[121] and it becomes *de facto* the highest emitting sector in the ERP scenario by 2050.

Unlike other sectors with more targeted policy measures, heavy industry overall does not undergo a substantive shift to consumption of alternative fuels, beyond a decline in coal, coke, and coal product use common to all sectors. This reduction is generally offset by greater consumption of natural gas, natural gas liquids, and, to a lesser degree, electricity and biomass. This illustrates the challenge and complexity of decarbonizing this sector. The results also suggest that further exploration for support is warranted, for example, through examining the impact of targeted innovation and projects for specific sub-sectors,[122] among other opportunities.

121 116 Mt/yr by 2050 under the ERP scenario.

122 As in the iron and steel sub-sector, where major plant upgrades have been announced by ArcelorMittal and Algoma to switch to less carbon-intensive forms of steel production — these announced projects are included in the modelled ERP baseline.

4.3 Gross domestic product and jobs

Highlights:

- Our model projects similar rates of growth in GDP and jobs in RBK and ERP scenarios through 2050, with some sectoral differences.
- The model suggests continued growth even in high-emission sectors such as oil and gas in the ERP scenario, as well as higher-than-average growth in the utilities sector.
- With more stringent emissions targets and supportive policies, Canada is poised to tap into further opportunities from deep technological and economic transformation beyond those estimated in this report.

Energy and emissions policies will have implications for income, GDP, and job growth. Our modelling results suggest that the transition to net-zero will require a shift away from highly polluting production models to best harness the advantages of new technologies and emerging sectors.

4.3.1 Gross domestic product growth

Highlights:

- GDP continues to grow under ERP, including in the oil and gas sector, although more modestly than under the RBK scenario.[123]

In the RBK scenario, GDP grows by an average of 2.4% annually, with the highest growth in agriculture and forestry (4.4%), manufacturing (2.6%), and oil and gas (2.6%) sectors *(Figure 4.17)*. At 2.2%, average annual GDP growth under the ERP scenario is slightly lower, with the highest annual average growth in agriculture and forestry (4.2%), utilities (4.0%), manufacturing (2.4%), and transportation (2.4%).

Oil and gas (along with a few other sectors) experience higher average growth relative to total GDP growth under the RBK scenario. Under the ERP scenario, there is considerably more development in the utilities sector (4.0% compared to 2.4% in RBK), and growth in oil and gas is slightly lower (approximately 2% annually) but not insignificant. The services sector is by far the largest contributor to GDP in both scenarios, making up over 70% of GDP through to 2050.

The composition of the economy (i.e., the relative proportions made up by different sectors) stays fairly constant through the modelled time period in both scenarios. However, because it is difficult to capture breakthrough innovation and related economic growth with a computable general equilibrium model,[124] interpretation

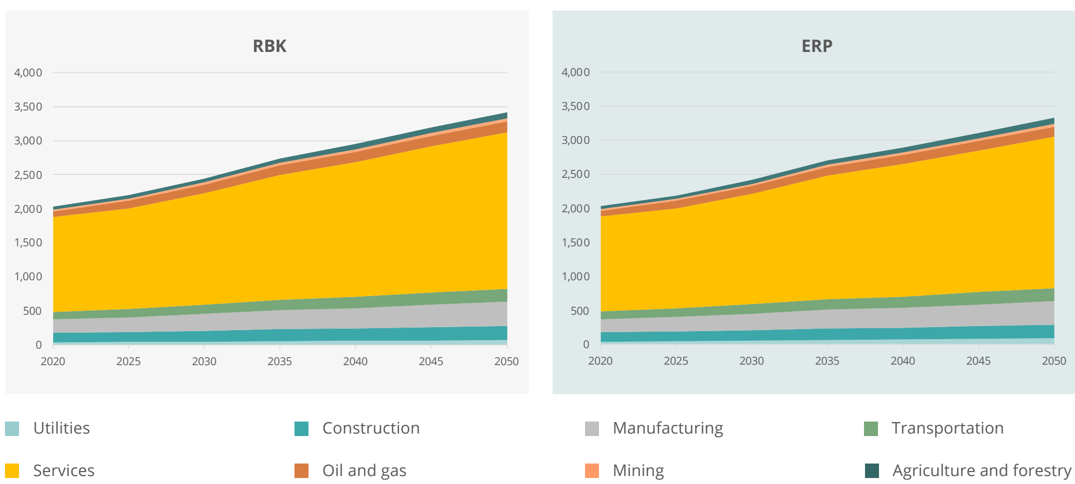
123 Not accounting for the likely GDP losses resulting from the impacts of climate change, especially in scenarios with weak action.

124 As the model includes only the technologies that are added to it, a limitation of modelling is that it cannot predict disruptive technology that can change economic dynamics.

of these results warrants consideration of economic opportunities that are poorly represented in the results. For example, decarbonization mandates will likely generate new types of demand, leading to growth in certain sectors (e.g., specialized manufacturing and technology) and emergence of new sub-sectors, which are difficult to predict using a static set of model conditions.

Also not explored or accounted for in this study are the co-benefits and cost savings that can go in tandem with decarbonization, such as improved air quality, which leads to a lower rate (and economic burden) of morbidity. Furthermore, the absence of climate change costs in our modelling likely results in inflated economic results. This is particularly important to consider when interpreting the economic implications of the RBK scenario, including the viability of growth in oil and gas production in a world where global demand is likely to decline.

FIGURE 4.17: Gross domestic product to 2050 (billions of 2015 $CAD), RBK and ERP scenarios



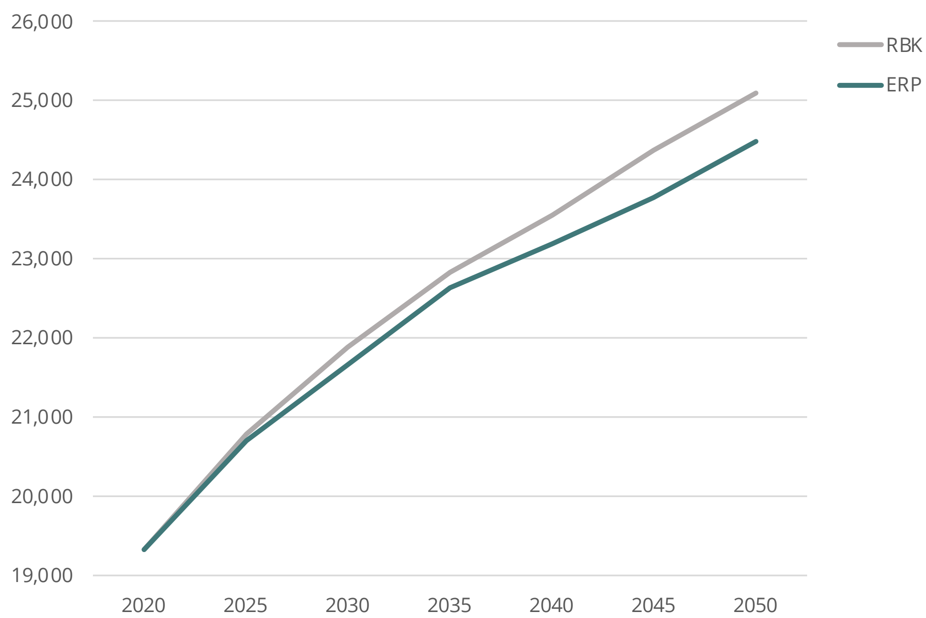
4.3.2 Jobs by sector

Highlight:

- Under the ERP scenario, jobs continue to grow, including in the oil and gas sector, although more modestly than in the RBK scenario. However, as other studies have shown, there is significant opportunity for job growth in emerging sectors that are not accounted for in this analysis.

The average annual growth in total jobs between 2020 and 2050 is around 1% in both the RBK and ERP scenarios *(Figure 4.18)*. Generally, our modelling shows slightly higher average annual job growth under the RBK scenario (0.6% to 1.5%) compared to ERP (0.5% to 1.4%), with growth tending to slow between 2035 to 2050 in both scenarios. We reiterate here that, as with GDP, the model does not capture well the skills and labour opportunities associated with new decarbonization pathways.

FIGURE 4.18: Jobs to 2050 (thousands of full-time equivalent positions), RBK and ERP scenarios



Sector differences in job growth are more pronounced, with higher-emitting sectors generally experiencing lower growth rates under ERP. The largest percentage differences are seen in the mining sector (1% average annual growth rate in RBK vs. 0.6% in ERP) and the oil and gas sector (0.4% average annual growth rate in RBK vs. 0.2% in ERP)[125] by 2050. Furthermore, due to higher demand for electricity in the ERP scenario, the utilities sector experiences considerable growth, generating approximately 15% more jobs in ERP than RBK by 2050.[126,127] This suggests an area of focus for reskilling and related labour-force initiatives.

While jobs in the oil and gas sector are indeed impacted by ERP policies, they are far more vulnerable to oil price fluctuations. In an initial review of the influence of oil price, we observed that a lower average oil price results in 24% fewer oil and gas sector jobs by 2050 compared to medium oil prices in the RBK scenario.[128] By contrast, the application of ERP policies reduces oil and gas sector jobs by only about 5%. This finding and related analyses[129] highlight the point that economic stability and resilience should be carefully considered when analyzing policy impacts on job growth, particularly in sectors that are more susceptible to commodity price fluctuations. Further exploration of such factors will be the subject of our ongoing work.

125 194,000 jobs in the RBK scenario vs. 184,000 jobs in the ERP scenario are projected for the oil and gas sector in 2050. By comparison, nearly 100 times more jobs are projected for the services sector.

126 127,000 jobs in the RBK scenario and 146,000 jobs in the ERP scenario in 2050.

127 In economic examinations of the increase in jobs relative to increase in GDP, generally, the rate of increase in jobs is lower than the rate of increase in GDP. For oil and gas, the difference between the two rates is larger than for the other sectors — this area also bears further exploration.

128 Our "low oil price" case assumes a $52 per barrel cost after 2025 compared to "medium oil price," which assumes oil prices around $86 per barrel of crude oil. For context, year-to-year average oil prices have fluctuated between 1% and over 80% in the last 10 years. In 2015, an estimated over 25 thousand jobs were lost across Canada — most of them in Alberta — as a result of the oil price downturn during that year.

129 See: https://climateinstitute.ca/alberta-has-a-chance-to-kick-start-clean-growth/

As is the case with our GDP results, a nuanced perspective is required to better understand the employment dynamics simulated in our model. A recent report by Clean Energy Canada[130] projected 2.2 million jobs added to the Canadian clean energy sector by 2050 under net-zero emissions, which will more than offset potential job declines in fossil fuels. The report further estimates that the country's clean energy sector in 2050 will be worth 63% more than the current (2025) inflation-adjusted value of the fossil fuel sector. Furthermore, we reiterate that model projections are generally limited in their ability to account for the job growth associated with the likely emergence of new sectors and transition toward new technologies that are currently unknown or in nascent stages of development.[131] Therefore, more innovation-driven job growth is possible, beyond what is estimated using current-day modelling assumptions.

Forward-looking policy that focuses on innovation is critical for maintaining global leadership in emerging sectors as well as for supporting workforce reskilling or upskilling to help employees and employers leverage the economic opportunities presented by decarbonization.[132] A skills gap has already been identified as a major problem for greener economic growth in Canada,[133] especially as other countries compete for investment and highly skilled workers. Continued policy development to support deeper transformation and knowledge-building can help better position Canada within an evolving global market.

Provincial job outcomes

On a provincial scale, scenario-based differences in job growth are similar to those on the national scale, with the utilities sector consistently seeing higher job growth under the ERP scenario than under the RBK scenario. Of Canada's four most populous provinces, Alberta and British Columbia are projected to see the highest total annual job growth on average (approximately 1.2%) under the ERP scenario, followed by Ontario (approximately 1%) and Québec (approximately 0.5%).

For both scenarios and in most provinces, growth is driven primarily by gains in the services sector and higher-than-average job growth in utilities and in manufacturing. Alberta and British Columbia see job growth in all sectors, including oil and gas: Alberta is set to see continued growth in oil sands jobs and British Columbia sees job gains in oil and gas services and in LNG development.

Job growth is projected in nearly all sectors in Ontario and Québec, although some job loss in petroleum refining is expected in Ontario, while agriculture and forestry jobs tend to fluctuate through to 2050 in the four most populous provinces.

130 Clean Energy Canada (2023) *A Pivotal Moment*. Retrieved from https://cleanenergycanada.org/wp-content/uploads/2023/03/A-Pivotal-Moment-Report.pdf

131 Which would include not only build-out and maintenance, but also education/training and innovation spurred by policy-driven transformation of demand and investment flows.

