Exploring economic opportunities in Canada’s oil and gas endowed region under net zero policy

by

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Abstract

In exploring the effects of Canada's net zero target, energy-economy researchers have primarily focused on the negative economic effects of greenhouse gas reductions, although they have shown some possible upsides to the energy transition, notably in renewables, energy efficiency, and zero-emission end-uses. Depending on the region, economic activity triggered by the energy transition could be much greater, but because of the speculative nature of such activities, researchers have left many possibilities unexamined. I use an energy-economy model called gTech to explore the 1) effects of net zero policy in Canada's oil and gas endowed region, and 2) potential economic opportunities for the region during the energy transition by promoting growth in emerging energy sources and technologies such as carbon capture and storage, direct air capture, hydrogen produced from natural gas, and mineral mining. I find that an increase in economic activity beyond that shown in other modeling exercises is plausible.

Key words

Climate policy; Economics; Energy; Energy-economy modeling, Net zero emissions; Oil and gas endowed regions

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List of Acronyms

B.C. - British Columbia

BECCS – Bioenergy with Carbon Capture and Storage

BPD – Barrels Per Day

CCS - Carbon Capture and Storage

CS – Carbon Storage

CEC - Clean Energy Canada

CGE - Computable General Equilibrium

CO_2 - Carbon Dioxide

DAC - Direct Air Capture

EMRG - Energy and Materials Research Group

GDP - Gross Domestic Product

GEEM - General Equilibrium Energy Model

GHG - Greenhouse Gas

IEA - International Energy Agency

LULUCF - Land-use, Land-use Change, and Forestry

Mt - Megatonnes

$MtCO_2e$ - Megatonnes of Carbon Dioxide Equivalent

OBPS - Output-Based Pricing System

PPF - Public Policy Forum

RPPs – Refined Petroleum Products

SFU - Simon Fraser University

tCO_2e - Tonnes of Carbon Dioxide Equivalent

U.S. - United States

WTI - Western Texas Intermediate

1. Introduction

Countries around the world now recognize the enormous cost of climate change and have established greenhouse gas (GHG) emission reduction targets. Canada has set a national target to be net zero emissions by 2050. To achieve net zero 1) all industries must no longer emit GHG emissions by 2050 and/or 2) industries that continue to emit at reduced levels must offset these emissions by removing carbon dioxide (CO_2) from the atmosphere through methods like direct air capture (DAC) combined with carbon storage, or carbon capture and storage (CCS) from point emission sources (ECCC, 2022).

The federal government has set interim emissions targets from 2030 to 2050. Moreover, the *Canadian Net-Zero Emissions Accountability Act* requires the federal government to develop credible emissions reduction plans to achieve the emissions targets in five-year increments (Government of Canada, 2023a). The 2030 Emissions Reduction Plan is the first iteration of the act and outlines measures to reach Canada's Nationally Determined Contribution under the Paris Agreement, a 40-45% economy-wide reduction in GHG emissions below 2005 levels by 2030 (Government of Canada, 2022a). Independent assessments confirm that the 2030 Emissions Reduction Plan is credible and sets Canada almost on track to reaching the 2030 emission target (Sawyer et al., 2022a). While the 2030 Emissions Reduction Plan lays a foundation for net zero by 2050, there is uncertainty about the policy pathway needed past 2030.

Canada's oil and gas endowed region is currently in the spotlight for emissions reduction policy because the oil and gas sector is the highest emitting sector in Canada. The federal government recently proposed a sector-specific cap on oil and gas emissions as a policy that could contribute to Canada's 2030 emissions target and net zero by 2050. Recent technological advancements have started to reduce emissions intensity in the oil and gas sector. Emissions per barrel of oil have decreased by 33% from 1990 to 2020 (ECCC, 2022). Decarbonization of the sector depends on an array of actions affecting infrastructure, carbon storage sites, energy grid mixes, and the availability of clean electricity and other fuels. Specific options include zero-emission electrification, using solvents instead of steam in upstream oil sands extraction, fuel switching, energy efficiency, other process improvements, methane leak reduction, point source CCS, and DAC with carbon storage. Given that achieving net zero will require adjustments to Canada's fossil fuel-based energy system, the future of economic activity is uncertain in our oil and gas endowed region in terms of how jobs and gross domestic product (GDP) will potentially change or be distributed.

Since the announcement of Canada's net zero target, research has begun to focus on the future of Canada's oil and gas endowed region in a net zero world through energy-economy modeling analyses. Energy-economy modelers have primarily focused on how this region will be negatively affected by domestic and global GHG emission reduction efforts in the energy transition. To a limited extent, they have shown some possible upsides, notably via investment and jobs in renewable energy, energy efficiency, and zero-emission end-use devices such as electric vehicles and heat pumps. Depending on the region, economic activity triggered by the energy transition could be much greater than this, but because of the speculative nature of such activities, researchers have left numerous technological and industrial possibilities unexamined.