132 Smart Prosperity Institute. (May 2022). *Jobs and skills in the transition to a net-zero economy.* Retrieved from https://institute.smartprosperity.ca/sites/default/files/Jobs_and_Skills_in_the_Transition_to_a_Net-Zero_Economy.pdf
See also: https://climateinstitute.ca/alberta-has-a-chance-to-kick-start-clean-growth/

133 Conference Board of Canada and Future Skills Centre. (February 2022). *Green Occupation Pathways: from vulnerable jobs to rapid-growth careers.* Retrieved from https://fsc-ccf.ca/wp-content/uploads/2022/02/FSC-green-occupation-pathways-EN.pdf

5. Introduction to the net-zero pathways

As we discussed in **Section 4**, by 2050 the model projects fewer emissions in the ERP (459 Mt/yr) vs. in the RBK scenario (704 Mt/yr). For ERP, 2050 sees a 38% reduction in annual emissions compared to 2005 values. This is in sharp contrast to the RBK annual emission trajectory, which exhibits only a 6% decline over the same time period. Despite this potential progress, projected emissions by 2050 under the ERP scenario still fall significantly short of our 50 Mt/yr net-zero goal and, instead, result in an emissions overshoot of approximately 400 Mt/yr by 2050.[134] Even this outcome is based on the successful execution and timely achievement of most announced federal and provincial climate policies on the table.

In our net-zero analysis, we set out to explore how Canada could achieve net-zero emissions by 2050 under different cost and technology-availability pathways. In this section, we introduce our five net-zero pathways of interest and describe some preliminary implications of early analysis. We look forward to building on this starting point in future project phases.

5.1 Pathway definitions

We have selected five pathways for Canada's net-zero transition, principally defined by their use of different energy sources. The five net-zero pathways of interest — High Electrification (Electrification), High Electrification with Renewables (Renewables), Bioenergy, Hydrogen, and Fossil with CCUS — are described below. These pathways span a range of possible future directions for Canada. Two of the pathways, for example — Fossil with CCUS and Renewables — are intended to be "book-end" scenarios that show the implications of following two diametrically opposed pathways, as advocated by various constituencies.[135] Each pathway was set to achieve our goal of 50 Mt of emissions annually by 2050.[136]

A description of each pathway is provided below. The assumptions made to define pathways, cost inputs, and technology availability are provided in the separate Navius Research methodology report.

134 As explained in Section 4.1 Greenhouse gas emissions, we assume a target of 50 Mt annually by 2050, which can be mitigated by land use, land-use change, and forestry, as noted.

135 In the Fossil with CCUS pathway, Canada focuses on producing more fossil fuels and simply tries to offset emissions through CCUS and DAC, whereas the Renewables pathway considers how the energy system would be affected if fossil fuels were phased out completely by 2050 and no new nuclear options were allowed.

136 To address the net-zero cap for these pathways, the model was constrained to force emissions to 50 Mt/yr by 2050.

High electrification

The High-Electrification (referred to as Electrification) pathway reflects a future scenario in which electricity becomes cost-competitive enough to replace natural gas and other fossil fuels in a wide range of energy uses, such as process heat, buildings, and transportation. In this future, electricity is dominant and there is no restriction on how it is produced. Low-carbon electricity options available include wind and solar power, new large nuclear and small modular nuclear reactors (SMnRs), as well as fossil-fuel generation with CCUS.

This pathway is characterized by low costs for wind and solar power, EV batteries, and heat pumps, compared to those used in the ERP and RBK scenarios and some of the other pathways, as well as the availability of energy-storage options such as hydrogen storage, flow batteries, lithium-ion batteries, and pumped hydro.

High electrification with renewables

The High Electrification with Renewables pathway (Renewables) is envisioned as a future in which targets for high electrification are primarily met with renewables (e.g., existing hydro, wind, solar, and biomass energy).[137] It is assumed that increased electricity demand is not met through nuclear power, either new larger nuclear plants or SMnR technologies.

This pathway is distinctive in that we apply an explicit and managed wind-down of oil and gas production by 2050 to achieve near-zero fossil-fuel production. The wind-down is intended to explore the implications of following a significantly carbon-constrained pathway to meet global reduction targets.[138]

For this pathway, our cost assumptions align with those of the Electrification pathway, except that we exclude nuclear options and include an oil and gas production phase-out (which implies cessation of oil and gas exports as well).[139] Relative to other pathways, this pathway assumes low costs for solar/wind power, batteries, EVs, and heat pumps; average costs for CCUS, hydrogen, and fuel-cell EVs (FCEV); and high cost of DAC and biofuels. This pathway is also characterized by low costs for wind and solar power, EV and EV batteries, and heat pumps, compared to costs used in the RBK scenario.

137 Geothermal is not currently accounted for as a renewable energy pathway in the Navius model . We are exploring its inclusion either within the model or as a parallel exploration, depending on the potential and complexity associated with it. Offshore wind is also not incorporated in the model.

138 Comparable pathways include those from *the Net- Zero America: Pathways, Infrastructure, and Impacts* study (Princeton University). See: https://netzeroamerica.princeton.edu/, which describes an aggressive electrification scenario in which the supply side has been constrained to be 100% renewable, no nuclear plants are built, and there is no new underground carbon storage by 2050. David Suzuki Foundation's "Zero Plus" scenario also explores greater levels of electrification in buildings, transportation, and industrial sectors, as well as giving greater priority to energy efficiency and building retrofit options. This scenario excludes CCUS, carbon storage, offsets, SMnR/large nuclear, and large hydro, and phases out oil and gas by 2035.

139 Winding down oil and gas production and exports eliminates the problem of Scope 3 emissions from this sector. A common source of criticism is that domestic energy policy "exports emissions" elsewhere. The impact of oil and gas phase-out (for domestic use and for exports) on GDP will be the subject of future investigation.

Bioenergy

In this Bioenergy pathway, biofuels (both liquid and gaseous forms) become more competitive with their fossil-fuel counterparts and more accessible and applicable to selected end uses. Although electrification still powers much of the economy, natural gas continues to play a prominent role and leverages a natural gas stream composed largely of RNG. Bioenergy with carbon capture and storage is considered a generally available technology option.[140] Bio-based liquid fuels are also available to act as drop-in fuels to meet transportation demand.[141]

Relative to other pathways, this pathway assumes low costs for CCUS and biofuels; average costs of hydrogen, EVs, and FCEV; and higher costs of DAC, batteries, heat pumps, and wind and solar electricity generation.[142]

Hydrogen

For the Hydrogen pathway, future hydrogen production and fuel-cell technology become cost-competitive enough to be used for energy storage, as well as a replacement fuel in transportation and in industry. Fuel switching offers an attractive alternative for those sectors that present electrification challenges.

This pathway assumes low costs for CCUS, hydrogen, and FCEV; moderate costs of EVs and biofuels; and high costs of DAC, batteries, heat pumps, and solar and wind electricity generation.

Fossil with carbon capture, utilization, and storage

The Fossil with CCUS pathway envisions a focus on fossil fuels through the increased use of natural gas and oil, with fully decarbonized upstream production through engineered carbon capture. In this fossil-based future (which also allows for nuclear), Canada continues to rely heavily on combustion applications such as in transportation and heat, which would be offset by CCUS and DAC.[143]

This pathway assumes low costs of CCUS technologies; moderate costs of DAC, EVs, hydrogen, and FCEV; and high costs of batteries, heat pumps, and solar and wind electricity generation.

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140 In the model, industrial heat is used in biofuel production. When that heat source is coupled with CCUS, it is referred to as bioenergy with carbon capture and storage. The model does not specify a CCUS technology specifically for biofuel production; instead, this is a general technology that can be used by all industrial processes. Bioenergy with carbon capture and storage is therefore theoretically available in all of the net-zero pathways.

141 In *Net- Zero America: Pathways, Infrastructure, and Impacts* study (Princeton University). See: https://netzeroamerica.princeton.edu/, the study team also explored less aggressive end-use electrification but higher biomass supply, with the intention of allowing biomass liquid fuels to meet the demands of non-electrified transportation.

142 Costs of solar and wind power have declined significantly in recent years. Our input parameters reflect the observed cost declines as well as expected future declines. “High” cost settings for wind and solar power are those at the higher end of the projected future cost range.

143 For this pathway, we apply cost assumptions that allow a continued economic dependence on fossil fuels and the ability to offset emissions with CCUS and DAC, whereas these costs are set higher in the other pathways.

Summary of pathway constraints

The constraints applied to the scenarios and pathways are summarized in *Table 5.1.* Our intention was to construct pathways that are sufficiently distinct to enable us to explore varied technology-focused policies, rather than to examine the impacts of individual cost parameters (such as the cost declines needed for selected technologies). Further assumptions made to define pathways, cost inputs, and technology availability are provided in the separate Navius Research methodology report.

TABLE 5.1: Summary of pathway constraints applied[144]

Pathway	DAC cost	New nuclear available	SMnRs available	Battery cost	EV cost	Heat pump	CCUS cost	Hydrogen cost	FCEV cost	Solar and wind cost	Biofuels cost
0. Reference runs (ERP & RBK)	REF	no	no	REF	REF	REF	REF	REF	REF	REF	REF
1. Electrification	high	yes	yes	low	low	low	REF	REF	REF	low	high
2. Renewables	high	no	no	low	low	low	REF	REF	REF	low	high
3. Bioenergy	high	no	no	high	REF	high	low	REF	REF	high	low
4. Hydrogen	high	no	no	high	REF	high	low	low	low	high	REF
5. Fossil fuels with CCUS	REF	yes	yes	high	REF	high	low	REF	REF	high	REF

5.2 Exploration of the net-zero pathways

While further development and analysis of the net-zero pathways is the subject of our ongoing work, we present here selected observations from preliminary analysis.

5.2.1 Emissions

Table 5.2 shows the 2050 sectoral emissions that make up the cap of 50 Mt in each net-zero pathway. Although these results are exploratory, we can already see the varied impact of (and consequent expectation for) emerging sectors such as DAC, which does not play out in a material way in either the RBK or ERP scenarios.[145] This DAC expectation is particularly evident for the Fossil with CCUS pathway, followed by Electrification.[146] The negative emission values in several sectors (e.g., Electricity) result from the deployment of CCUS technologies in combination with biofuels, including liquid fuels and RNG.[147]

144 Note that an additional constraint — oil and gas production wind-down by 2050 — is explicitly applied to the Renewables pathway.

145 DAC is represented as a separate sector, with negative emissions to indicate the level of associated abatement.

146 The cost for DAC for the Fossil with CCUS pathway was set at the low cost assumption, and at the high cost assumption for all other net-zero pathways. DAC cost was also set to reference or average costs for both baseline scenarios (RBK and ERP).

147 As biofuels would include sequestration, and can be net-negative as a result.

TABLE 5.2: Annual greenhouse gas emissions by 2050 (Mt/yr), net-zero pathways vs. RBK and ERP scenarios

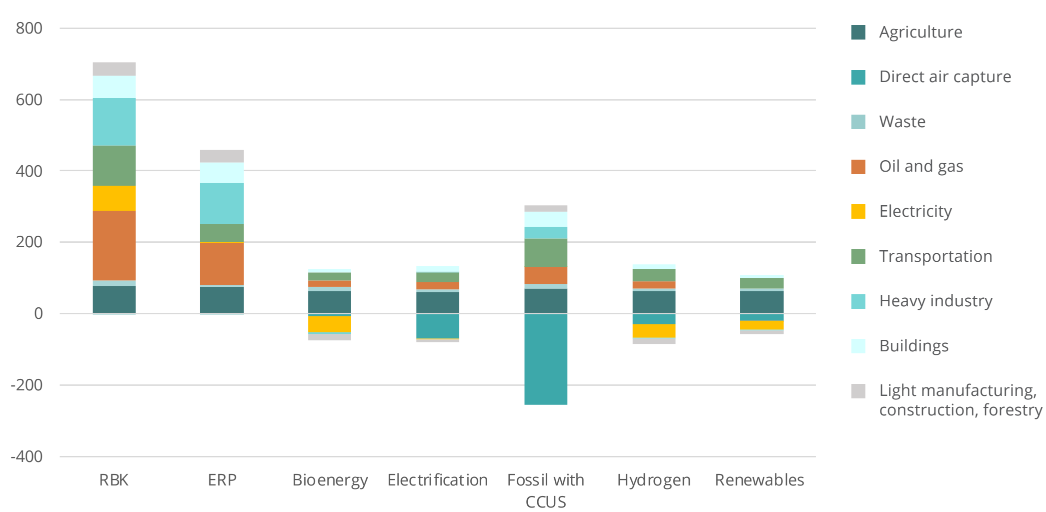
	RBK	ERP	Bioenergy	Electrification	Fossil with CCUS	Hydrogen	Renewables
Agriculture	78	74	64	61	71	62	61
Direct air capture	0	0	−8	−69	−256	−29	−20
Waste	15	7	10	7	11	9	9
Oil and gas	196	116	20	19	47	20	0
Electricity	69	3	−45	−4	1	−39	−26
Transportation	114	49	21	29	78	35	30
Heavy industry	131	117	−4	2	33	−1	0
Buildings	64	57	12	14	44	12	8
Coal production	1	2	0	0	1	0	0
Light manufacturing, construction, forestry	36	34	−19	-8	17	-17	-11
Total	**704**	**459**	**51**	**51**	**47**	**51**	**51**

Figure 5.1 shows how emissions are distributed across sectors for the net-zero pathways in 2050. Combined with *Table 5.1*, we see that, by 2050, all net-zero pathways (with the exception of Fossil with CCUS) anticipate:

- 61 to 64 Mt/yr of emissions resulting from agriculture;
- 21 to 35 Mt/yr from transportation;
- 8 to 14 Mt/yr from buildings; and,
- 9 to 10 Mt/yr from waste.

Similarly, all of our net-zero pathways suggest abatement in the range of 109 to 235 Mt/yr from DAC and/or CCUS uptake.[148]

FIGURE 5.1: Emissions ($MtCO_2e/yr$) in 2050, by pathway or scenario and by sector

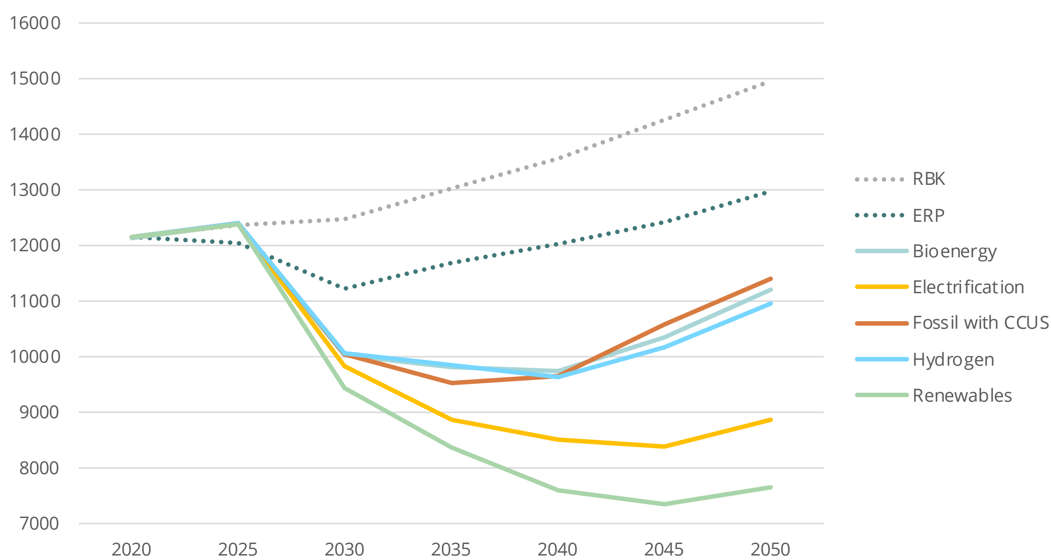


148 This range of values is derived from summing the negative values shown in Table 5.2. The electricity sector, for example, is a large taker of CCUS in 2050 for the Bioenergy (–50 Mt/yr), Hydrogen (–45 Mt/yr), and Renewables (–30 Mt/yr) pathways. The Renewables pathway shows outcomes for natural gas with CCUS, as well as cogeneration, which likely impacts the CCUS uptake we see for this sector.

5.2.2 Energy consumption

In order to achieve net-zero as specified, we see a nearly immediate reduction in energy consumption across all of the net-zero pathways *(Figure 5.2)*. After an initial sharp decline, energy consumption begins to increase again as early as 2035 for the Fossil with CCUS pathway, and by 2040 and 2045 for the other pathways. This reflects a change to a cleaner and more efficient energy-mix profile over time, with the introduction of fuels such as biofuels and hydrogen, increasing electrification, as well as the presence of CCUS and DAC across most pathways. This area will undergo further investigation in our ongoing analysis.[149]

FIGURE 5.2: Annual energy consumption (PJ) by 2050, net-zero pathways vs. RBK and ERP scenarios

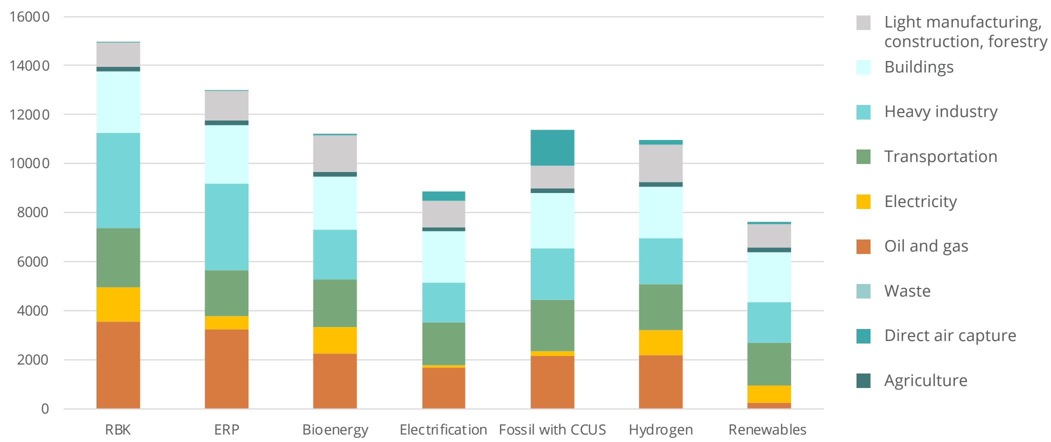


5.2.3 Energy consumption by sector

Figure 5.3 illustrates annual energy consumption by sector across the pathways in the year 2050. Total energy consumption is highest for the Fossil with CCUS pathway and generally lower in deep electrification pathways (Electrification and Renewables). Most of the differences are seen in the electricity; heavy industry; light manufacturing, construction, and forestry; and the oil and gas sectors, while the buildings and agriculture sectors are similar across pathways.

149 Our next iteration of model decomposition data will enable us to further assess the underlying causes of changes in fuel consumption, including the impacts of structural change, energy efficiency, and efficiency gains from fuel switching to electricity.

FIGURE 5.3: Annual energy consumption (PJ) in 2050, net-zero pathways vs. RBK and ERP scenarios



By 2050, oil and gas energy consumption is more than 80% lower in the Renewables pathway than the other net-zero pathways due to the production phase-out constraint we have applied *(Table 5.3)*. We also see lower energy use by heavy industry and higher use by the electricity sector for this pathway compared to the ERP scenario. The Fossil with CCUS pathway also shows less energy consumption for oil and gas, heavy industry and electricity compared to the ERP scenario, but this is partially made up for by the anticipated energy consumption demands of DAC (1,473 PJ/yr). These preliminary observations and model outcomes are subject to further development.[150]

TABLE 5.3: Annual energy consumption by 2050 (PJ), net-zero pathways vs. RBK and ERP scenarios

	RBK	ERP	Bioenergy	Electrification	Fossil with CCUS	Hydrogen	Renewables
Oil and gas	3,556	3,229	2,243	1,681	2,154	2,191	266
Electricity	1,399	564	1,105	98	204	1,006	691
Transportation	2,416	1,869	1,919	1,752	2,092	1,891	1,753
Heavy industry	3,866	3,509	2,046	1,618	2,110	1,862	1,630
Buildings	2,514	2,398	2,151	2,081	2,254	2,118	2,062
Agriculture	208	205	196	174	189	193	184
Coal production	18	19	3	1	10	1	2
Light manufacturing, construction, forestry	982	1,182	1,498	1,086	915	1,523	957
Direct air capture	0	0	49	376	1473	173	96
Total	**14,960**	**12,974**	**11,210**	**8,866**	**11,401**	**10,957**	**7,639**

150 For example, the amount of energy consumed by the electricity sector in the Electrification pathway for 2050 is low compared to the other pathways (98 PJ/yr), which is an unanticipated result, given that the Renewables pathway does not show the same outcome.

The pathways also differ considerably with regard to the type of fuels consumed throughout the economy *(Figure 5.4; Table 5.4)*. The Renewables pathway is overall the least reliant on fossil fuels, with electricity making up over 40% of economy-wide consumption, followed by RNG (27%). The Fossil with CCUS pathway stands out as having by far the highest natural gas (5,208 PJ/yr or 46% of total) and petroleum (1,631 PJ/yr or 14% of total) consumption of the five net-zero pathways, and very little consumption of RNG (<1%) and biofuels (1.3%).

Somewhat surprising is the high consumption of natural gas (2,720 PJ/yr, or 24%) in the Bioenergy pathway; however this scenario also projects the highest consumption of biofuels (921 PJ/yr) and RNG (2,789 PJ/yr). Electricity consumption is modest across the board for all pathways, at 28% to 40% of total energy consumed.

FIGURE 5.4: Annual energy consumption (PJ) by fuel type in 2050, net-zero pathways vs. RBK and ERP scenarios

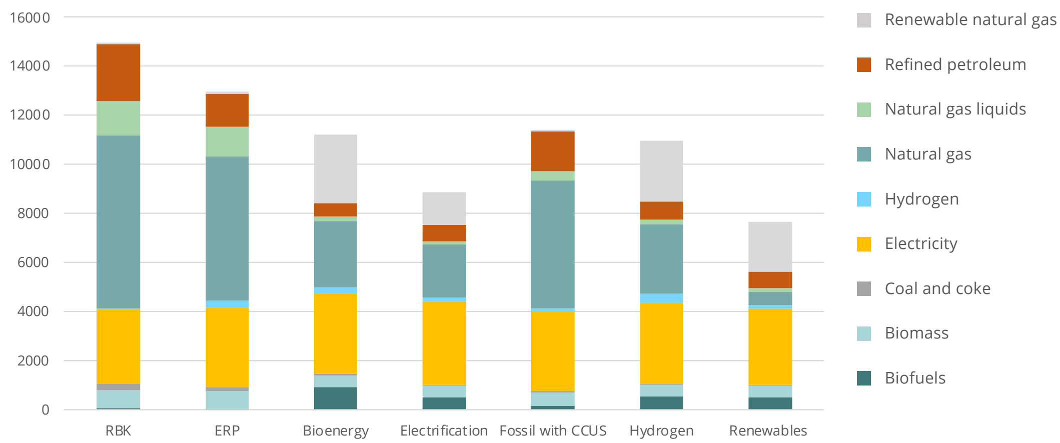


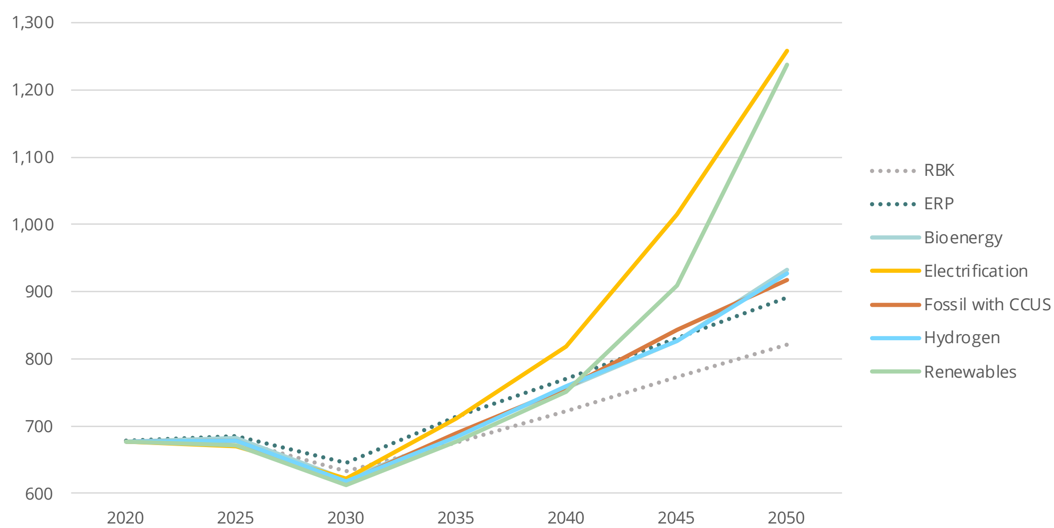
TABLE 5.4: Annual energy consumption (PJ) by fuel type in 2050, net-zero pathways vs. RBK and ERP scenarios

	RBK	ERP	Bioenergy	Electrification	Fossil with CCUS	Hydrogen	Renewables
Biofuels	51	42	921	516	149	543	515
Biomass	739	714	480	456	551	560	453
Coal and coke	251	169	45	49	44	51	53
Electricity	3,038	3,232	3,292	3,400	3,255	3,283	3,099
Hydrogen	35	294	242	148	141	392	129
Natural gas	7,074	5,867	2,720	2,153	5,208	2,824	540
Natural gas liquids	1,382	1,230	192	142	364	185	149
Refined petroleum	2,337	1,327	529	658	1,631	754	679
Renewable natural gas	53	101	2,789	1,344	58	2,466	2,022
Total	**14,960**	**12,974**	**11,210**	**8,866**	**11,401**	**10,957**	**7,639**

5.2.4 Electricity generation

To meet the energy demand, the model predicts a significant increase in annual electricity generation *(Figure 5.5)*, which also has implications for storage, imports, and exports. In pathways that emphasize electrification (Electrification and Renewables), an increase in generation of about 83% to 86% is needed over the next 30 years.[151] Even the less electrification-heavy and non-net-zero scenarios (such as the ERP scenario) require over 30% more generation by 2050. The main differences between the pathways are related to solar, wind, and natural gas with CCUS generation.

FIGURE 5.5: Annual electricity generation (TWh) by 2050, net-zero pathways vs. RBK and ERP scenarios



The Electrification and Renewables pathways have the highest amount of solar and wind generation by 2050, amounting to 718 TWh/yr (57% of energy mix) for Electrification and 693 TWh/yr (56% of energy mix) for Renewables *(Table 5.5)*. This is anticipated given that growth in generation in all pathways is primarily made up of solar and wind power expansion. Bioenergy and Hydrogen pathways maintain the highest share of natural gas with CCUS generation, at 186 TWh/yr (20% of energy mix) for Bioenergy and 168 TWh/yr (18% of energy mix) for Hydrogen. The Fossil with CCUS pathway has a relatively small share of natural gas with CCUS generation (about 6% of energy mix). However, this pathway also anticipates the lowest increase in total electricity generation of all the net-zero scenarios and has significant DAC and CCUS abatement.[152]

The requirements for the net-zero pathways translate to between 66% and 215% added wind and solar generation, with high-renewables pathways (Electrification and Renewables) needing to build more generation capacity to partly offset intermittent

151 All values are in comparison to 2020. Notably, the David Suzuki Foundation's study shows less generation (<1,000 TWh) in its high-electrification scenario, whereas the Electrical Power Research Institute's study suggests 1,000–1,200 TWh in its net-zero scenarios.

152 The Fossil with CCUS pathway also shows higher amounts of solar and wind electricity generation than the Hydrogen and Bioenergy pathways.

resource availability. All pathways assume added solar and wind generation capacity of 237–717 TWh/yr by 2050, which is six to 18 times higher than 2020 estimates.[153]

TABLE 5.5: Annual electricity generation (TWh) in 2050, net-zero pathways vs. RBK and ERP scenarios

	RBK	ERP	Bioenergy	Electrification	Fossil with CCUS	Hydrogen	Renewables
Coal	0	0	0	0	0	0	0
Natural gas combustion	83	9	2	1	10	2	0
Solar	89	123	96	411	161	105	418
Wind	109	138	142	307	178	148	275
Cogeneration	69	69	38	31	43	34	13
Run-of-river hydro	27	27	27	27	27	27	27
Biomass	2	3	0	0	0	0	0
Hydro	362	366	365	363	364	365	365
Biomass cogeneration	0	0	0	0	0	0	0
Diesel	0	0	0	0	0	0	0
Nuclear	77	77	77	77	77	77	77
Heavy fuel oil	0	0	0	0	0	0	0
Natural gas combustion with carbon capture and storage	0	79	186	41	58	168	62
Total	**821**	**891**	**933**	**1259**	**917**	**926**	**1,238**

Small Modular Nuclear Reactors, or SMnR, despite being included as a model input, are outcompeted by other electricity-generation technologies in current model results. We also note the heavy presence of natural gas with CCUS in certain pathways, including Bioenergy and Hydrogen. These areas and others will be subject to further investigation.

5.2.5 Energy storage

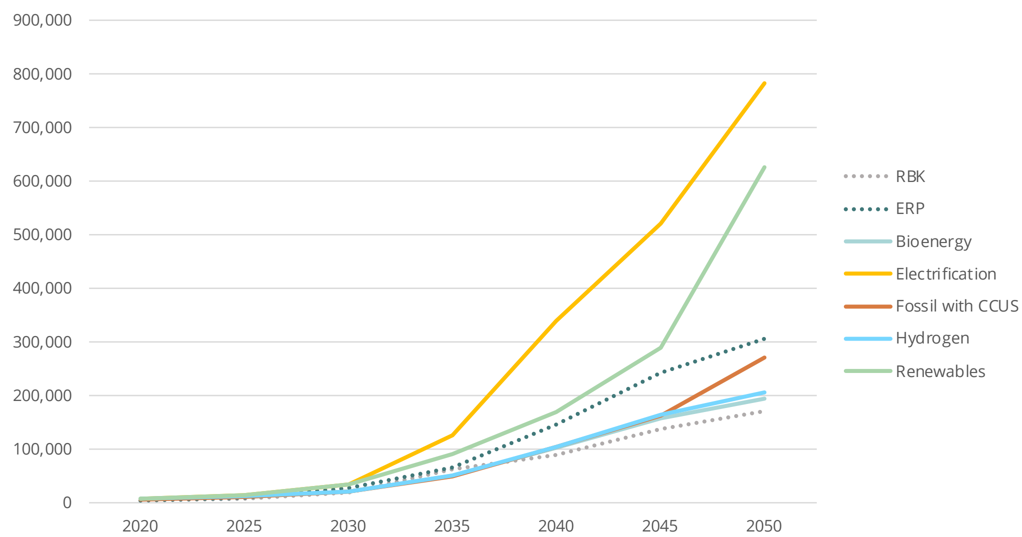
Grid-scale energy storage, including lithium batteries, flow batteries, pumped hydro, and hydrogen storage, are also expected to play an important role, especially in high-electrification pathways dominated by renewables (i.e., Electrification and Renewables). The magnitude of storage estimated ranges considerably for selected pathways. For outcomes focused on electrification, storage would need to increase to approximately 84 to 105 times that of 2020 values *(Figure 5.6)*.[154]

The ERP scenario also anticipates significant growth in renewables-based electricity generation and assumes medium energy-storage costs. This scenario entails a

153 From a starting point of approximately 40 TWh/yr in solar and wind power (2020).
154 A January 2023 report by the Canadian Renewable Energy Association suggests that energy storage is 347 MWh across Canada for 2022, see: https://renewablesassociation.ca/news-release-canada-added-1-8-gw-of-wind-and-solar-in-2022/
In contrast, our model shows 3,333 MWh for 2020, which exceeds this estimate. The model calibrates battery storage to 2015 and therefore leverages lithium-ion battery storage at an earlier juncture. Future model iterations will seek to constrain battery storage in 2020 to more closely align with empirical data.

substantial increase in storage capacity — more than those net-zero pathways focused on express forms of emissions abatement (e.g., carbon capture, biofuels, and hydrogen development). At 12.7 GW by 2035, the storage resource potential[155] modelled under our ERP scenario aligns with the higher end of some industry estimates (which anticipate from 8–15 GW of resource need that could be filled by storage by 2035).[156,157]

FIGURE 5.6: Energy storage capacity (MWh) to 2050, net-zero pathways vs. RBK and ERP scenarios



Granting that results are preliminary, this suggests an important role for storage technologies, especially in the high electrification-based pathways. This highlights the importance of programs such as the Smart Renewables and Electrification Pathways Program, which was recapitalized by $3 billion in the 2023 federal budget and supports smart renewable energy and electrical grid modernization projects such as energy storage.[158]

5.2.6 Carbon capture, utilization, and storage

By 2050, the highest annual adoption of CCUS is seen in the Bioenergy and Hydrogen pathways, followed by the Fossil with CCUS pathway *(Figure 5.7)*. The bulk of CCUS adoption is found in process heat, which makes up around half of the anticipated adoption of CCUS for the net-zero pathways and is applied largely (approximately 99%) in the oil and gas sector.[159]

155 The maximum instantaneous power output that can be discharged from the energy storage system to meet demand.

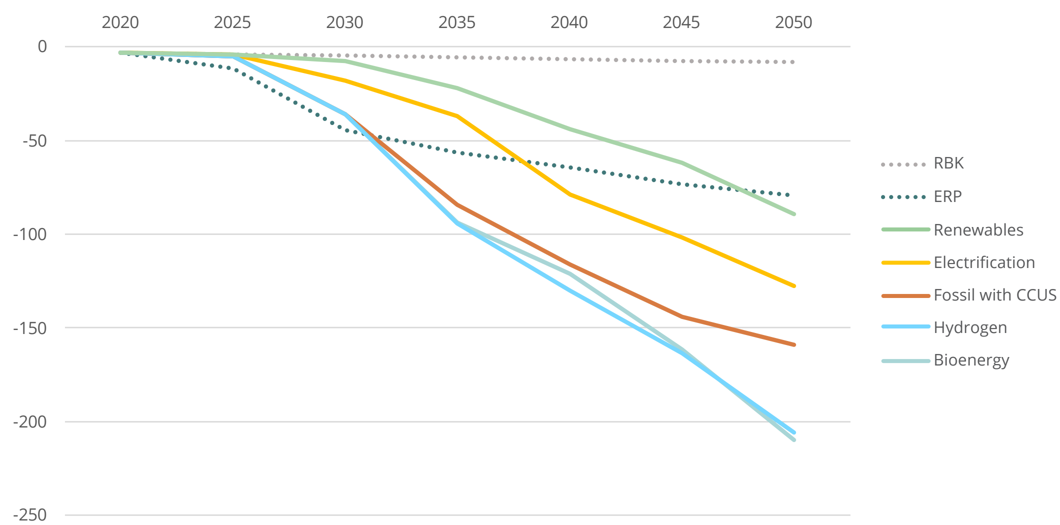
156 Power Advisory LLC (2022) *Energy Storage: A Key Pathway to Net Zero In Canada*. On behalf of Energy Storage Canada. See: https://static1.squarespace.com/static/61f81e15f490ed3db8dadda2/t/6345a24b3ee2440f883c885f/1665507916398/2022+Energy+Storage+-+A+Key+Pathway+to+Net+Zero+in+Canada.pdf

157 Investigating regional storage is also of interest, as results to date indicate some concentration (in terms of hydrogen storage potential) in selected pathways in certain areas.

158 We note that the *U.S. Inflation Reduction Act* continues explicit support for energy storage projects under an Investment Tax Credit structure of 30%, so long as prevailing wage requirements are met.

159 Notably, some process heat is still used by the oil and gas sector in the Renewables pathway, because, due to model limitations, the oil and gas production phase-out applied to this pathway reaches only 95%, rather than a full phase-out of 100%.

FIGURE 5.7: Annual adoption of carbon capture, utilization, and storage ($MtCO_2e$), net-zero pathways vs. RBK and ERP scenarios



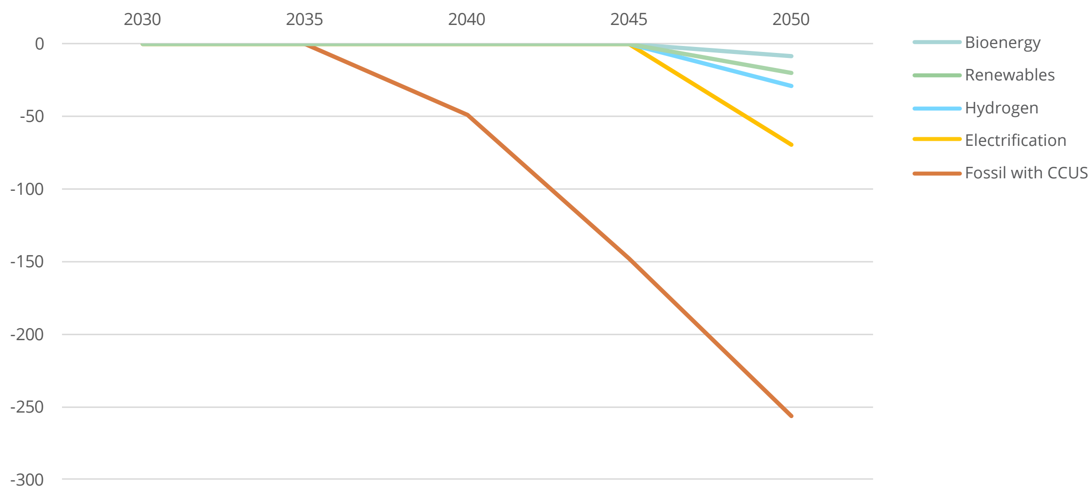
5.2.7 Direct air capture

Preliminary evaluation shows that, by 2050, DAC sees significant adoption in all net-zero pathways. By contrast, there is negligible to no uptake of DAC in the RBK and ERP scenarios *(Figure 5.8)*. DAC adoption begins around 2040 for the Fossil with CCUS pathway (in which fossil fuels remain a leading fuel source and DAC costs are low). By 2050, all of the remaining net-zero pathways use DAC in some capacity in order to achieve 2050 emissions targets, and Electrification and Hydrogen do so in particular. However, by 2050, DAC uptake in the Fossil with CCUS pathway is almost four times greater than in the Electrification pathway and nine times that of the Hydrogen pathway.

The drastically higher DAC uptake in the Fossil with CCUS pathway is attributed to increased use of fossil-based electricity and natural gas that need abatement, but is also a function of DAC input costs, which were set at a moderate level for this pathway.[160] Other pathways, including Electrification, Hydrogen, and Renewables, also require a significant degree of DAC to offset unabated emissions across sectors. Interestingly, DAC costs for these pathways were all set at a higher level than in the Fossil with CCUS pathway, which suggests there may be less opportunity for CCUS or other means of decarbonization in some sectors.

160 Our explicit input costs are provided in the separate Navius methodology report. However, for these purposes, we apply a "reference" (middle-of-the-road) cost for DAC, where the levelized cost of capture in a DAC plant starts at \$734/tCO_2e and declines with experience with the technology to a potential price floor of \$164/tCO_2e.

FIGURE 5.8: Annual direct air capture abatement ($MtCO_2e$), net-zero pathways



Results suggest that the adoption of DAC may rely on multiple factors. One such factor likely includes stronger targeted policy support given the negligible DAC adoption we see in ERP, and given that ITC support for DAC is already a part of the ERP policy package. In the net-zero results, we see that DAC becomes an economically viable option closer to mid-century, which is an outcome of the technology costs, legislated policy, and market conditions in the model. Overall, emissions are mainly captured using CCUS rather than DAC (except in the Fossil with CCUS pathway), which likely reflects that CCUS technologies are more economical to implement unless DAC costs are lowered.[161,162]

Altogether, the net-zero pathways suggest that DAC and CCUS make stark and materially significant contributions to emission reductions. For the Fossil with CCUS pathway alone, these reductions are on the order of a 415 Mt annual expectation, approximately split between DAC (62%) and CCUS (38%), whereas for the Hydrogen pathway they are 235 Mt/yr, and for the Electrification pathway 197 Mt/yr. In future research we aim to better understand the alternatives to this heavy use of DAC and CCUS, and explore scenarios in which these options are further constrained or unavailable.

161 Comprehensive investment in DAC research, development, and upscaling could lower the costs more quickly than forecasted, leading to faster adoption than currently expressed in the results.

162 The analysis, however, does not consider the scale-up that may be needed after Canada reaches its net-zero target in order to remove a portion of historical emissions (i.e., go "net-negative"). This is an area to be further explored in subsequent work.

6. Conclusion and next steps

In this paper, we described our project approach, established Canada's anticipated emissions trajectory to 2050, and introduced our five net-zero pathways. We found that, although our current policy trajectory is projected to make good progress on emission reductions, this result is optimistic as we assume the timely and optimal execution of legislated policy. Even so, we still fall significantly short of achieving the net-zero target in 30 years. Our initial modelling of technical pathways to net-zero emissions already show the depth of the interventions required to achieve our target and the urgency of planning now.

Ongoing work will focus on deepening the examination of our net-zero pathways, including exploring regional and sector-level aspects of the modelling to better understand the challenges, opportunities, and tradeoffs in achieving net-zero across Canada. One of our next steps is a policy simulation exercise to explore how we can improve emissions outcomes and make further progress toward net-zero. This work will also integrate the new ERP elements recently introduced in Budget 2023.

A concurrent project phase will also centre on identifying Canada's renewable energy, hydrogen, and DAC/CCUS resource potential and mapping the scale of infrastructure deployment required to realize this potential. The work from pathway development, policy simulation and mapping exercise will be integrated to form our final project report.

6.1 A note on cumulative emissions

A further critical aspect to consider in net-zero planning is emissions accumulation over time. Modelling total emissions accrued under the ERP scenario shows that Canada could conceivably contribute approximately 16.3 billion tonnes of emissions to the atmosphere over the period 2020 to 2050. The emissions picture is bleaker still for our RBK scenario, for which the model projects that Canada will emit as much as 20.7 billion tonnes over the same period.[163]

The global community needs to reduce emissions to an approximate global carbon budget of 420 billion tonnes CO_2 (420 Gt) to have a chance at remaining within a 1.5 °C

163 Since the Navius model reports in five-year intervals, these estimates were derived by averaging the total annual emissions from the beginning and the end of each five-year interval from 2020 to 2050 and accounting for the sum total of these annual averaged emissions over the full 30-year period. So, for example, we would average the total annual GHG emissions estimated for 2020 and for 2025, and then multiply that value by the four years in between to approximate cumulative emissions from 2020 to 2025.

warming scenario without "overshoot."[164] Our modelled ERP trajectory is thus projected to use up 4% of the global budget over the next 30 years, and the RBK trajectory will use up 5%. Although discussions on this area are in their infancy, this share is likely inequitable when we consider that Canada's current emissions contribution is 1.5% of the global total, its population is 0.48% of the world total, and the country contributes 1.2% of global GDP.

The consideration of cumulative emissions underscores just how difficult it will be to stay under the 1.5°C global target, and the longer Canada waits to cut emissions, the more drastic measures to achieve negative emissions will be needed in the future. From this vantage point, frontloading significant emissions reductions in earlier years is not only necessary to achieve domestic net-zero targets, but absolutely crucial in terms of reducing total emissions, which is the ultimate determinant of climate change and its impacts. We will examine the impact of different emissions trajectories in future project phases to contribute further understanding to this important area.

164 The Intergovernmental Panel on Climate Change's 2021 assessment suggests a remaining global carbon budget of about 420 $GtCO_2$ for a two-thirds chance of limiting warming to 1.5 °C, and of about 580 $GtCO_2$ for an even chance (medium confidence) of limiting warming to that level. However, a number of other factors significantly complicate arriving at any certainty on these estimates, including geophysical uncertainty, uncertainty in the level of historic warming, and many other factors. See: https://www.ipcc.ch/sr15/chapter/chapter-2/
We also note that the global carbon budget is for carbon dioxide only, whereas our emissions estimates are in carbon dioxide equivalent (CO_2e, or total GHG emissions). Ultimately, however, Canada's current estimated CO_2e trajectory will still contribute CO_2 "equivalent" to the global carbon budget. We recognize that several nuances to this argument remain to be considered (such as the varying residence time in the atmosphere of other GHGs).

APPENDIX A: Rollback scenario, policies included[165]

The tables below describe the federal and provincial policies included in the Rollback Scenario. The Rollback Scenario includes legislated federal and provincial carbon pricing and regulatory policies as of November 2021. It also includes provincial and federal funding programs and subsidies, such as those in the 2020 Fall Economic Statement, Budget 2021 subsidies and Budget 2022 top-ups, as described in the tables below. *Note that provincial policies are not included in the list below if there is an equally or more stringent federal policy (e.g., federal renewable fuel requirements).*

Carbon Pricing (detail)

The federal government has implemented a carbon pollution pricing backstop that applies in all provinces without an equivalently stringent carbon pricing system. The federal policy includes two components: (1) a carbon levy applied to fossil fuels that reaches $50 per tonne of 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 kilotonnes of CO_2e annually.

Provinces either have their own equivalent carbon pollution pricing system (British Columbia, Québec, Nova Scotia, New Brunswick, Newfoundland and Labrador, Northwest Territories), a partial federal and partial provincial system (Saskatchewan, Alberta, Ontario, Prince Edward Island), or are fully subject to the federal backstop (Manitoba, Yukon, and Nunavut)[166]. In this analysis, the carbon levy revenue is returned to households and the revenue raised by the output-based pricing system is returned to industry (half by cutting corporate income taxes, and the other half by investing in clean energy technology in each respective province/territory).

For some provinces (British Columbia, Alberta, and Québec), we simulate a detailed representation of the provincial pricing system – these are detailed in the following table. For Alberta's output-based pricing system (TIER), which applies to industrial facilities emitting more than 100 kilotonnes of CO_2e annually, we have used the 2020 TIER compliance report to estimate facility-specific benchmarks. For sectors that were either excluded from the 2020 compliance report[167] or for which mapping to gTech sectors was not possible, a benchmark at 90% free allowances was used. We assume an annual 1% tightening rate for all sectors except for conventional oil and gas sectors and non-combustion emissions. Benchmark tightening is assumed

165 Two additional provincial policies — Québec's New Oil Heating Ban and Chauffez Vert Program — will be included in future model iterations.
166 Government of Canada (2023). Carbon pollution pricing systems across Canada. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html
167 Government of Alberta. (2021). Alberta Industrial Greenhouse Gas Compliance. Retrieved from: https://open.alberta.ca/dataset/c0cb77ca-fac0-4171-89af-0048e2189120/resource/3a2316ec-07df-4f07-a3e1-b3ac3c5f32cf/download/aep-alberta-industrial-greenhouse-gas-compliance-summary-2020-compliance-results-tier.pdf

to continue until the carbon price remains constant (2022 under the currently implemented policy). TIER electricity benchmarks are not assumed to increase in stringency and remain at 0.37tCO_2e/MWh through 2050. For all other provinces, we assumed that the federal pricing system is applied.

All Policies Modelled

Region:	Federal
Policy:	Carbon Pollution Pricing Backstop *(before*[168] *the amendment in October 2022*[169]*).* This policy includes two components: (1) a carbon levy applied to fossil fuels that reaches $50 per tonne (t) carbon dioxide equivalent (CO_2e) by 2030 and is constant thereafter in nominal terms; and (2) an output-based pricing system for industrial facilities emitting more than 50 kilotonnes (kt) CO_2e annually. Provinces either have their own equivalent carbon pollution pricing system (British Columbia, Québec, Nova Scotia, New Brunswick, Newfoundland and Labrador, Northwest Territories), a partial federal and partial provincial system (Saskatchewan, Alberta, Ontario, Prince Edward Island), or are fully subject to the federal backstop (Manitoba, Yukon, and Nunavut). Revenue raised by this policy is returned to households in each respective province/territory.
References:	Government of Canada (2023). Carbon pollution pricing systems across Canada. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html
Region:	Federal
Policy:	Energy Efficiency Regulations 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 on incandescent light bulbs.
References:	Natural Resources Canada. (n.d.). Canada's Energy Efficiency Act and Energy Efficiency Regulations. Retrieved from www.nrcan.gc.ca/energy/regulations-codes-standards/6861
Region:	Federal
Policy:	Green Freight Assessment Program Four-year funding program launched in 2018 with a budget of $3.4 million available for conducting medium- and heavy-duty fleet performance reviews, implementing operational best practices, installing fuel-saving technologies, and purchasing alternative-fuel vehicles.

168 https://laws-lois.justice.gc.ca/eng/acts/G-11.55/section-sched247155-20180621.html
169 https://laws-lois.justice.gc.ca/eng/acts/G-11.55/FullText.html#h-247156 (see Schedule 4)

References:	Government of Canada. (2020). Green Freight Assessment Program. Retrieved from https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/greening-freight-programs/green-freight-assessment-program/20893
Region:	Federal
Policy:	Hydrofluorocarbon Controls The Canadian government was one of the signatories of the 2016 Kigali Agreement amending the Montreal Protocol on ozone-depleting substances. Canada has pledged to reduce its hydrofluorocarbon-related greenhouse gas consumption by 10% in 2019, increasing in stringency until 85% HFC reduction is achieved by 2036.
References:	Government of Canada. (2022). Regulatory amendments on hydrofluorocarbons: frequently asked questions. Available from: Regulatory amendments on hydrofluorocarbons: Frequently asked questions – Canada.ca
Region:	Federal
Policy:	Light-duty zero-emission vehicle (ZEV) incentive 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.
References:	Government of Canada. (n.d.) Zero-emission vehicles. Retrieved from https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles
Region:	Federal
Policy:	Regulations Amending the Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations The amended Heavy-Duty Vehicle Emissions Standard increases the vehicle emission stringency for vehicles manufactured in model years 2018 to 2027.
References:	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. Retrieved from http://gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors98-eng.html
Region:	Federal
Policy:	Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations 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 U.S. regulations.

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

Region:	Federal
Policy:	Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations This policy closes coal-fired power plants by 2030 unless they emit less than 420 tonnes CO_2e per gigawatt-hour (GWh).
References:	Government of Canada. (2018). Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations: SOR/2018-263. Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-167/page-2.html#h-4

Region:	Federal
Policy:	Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity This policy limits the emissions intensity of natural gas-fired electricity generation to 420 t CO_2e/GWh.
References:	Government of Canada. (2018). Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity: SOR/2018-261. Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-261/index.html

Region:	Federal
Policy:	Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds Oil and gas facilities must adopt methane-control technologies and practices.
References:	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. Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.htm

Region:	Federal
Policy:	Renewable Fuels Regulations Specifies a minimum renewable content of 5% for gasoline and 2% for diesel, by volume. This will become part of the Clean Fuel Regulation (CFR) once the CFR comes into force.
References:	Government of Canada (2013). Renewable Fuels Regulations: SOR/2010-189. Retrieved from https://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-189/index.html

Region:	Federal
Policy:	Zero Emission Vehicle Infrastructure Program 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-fuelling stations, including medium- and heavy-duty vehicle charging and re-fuelling stations.
References:	Government of Canada. (2020). Zero Emission Vehicle Infrastructure Program. Retrieved from https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/zero-emission-vehicle-infrastructure-program/21876
Region:	Federal
Policy:	Net Zero Accelerator 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. The Net Zero Accelerator is simulated as an $8 billion government investment over seven years for industrial low-carbon technologies, including carbon capture and storage or utilization 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.
References:	Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf
Region:	Federal
Policy:	Canada Infrastructure Bank Spending 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 clean 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. Since then, CIB funding has been extended and will receive a total of $35 billion with priorities to invest in green infrastructure ($5 billion), public transit ($5 billion) and clean power ($5 billion). CIB spending is simulated as a $1.5 billion subsidy for zero-emission buses, $500 million for electric charging and hydrogen refueling infrastructure (included in the “charging stations” funding 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.

References:	Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf
Region:	Federal
Policy:	Interest-free home retrofit loan 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. Budget 2022 allocated an additional investment of $458.5 million into the low-income loan program. 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.
References:	Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html
Region:	Federal
Policy:	Residential Efficiency Retrofits Budget 2021 included $2.6 billion for residential energy efficiency improvements over seven years. 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.
References:	Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html
Region:	Federal
Policy:	Residential Efficiency Retrofits Budget 2021 included $2.6 billion for residential energy efficiency improvements over seven years. 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.
References:	Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html
Region:	Federal

Policy:	Community Buildings Upgrade and Low Carbon Economy Fund
	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. An additional community-oriented fund that was simulated as funding for community and commercial efficient building shell and heating technologies, is the Low Carbon Economy Fund. This $2.2 billion fund was introduced in Budget 2022 and supports territorial, provincial and municipal governments, schools, colleges, universities, businesses, NGOs, hospitals and Indigenous organizations and communities in their effort to reduce GHG emissions. The two subsidies were simulated as a $3.7 billion ($1.5 billion + $2.2 billion) subsidy for community and commercial efficient building shell and heating technologies over four years. Subsidy values are assumed to be nominal.
References:	Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html
	Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont
Region:	Federal
Policy:	Renewable Electricity Investments
	The Healthy Environment and Healthy Economy federal climate plan states that $964 million over four years will be invested in renewable electricity generation. Budget 2022 announced that an additional $600 million will be invested in renewable electricity and grid modernization and $250 million to support large clean electricity projects. This is simulated as a $1.8 billion subsidy ($964 million + $850 million) over four years flowing into the renewable electricity generation sector. Subsidy values are assumed to be nominal.
References:	Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf
	Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html
	Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont
Region:	Federal
Policy:	Low Carbon Fuel Fund
	The Healthy Environment and Healthy Economy federal climate plan states that $1.5 billion will be invested in renewable fuels such as hydrogen, renewable natural gas and liquid biofuels. This is simulated as a low carbon fuel subsidy over five years. Subsidy values are assumed to be nominal.

References:	Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf
Region:	Alberta
Policy:	Capping oil sands emissions
	Limits emissions from the oil sands to 100 megatonnes (Mt) CO_2e annually. Note this cap is not represented in gTech currently, as the emissions from the oil sands are far less than 100 Mt per year in the base case.
References:	Government of Alberta (2020). Capping oil sands emissions. Retrieved 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
Region:	Alberta
Policy:	*Renewable Electricity Act*
	Regulation requiring 30% of electricity produced in Alberta to come from renewable sources by 2030. Interim targets of 15% by 2022, 20% by 2025, and 26% by 2028 have been established.
References:	Alberta. (2020). Renewable Electricity Act. Statutes of Alberta, 2016 Chapter R-16.5. Retrieved from https://www.qp.alberta.ca/1266.cfm?page=r16p5.cfm&leg_type=Acts&isbncln=9780779814060
Region:	Alberta
Policy:	Carbon capture, utilization, and storage (CCUS) investments
	Alberta has contributed funding to several CCUS projects, including the Shell Canada Energy Quest Project and the Alberta Carbon Trunk Line.
References:	Natural Resources Canada. (2018). Shell Canada Energy Quest Project. Retrieved from www.nrcan.gc.ca/energy/funding/cef/18168 Natural Resources Canada. (2016). Alberta Carbon Trunk Line (ACTL). Retrieved from www.nrcan.gc.ca/energy/publications/16233
Region:	British Columbia
Policy:	Carbon tax
	Continue increasing the carbon tax by $5/tCO_2e$ annually, until it reaches $50 per tonne in 2022.
References:	Government of British Columbia. (n.d.). British Columbia's Carbon Tax. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/carbon-tax

Region:	British Columbia
Policy:	*Clean Energy Act*
	A minimum of 93% of provincial electricity generation must be provided by clean or renewable sources.
References:	Government of British Columbia. (2010). Clean Energy Act. Retrieved from http://www.bclaws.ca/civix/document/id/lc/statreg/10022_01

Region:	British Columbia
Policy:	Light-duty ZEV subsidies
	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 its introduction.
References:	Government of British Columbia. (2020). Go Electric Passenger Vehicle Rebates. Retrieved from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/passenger-vehicles

Region:	British Columbia
Policy:	Low Carbon Fuel Requirement Regulation (part of the Low Carbon Fuel Standard)
	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.
References:	Government of British Columbia. (2020). Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act, SBC 2008, c. 16. Retrieved from https://www.bclaws.ca/civix/document/id/complete/statreg/08016_01

Region:	British Columbia
Policy:	PST exemption
	Use of electricity in residential and industrial buildings is exempt from provincial sales tax.
References:	Government of British Columbia. (2017). Provincial Sales Tax (PST). Tax Rate. Retrieved from https://www2.gov.bc.ca/gov/content/taxes/sales-taxes/pst

Region:	British Columbia
Policy:	Specialty Use Vehicle Incentive
	Rebates of up to $50,000 for plug-in hybrid, electric, and hydrogen on-road medium- and heavy-duty freight vehicles.

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

Region: British Columbia

Policy: Zero Emission Vehicle Standard

Requires a minimum share of light-duty vehicles sold in B.C. to be zero-emission. This mandate achieves 10% electric vehicle sales by 2025, 30% by 2030, and 100% by 2040.

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

Region: British Columbia

Policy: Renewable Natural Gas Regulation

In 2018, CleanBC announced a minimum requirement of 15% renewable sources, by volume, in distributed natural gas. Based on B.C.'s own modelling, as reported in the 2019 methodology report, we assume that this policy would require 15% of biofuels or hydrogen blending with distributed natural gas by 2030.

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

Navius Research (2020). Supporting the development of CleanBC. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/supporting-development-cleanbc_methodology-report_navius.pdf

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Region: Manitoba

Policy: Biofuels Mandate amendment

Renewable fuel content requirement at 10% for gasoline and 5% for diesel, by volume.

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

Region: Manitoba

Policy: Coal phase-out

Manitoba Hydro phased out its last coal-fired generating unit in 2018.

References: Manitoba Hydro. (n.d.). Generation Stations. Retrieved from https://www.hydro.mb.ca/corporate/facilities/generating_stations/

Region: Manitoba

Policy:	Efficient Trucking Program
	Joint provincial and federal fund of $11.8 million for heavy-duty vehicle efficiency retrofits. Applications closed April 2020.
References:	Red River College. (2020). Vehicle Technology and Energy Centre. Efficient Trucking Program. Driving sustainability forward in Manitoba. Retrieved from https://www.rrc.ca/vtec/efficient-trucking-program/
Region:	Manitoba
Policy:	Keeyask Hydro-electricity Project
	Ongoing construction of a 695-megawatt (MW) hydro generating station was completed in 2022.
References:	Manitoba Hydro. (n.d.). Keeyask Generating Station. Retrieved from https://www.hydro.mb.ca/projects/keeyask/
Region:	New Brunswick
Policy:	Renewable Portfolio Standard
	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.
References:	Government of New Brunswick. (2015). New Brunswick Regulation 2015-60 under the Electricity Act (O.C. 2016-263). Retrieved from www.gnb.ca/0062/acts/BBR-2015/2015-60.pdf
Region:	Newfoundland and Labrador
Policy:	Freight Transportation Fuel Efficiency Program
	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.
References:	Government of Newfoundland and Labrador. (n.d.). Freight Transportation Fuel Efficiency Program. Retrieved from https://www.gov.nl.ca/mae/occ/low-carbon-economy-programs/freighttransportation/
Region:	Newfoundland and Labrador
Policy:	Muskrat Falls Hydro Project
	A hydro project with a capacity of 824 MW.
References:	Naclor Energy. (2019). Muskrat Falls Project: Project Overview. Retrieved from https://muskratfalls.nalcorenergy.com/project-overview/
Region:	Nova Scotia

Policy:	Cap-and-trade program
	Annual caps on certain activities in Nova Scotia, including fuel suppliers, electricity importers, and large final emitters.
References:	Government of Nova Scotia. (n.d.). Nova Scotia's Cap-and-Trade Program. Retrieved from https://climatechange.novascotia.ca/nova-scotias-cap-trade-program
Region:	Nova Scotia
Policy:	Cap on GHG emissions from electricity generation
	This policy requires emissions from the electricity sector to decline to 4.5 Mt by 2030.
References:	Government of Nova Scotia. (2013). Greenhouse Gas Emissions Regulations made under subsection 28(6) and Section 112 of the Environment Act. Retrieved from www.novascotia.ca/JUST/REGULATIONS/regs/envgreenhouse.htm
Region:	Nova Scotia
Policy:	Renewable Portfolio Standard
	This renewable portfolio standard requires that 25% of electricity consumption be provided from renewable resources in 2015, increasing to 40% by 2020. In the next model iteration, the NS Renewable Portfolio Standard will increase to 80% by 2030.
References:	Government of Nova Scotia. (2020). Renewable Electricity Regulations made under Section 5 of the Electricity Act. Retrieved from https://novascotia.ca/just/regulations/regs/elecrenew.htm
Region:	Nova Scotia
Policy:	Maritime Link
	This transmission line will connect Nova Scotia to hydroelectric generation from Newfoundland and Labrador (in particular, to the Muskrat Falls hydroelectric project).
References:	Emera Newfoundland and Labrador. (2014). Maritime Link. Retrieved from http://www.emeranl.com/en/home/themaritimelink/overview.aspx
Region:	Ontario
Policy:	Coal phase-out
	Ontario phased out its last coal-fired generating unit in 2014. In 2019, about 94% of Ontario's electricity generation was emissions-free.
References:	Government of Ontario. (2020). The End of Coal. Retrieved from https://www.ontario.ca/page/end-coal#:~:text=Ontario%20enshrined%20its%20commitment%20in,to%20generate%20electricity%20in%20Ontario

Region:	Ontario
Policy:	Greener Diesel Regulation
	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 emissions from standard petroleum diesel.
References:	Government of Ontario. (2021). CleanerTransportation Fuels. Retrieved from https://www.ontario.ca/page/cleaner-transportation-fuels
Region:	Ontario
Policy:	Greener Gasoline Regulation
	Minimum renewable fuel content rising to 15% by volume for gasoline by 2030. Renewable gasoline must have an average of 50% less life-cycle GHG emissions than emissions from standard petroleum gasoline.
References:	Government of Ontario. (2021). Cleaner Transportation Fuels. Retrieved from https://www.ontario.ca/page/cleaner-transportation-fuels
Region:	Ontario
Policy:	Nuclear power plant refurbishment
	Ontario will refurbish 10 nuclear power plants, which, combined, will provide more than 9,800 MW emissions-free capacity.
References:	Government of Ontario. (2018). Chapter 2. Ensuring a Flexible Energy System. Retrieved from https://www.ontario.ca/document/ontarios-long-term-energy-plan-2017-order-council-21202017/chapter-2-ensuring-flexible-energy-system#section-8
Region:	Québec
Policy:	Cap-and-trade system for GHG emissions allowances
	Cap-and-trade system for industrial and electricity sectors as well as fossil-fuel distributors. Revenue raised by the policy is invested in low-carbon technologies.
References:	Gouvernement du Québec. (2020). The Carbon Market, a Green Economy Growth Tool! Retrieved from http://www.environnement.gouv.qc.ca/changementsclimatiques/marche-carbone_en.asp.
Region:	Québec
Policy:	Electric vehicle incentives
	Provides incentives between $4,000 and $8,000 for the purchase of a ZEV.
References:	Gouvernement du Québec. (2019). Discover electric vehicles. Retrieved from http://vehiculeselectriques.gouv.qc.ca/english/

Region:	Québec
Policy:	ZEV standard
	Automakers that sell over 4,500 vehicles in the province are required to meet a minimum ZEV 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 ZEVs accounting for 9.9% of new sales in 2025. A recently developed amendment will change the credit accounting system and ZEV sales targets for the years 2025 and thereafter. Under the revised system, the sale of one new light-duty zero emission vehicle will equal one credit. The minimum sales targets for post 2025 have been set to increase from 12.5% in 2025 to 65% in 2030 and 100% in 2035. To account for this change, the credit system and targets have been updated in the modeling.[170]
References:	Gouvernement du Québec. (2018). The zero-emission vehicle (ZEV) standard. Retrieved from http://www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm Québec. (2017). chapter A-33.02, r. 1. Available from: https://www.legisquebec.gouv.qc.ca/en/document/cr/A-33.02,%20r.%201/ Gazette Officielle Du Québec, January 26, 2022, Vol. 154, No. 4. Available from: http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=1&file=105485.pdf
Region:	Québec
Policy:	Renewable Natural Gas Regulation
	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 to 5% in 2025.
References:	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/
Region:	Saskatchewan
Policy:	Boundary Dam Carbon Capture Project
	This project stores and captures CO_2 emissions from a 115 MW coal plant.
References:	SaskPower. (2019). Boundary Dam Carbon Capture Project. Retrieved from https://www.saskpower.com/our-power-future/infrastructure-projects/carbon-capture-and-storage/boundary-dam-carbon-capture-project
Region:	Saskatchewan

170 While this policy amendment had not yet been implemented by November 2021, this update is included here, as additional modeling development would have been necessary to scenariorize the zero emission vehicle mandate credit system parameterization.

Policy:	Ethanol Fuel (General) Regulations Requires a minimum renewable fuel content of 7.5% for gasoline, by volume.
References:	Government of Saskatchewan. (2020). Ethanol Fuel (General) Regulations (E-11.1 Reg 1). Retrieved from: https://publications.saskatchewan.ca/#/products/1064
Region:	Saskatchewan
Policy:	*Renewable Diesel Act* Specifies a minimum renewable fuel content of 2% for diesel, by volume.
References:	Government of Saskatchewan. (2012). Renewable Diesel Act (R-19.001). Retrieved from https://publications.saskatchewan.ca/#/products/64461

APPENDIX B: Emissions Reduction Plan scenario, policies modelled

The tables below describe the federal and provincial policies included in the Emissions Reduction Plan Scenario. This scenario is an announced policy scenario. It includes the same policies as the Rollback Scenario (see Appendix A) as well as federal policies announced in Canada's *2030 Emissions Reduction Plan (ERP), Budget 2022* federal funding programs, and announced provincial policies, as described in the tables below. For many announced policies, there is significant uncertainty regarding coverage, design, stringency, and timelines. The characterization of these announced policies is illustrative.[171] The purpose is to represent the level of emission reductions that could be achieved if these policies were to be implemented (as assumed herein).

Carbon Pricing (detail)

The federal government announced that the federal fuel charge and Output-Based Pricing System (OBPS) carbon price will be annually increased by $15 per tonne of CO_2e after 2022 until the tax reaches $170 per tonne of CO_2e in 2030 and stays constant at that level thereafter.[172,173] 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 and OBPS backstop apply to all provinces and territories, except for Québec, and that an annual 2% tightening rate will apply to all OBPS sectoral benchmarks starting in 2023. Québec's cap is assumed to be sufficiently stringent in its current design. Fuel charge proceeds are returned to households in the province in which they were collected. OBPS proceeds are assumed to be split 50% to fund low-carbon industrial technologies, and 50% to reduce corporate taxes.

For the TIER program, we assume that the TIER carbon price will follow the federal carbon pricing schedule and that the 1% benchmark tightening rate will continue out to 2030, after which point carbon pricing will remain at $170 per tonne of CO_2e. The TIER electricity benchmark is assumed to remain at 0.37tCO_2e/MWh.

171 Since the time of this analysis (Spring 2022), more policy information has been released, such as a 2035 coming into force date for the Clean Electricity Regulations.
172 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
173 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

Modelled Policies

Region:	Federal
Policy:	Federal fuel charge
Stringency and timeline:	The federal government announced that the federal fuel charge will be increased by \$15/tCO_2e annually after 2022, until the tax reaches \$170/tCO_2e in 2030 and will stay at that level thereafter. 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.
Emissions/ sectors 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 100% of proceeds are returned to households.
Approach and 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 Québec. Québec's cap is assumed to be sufficiently stringent in its current design.
Region:	Federal
Policy:	Output-Based Pricing System
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 increased annually by \$15/tCO_2e until it reaches \$170/tCO_2e in 2030. Furthermore, sectoral OBPS benchmarks will be increased in stringency by two percentage points annually, 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 clean electricity standard.
Emissions/ sectors covered:	The OBPS applies to industrial facilities emitting more than 50 ktCO_2e annually in provinces that do not have an equally stringent performance standard or a carbon price for industrial emitters.
Approach and 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 Québec and Alberta, and that an annual 2% tightening rate will apply to all sectoral benchmarks starting in 2023. In the current model policy set-up, 50% of performance standard proceeds / revenue recycling has been set up to fund low-carbon industrial technologies and 50% is used to cut corporate taxes.
Region:	Federal
Policy:	Regulations on emissions from the oil and gas sector

Stringency and timeline:	The federal government has announced its intention to cap greenhouse gas emissions from the oil and gas extraction sector. The policy mechanisms that will be used to achieve this target have not yet been announced. To our knowledge, it has also not yet been specified if this will cover upstream and downstream (natural gas distribution, refineries, LNG production) oil and gas sector emissions and if it will include both combustion and direct non-combustion emissions (e.g., methane emissions).
Emissions/ sectors covered:	To our knowledge, it has not yet been specified whether the cap will cover upstream and downstream (natural gas distribution, refineries, liquefied natural gas production) emissions from the oil and gas sector and whether it will include both combustion and direct non-combustion emissions (e.g., methane emissions).
Approach and assumptions:	This is modelled as a linear reduction in emissions of 42% by 2030.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Region:	Federal
Policy:	75% reduction in methane emissions from the oil and gas sector
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 reduce methane emissions in the upstream oil and gas sector 40%–45% below 2012 levels by 2025.
Emissions/ sectors covered:	The current methane regulations cover upstream oil and gas emissions. To our knowledge, it has not yet been announced whether the 75% reduction will apply to only upstream oil and gas emissions or both upstream and downstream (including refineries, natural gas distribution, and liquefied natural gas production) oil and gas emissions.
Approach and assumptions:	The 75% methane-reduction requirement is simulated as a regulatory requirement demanding increased abatement actions and technologies for surface case vent flows, leaks, and venting, such as increased monitoring, flaring, and well reworking, in the upstream oil and gas sector.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf SOR/2018-66. 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

Region:	Federal
Policy:	Clean Electricity Standard for 2035 (now the Clean Electricity Regulations)

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. The CER will cover electricity generation sold to the electricity grid. It is uncertain whether the CER will cover cogeneration providing electricity to the grid.
Emissions/ sectors covered:	To our knowledge, there is currently no information available regarding the emissions that will be covered under this policy.
Approach and assumptions:	At the time of setting up the modeling assumptions for this analysis, there was little information regarding the timelines of this policy. In this analysis, we assume a linear stringency increase between 2025 and net-zero in 2035 for utility-generation GHG emissions, while allowing for offsets and CCUS for natural gas. It has since been announced that the CER will not be binding prior to 2035. Removing the 2025 and 2030 GHG constraint used in this analysis would result in higher GHG emissions in those years.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf 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

Region:	Federal
Policy:	Waste methane capture
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.To our knowledge, there is currently little information available for this policy.
Emissions/ sectors covered:	To our knowledge, there is currently little information available for this policy.
Approach and assumptions:	We simulate this by requiring 50% of all landfills to adapt flaring or methane capture and utilization by 2025.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Region:	Federal
Policy:	Clean Fuel Regulations

Stringency and timeline:

The federal government is developing a performance-based fuel-supply standard requiring liquid fossil-fuel suppliers to reduce the life-cycle GHG intensity of their fuels. The Canada Gazette Part I required a carbon-intensity reduction of 3.5 g CO_2e/MJ in 2022, increasing to 14 g CO_2e/MJ in 2030.

The Clean Fuel Regulations (CFR) create a credit-based compliance market that 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 transportation.

Emissions/ sectors covered:

Transportation

Approach and assumptions: Upstream credit generation (Compliance Category 1)
Credit creation through carbon capture and storage is endogenously simulated by gTech as a function of compliance costs and provincial and federal policies. All CCUS projects linked to liquid fossil fuel production are assumed to be considered "additional" and qualify for CFR credit generation. CCUS credit generation is pro-rated by the ratio of domestic use versus exports. For crude oil production, we assume that 20% of CCUS qualifies for credit generation, as about 80% of extracted crude oil is exported. For refineries, we assume that 80% of CCUS can generate CFR credits, as a large share of refined petroleum products is used domestically Credit stacking under the Alberta TIER and offset program is assumed to be allowed. We further assume that generic quantification method credits for actions such as methane conservation and refinery process improvements are created up to the 10% limit by 2030 (about 2.9 Mt CO_2e worth in credits in 2030).

Fuel blending (Compliance Category 2)
Fuel blending is endogenously simulated by the model as a function of production and transportation costs as well as provincial and federal policies.

Credit generation through fuel switching in transportation (Compliance Category 3)
We use variable electricity carbon intensities based on prior gTech results. This approach accounts for the impact of electricity decarbonization driven by policies such as carbon pricing and regulations, which will impact the CFR credit market and allow for more credit generation through electrification. We use ECCC's assumption that 10% of residential charging would be adequately metered to generate credits, growing at 2.5% per year. Interstream credit trading is permitted. Supply of low-carbon gaseous fuels can generate gaseous credits which can be used by regulated suppliers to meet up to 10% of compliance through instream credit trading.

Credit banking: The Canada Gazette Part II Regulatory Impact Analysis (RIAS) assumes that about 3.8 Mt CO_2e of banked credits will be used to comply with the CFR in 2025 and that banked credits will drop to zero in 2026 and remain at zero thereafter. We have aligned the assumption on the number of banked credits used in each modeling period with the RIAS estimate.

References:	Government of Canada. (2022). Clean Fuel Regulations: SOR/2022-140. Canada Gazette, Part II, Volume 156, Number 14. Available from: https://www.gazette.gc.ca/rp-pr/p2/2022/2022-07-06/html/sor-dors140-eng.html Canada Energy Regulator. 2021. Market Snapshot: Canada's crude oil exports kept pace with production over the last decade. Available from: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2021/market-snapshot-canadas-crude-oil-exports-kept-pace-with-production-over-the-last-decade.html Statistics Canada. 2020. Supply and disposition of refined petroleum products, monthly. Available from: https://open.canada.ca/data/en/dataset/792aad48-1745-41dd-8424-55e49d98fa0c
Region:	Federal
Policy:	Light-duty vehicle emissions standard (sales targets)
Stringency and timeline:	In its 2020 plan A Healthy Environment and Healthy Economy, the federal government stated that it would align light-duty performance standards with the most stringent standards in North America. The federal government further announced that it is developing a ZEV sales mandate for new light-duty vehicles, similar to those in Québec, B.C., and California. The ERP announced a mandatory ZEV sales target of 20% in 2026, rising to 60% in 2030 and 100% in 2035.
Emissions/ sectors covered:	We expect this policy to apply to light-duty vehicle manufacturers.
Approach and assumptions:	As there were little details on policy design available at the time of this analysis, we assume that a policy similar to Québec's ZEV mandate, but with ZEV sales targets linearly increasing from 20% in 2026 to 60% in 2030 and from 60% to 100% in 2035, will be implemented. 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.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf
Region:	Federal
Policy:	Medium- and heavy-duty vehicle emissions standard
Stringency and timeline:	In its A Healthy Environment and Healthy Economy and Emissions Reduction Plan, the federal government announced its intention to "further improve the efficiency of heavy duty vehicles standards for post-2025 by aligning with the most stringent standards in North America — whether at the United States federal or state level." The federal government also expressed interest in developing an emissions standard for medium- and heavy-duty vehicles, similar to California's, which is the currently most stringent standard for heavy-duty vehicles in North America, with the goal to achieve 100% ZEV sales by 2040 in selected medium- and heavy-duty categories.

Emissions/ sectors covered:	California's Clean Trucks Regulation applies to manufacturers of on-road medium- and heavy-duty vehicles, excluding transit buses.
Approach and assumptions:	We assume that Canada will implement a medium- and heavy-duty emissions standard similar to California's Advanced Clean Trucks Regulation, but with the ZEV sales target rising to 100% by 2040, "where feasible" (modelled as 95%). Like in California's regulation, we assume that the policy applies to manufacturers of on-road medium- and heavy-duty vehicles, excluding transit buses. 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.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf Environment and Climate Change Canada. 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 Government of California. (2019). Final Regulation Order. Advanced Clean Trucks Regulation. Available from: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf

Region:	Federal
Policy:	Investment tax credit for CCUS
Stringency and timeline:	The 2022 federal budget introduced an investment tax credit for capital investments in CCUS. The target of this measure is to reduce emissions by at least 15 $MtCO_2e$ per year. The 2022 federal budget stated that a total of $2.6 billion would be invested in direct air capture and CCUS between 2022 and 2026, and $1.5 billion annually from 2027 to 2030.
Emissions/ sectors covered:	This tax credit is available for carbon capture and use or storage, direct air capture, and for investment in equipment for transportation, storage, and use.
Approach and assumptions:	This was modelled as an uncapped subsidy on investment, with reduced capital costs by 50% for CCUS through 2030 and 60% for direct air capture through 2030.
References:	Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont

Region:	Federal
Policy:	Incentives for Zero-Emission Vehicles (iZEV) Program

Stringency and timeline:	The ERP announced that an additional $1.7 billion will be provided for the iZEV Program, which provides rebates of up to $5,000 for light-duty ZEVs.
Emissions/ sectors covered:	The rebate program provides subsidies to on-road light-duty plug-in hybrid, battery-electric, and fuel cell-electric vehicles.
Approach and assumptions:	We simulate this as a $1.7 billion subsidy, additional to historic and remaining iZEV funds for zero-emission light-duty vehicles, including plug-in hybrid, battery-electric, and fuel cell-electric vehicles, over three years. Subsidy values are assumed to be nominal.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Region:	Federal
Policy:	Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program
Stringency and timeline:	The federal government has announced funding of $547.5 million over four years (or until available funding is exhausted) for the Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles (iMHZEV) Program, starting July 11, 2022.
Emissions/ sectors covered:	The rebate program provides subsidies to on-road heavy- and medium-duty plug-in hybrid, battery-electric, and fuel cell-electric vehicles.
Approach and assumptions:	We simulate this as a $547.5 million subsidy allocated equally per year from 2022 through 2026. Subsidy values are assumed to be nominal.
References:	Government of Canda. (2022). Medium and heavy-duty zero-emission vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles

Region:	Federal
Policy:	Charging stations
Stringency and timeline:	The ERP states that $400 million will be allocated to ZEV charging stations. In addition, $500 million in Canada Infrastructure Bank funds will be invested into improving the electric charging and hydrogen refueling infrastructure.
Emissions/ sectors covered:	Transportation
Approach and assumptions:	This is simulated as a $900 million subsidy for light-, medium-, and heavy-duty ZEVs, including plug-in hybrid, battery-electric, and fuel cell-electric vehicles, over five years. Subsidy values are assumed to be nominal.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Region:	Federal
Policy:	Large truck retrofits
Stringency and timeline:	The ERP includes a $199.6 million subsidy for retrofitting large trucks currently on the road.
Emissions/ sectors covered:	To our knowledge, there is currently little information regarding the retrofit actions that would qualify for funding under this policy.
Approach and assumptions:	This is simulated as a $199.6 million subsidy for efficient heavy-duty vehicles. Subsidy values are assumed to be nominal.
References:	Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

Region:	Replace home-heating oil
Category:	Announced
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 to replace heating oil.
Emissions/ sectors covered:	Funding available to low-income households for replacing home heating with heating oil.
Approach and assumptions:	This is simulated as a $250 million subsidy over five years for electric-heating technologies. Subsidy values are assumed to be nominal.
References:	Liberal Party of Canada. (2021). 2021 Platform. A Retrofit Economy that Cuts Pollution and Creates Jobs. Available from: https://liberal.ca/our-platform/a-retrofit-economy-that-cuts-pollution-and-creates-jobs/

Region:	Alberta
Policy:	Hydrogen projects
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 t 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 t 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.
Emissions/ sectors covered:	Hydrogen production
Approach and 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.

References:	Air Products. (2021). Air Products Announces Multi-Billion Dollar Net-Zero Hydrogen Energy Complex in Edmonton, Alberta, Canada. Retrieved from: https://www.airproducts.com/news-center/2021/06/0609-air-products-net-zero-hydrogen-energy-complex-in-edmonton-alberta-canada Atco. (2021). Suncor and ATCO partner on a potential world-scale clean hydrogen project in Alberta. Retrieved from: https://www.atco.com/en-au/about-us/news/2021/122920-suncor-and-atco-partner-on-a-potential-world-scale-clean-hydroge.html#:~:text=The%20project%20would%20produce%20more,sizable%20contribution%20to%20Canada's%20net
Region:	Ontario
Policy:	Direct reduced-iron steel projects
Stringency and timeline:	Two major steel companies in Ontario, ArcelorMittal and Algoma, announced that they will upgrade their steel plants, which will result in GHG reductions of about 3 Mt in each plant.
Emissions/ sectors covered:	Steel production
Approach and 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.
References:	Global Newswire (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 ArcelorMittal (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
Region:	British Columbia
Policy:	Natural gas utilities emissions cap
	The CleanBC Roadmap to 2030 announced a GHG emissions cap to reduce annual emissions from natural gas combustion in buildings and industry (excluding oil and gas) to 6 Mt per year, starting in 2030. In the model, this is simulated as a GHG emissions cap that requires annual emissions from natural gas combustion in buildings and industry (excluding oil and gas) not to exceed 6 Mt, starting in the 2030 time horizon (2026 - 2030).
References:	Government of British Columbia (2021). Clean BC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action

Region:	British Columbia
Policy:	100% Clean Electricity Delivery Standard The CleanBC Roadmap to 2030 announced a planned standard to increase clean electricity (from renewable sources) to 100% of supply by 2030 through phase-out of remaining gas-fired facilities by 2030. In the model, this is simulated as a renewable portfolio standard requiring 100% of B.C. generation to be from renewable sources by 2030.
References:	Government of British Columbia (2021). Clean BC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action
Region:	British Columbia
Policy:	Low Carbon Fuel Requirement Regulation — Update The CleanBC Roadmap to 2030 announced that the province intends to raise the Low Carbon Fuel Standard from 20% to 30% (relative to 2010 carbon-intensity values) in 2030 and expand the standard to cover marine and aviation fuels beginning in 2023. The modelling assumes that the average emissions intensity of gasoline, diesel, and marine and aviation fuels in B.C. are required to decrease 30% from 2010 levels by 2030. Coverage includes domestic aviation and navigation fuels.
References:	Government of British Columbia (2021). CleanBC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action
Region:	British Columbia
Policy:	ZEV Standard — Update The CleanBC Roadmap to 2030 proposes to accelerate the ZEV law for new light-duty vehicles to ZEV sales targets of 26% by 2026, 90% by 2030, and 100% by 2035. We assume that the B.C. ZEV mandate timelines will be accelerated, as proposed in the CleanBC Roadmap to 2030.
References:	Government of British Columbia (2021). CleanBC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action

Region: British Columbia

Policy: Heavy-duty ZEV standard

The CleanBC Roadmap to 2030 further announces that the province intends to add new ZEV targets for medium- and heavy-duty vehicles, in alignment with targets in California. It is still uncertain whether these targets will be mandatory and how they will be implemented. However, B.C.'s own 2021 CleanBC modelling includes a heavy-duty ZEV mandate with ZEV sales targets that require 32% of class 2B-3, 44% of class 4-8, and 23% of truck tractors sold to be zero-emissions by 2030. In this analysis, we have assumed that B.C. will implement a medium- and heavy-duty emissions standard aligned with California's. Note this is equivalent to what is modelled federally.

References: Government of British Columbia (2021). CleanBC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action
https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/2021_cleanbc_methodology_report.pdf

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Region: British Columbia

Policy: Carbon pollution standard in B.C. Building Code and highest-efficiency standards

The CleanBC Roadmap to 2030 announced a new carbon pollution standard, which is planned to be added to the B.C. Building Code. The standard is to take force in 2024 and to achieve zero-carbon new buildings by 2030. The standard was proposed to be performance-based, allowing for a variety of options, including electrification, low-carbon fuels such as renewable natural gas, and low-carbon district energy. The highest-efficiency standards will further require all new space- and water-heating equipment to be at least 100% efficient by 2030, and earlier where feasible. In the model, this is simulated as a stringency increase in the B.C. Building Code, by banning new oil and natural gas space- and water-heating equipment in buildings after 2025, in addition to requiring increased efficiency in new building shells over time. Furnaces using biomass are currently not restricted but could be included in the post-2025 ban for new equipment, as they are not 100% efficient.

References: Government of British Columbia (2021). CleanBC Roadmap to 2030. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action

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Region: Québec

Policy: Update: Renewable Natural Gas Regulation

Québec currently requires 5% of renewable natural gas, by volume, to be blended in distributed natural gas. Québec’s 2030 Plan for a Green Economy announced an increase to a minimum volume of 10% renewable natural gas injected into distributed natural gas by 2030. In the model, this is simulated as a stringency increase of the existing policy, rising from the 5% requirement in 2025 to 10% in 2030.

References:	Regulation respecting the quantity of gas from renewable sources to be delivered by a distributor. Retrieved from https://www.legisquebec.gouv.qc.ca/en/document/cr/R-6.01,%20r.%204.3 Gouvernement du Québec. (2020). 2030 Plan for a Green Economy. Retrieved from https://www.quebec.ca/en/government/policies-orientations/plan-green-economy#c75917
Region:	Québec
Policy:	Heavy-duty vehicle ZEV standard In its *Plan de mise en œuvre 2021-2026 du Plan pour une économie verte 2030*, Québec announced its intention to develop a heavy-duty ZEV mandate similar to California's. In the model, we assume that Québec will implement a medium- and heavy-duty emissions standard aligned with California's. Note this is equivalent to what is modelled federally.
References:	Gouvernement du Québec. (2020). Plan de mise en œuvre 2021-2026 du Plan pour une économie verte 2030. Retrieved from https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/environnement/publications-adm/plan-economie-verte/plan-mise-oeuvre-2021-2026.pdf?1608760053#:~:text=Le%20Plan%20de%20mise%20en%20%C5%93uvre%202021%2D2026%20est%20le,fois%20pr%C3%A9visible%2C%20flexible%20et%20pragmatique
Region:	Québec
Policy:	Biofuels mandate A draft regulation is planned to come into force January 1, 2023. Québec is planning to require a minimum blend of 10% renewable fuel in gasoline and 3% in diesel, by volume, starting in 2023 and rising to 15% for gasoline and 10% for diesel by 2030.
References:	Gouvernement du Québec. (2021). Gazette Officielle Du Québec, December 15, 2021, Vol. 153, No. 50. Integration of low-carbon-intensity fuel content into gasoline and diesel fuel. Retrieved from: https://www.publicationsduquebec.gouv.qc.ca/fileadmin/gazette/pdf_encrypte/lois_reglements/2021A/105402.pdf