In this paper, I try to rectify this shortcoming by focusing on Canada's oil and gas endowed region, specifically Alberta and Saskatchewan, in an exercise that integrates plausible resource and technology developments in an energy-economy model that simulates the achievement of net zero targets in this specific region, all of Canada, and the U.S. - Canada's major trading partner. The goal is to present a plausible perspective of how the energy transition might affect the economy of this region over the long term. Given that we can anticipate new industries and technologies playing a role in the energy transition, it is necessary to try and assess these potential opportunities in a net zero 2050 to help people in this region and their political leaders address the challenges and opportunities ahead.

I expand on this field of research by exploring the effects of net zero policy while also probing less restrictive assumptions about economic performance. Thus, I investigate different assumptions about potential energy sources and technologies that are plausible in a net zero world, given current infrastructure, expertise, geology, and proposed investments in our oil and gas endowed region. The sectors, processes, and technologies I explore include DAC with carbon storage, point source CCS, and hydrogen produced from natural gas with CCS, bioenergy production, electricity production with CCS, continued production and export of oil and gas to places in the world that convert these in zero-emission processes to electricity and hydrogen, and expanded mineral mining in response to the worldwide need for a dramatic increase in production of critical minerals for the energy transition.

In particular, to account for underrepresentation in recent studies, I simulate growth in DAC with carbon storage, point source CCS, mineral mining, and hydrogen produced from natural gas with CCS to better represent plausible opportunities in these sectors as well as how they can contribute to creating opportunities in other processes such as electricity production from fossil fuels with CCS, for example. I also model a scenario where the United States (U.S.) implements policies that achieve net zero by 2050 to explore how stringent climate policy in the U.S. could affect cost and adoption of abatement technologies and energy forms in Canada, as well as the trade dynamics between Canada and the U.S. I seek to understand how new industrial opportunities that rely on 1) the existing oil and gas endowment and 2) other local resource endowments, such as mineral mining, can enable emission reductions while providing economic opportunities in Canada's oil and gas endowed region.

Thus, in essence, I aim to answer the following question: "On a path to net zero by 2050, what is the full range of plausible economic opportunities for oil and gas endowed regions, notably for the western Canadian region comprised of the provinces of Alberta and Saskatchewan?". My method is to use a quantitative energy-economy model to understand the 1) effects of net zero policy in our oil and gas endowed region and 2) potential economic opportunities for this region under net zero policy through enhanced stimulus of opportunities with emerging energy sources, material resources, technologies, and production processes.

Reducing GHG emissions might impact fossil fuel endowed provinces in Canada, such as Alberta and Saskatchewan, through slowing economic growth from what it might otherwise have been. However, it is unrealistic to assume that without climate policy, GDP in these provinces or elsewhere will rise steadily to 2050. If Canada and the rest of the world fail to achieve substantial reductions by 2050, the catastrophic consequences of climate change could significantly slow economic growth, especially in the second half of this century. Thus, when presenting results in this paper, I include an independent estimate of how GHG policy failure over the coming decades might negatively affect economic output in this region of Canada. Moreover, while net zero achievement in

Canada will likely affect economic activity in our oil and gas endowed region relative to a global continuation of unabated fossil fuel combustion, I aim to explore how some of this effect might be offset by plausible opportunities arising under the energy transition.

To answer my research question, I require an energy-economy model that incorporates macroeconomic feedbacks in Canada and interactions with the U.S. to explore long-run effects of net zero on jobs and GDP in our oil and gas endowed region. I also require some technological detail to account for the effects of projected growth in key technologies such as DAC with carbon storage. Several recent net zero studies looking at similar metrics have used a computable general equilibrium (CGE) model called gTech to conduct their analyses. To expand on these studies and ensure consistency, I use the same model.

2. Background

2.1 Oil and Gas Industry

In 2020, fossil fuels made up 75% of Canada's total energy supply (NRCAN, 2022). The oil and gas industry generated 118 billion dollars in GDP (eight percent of Canada's total GDP), accounted for 16% of Canada's exports, and employed 178,500 direct and 415,000 indirect workers (ECCC, 2022). The industry is also the highest emitting industry in Canada, accounting for 27% of Canada's overall GHG emissions.

2.1.1. Oil production

Upstream oil production includes exploration, drilling, and extraction. Extraction is characterized as conventional extraction and unconventional extraction. Conventional oil is liquid at atmospheric temperature and pressure. The oil is found in rock formations with high permeability and porosity, which makes it easier to extract because the oil can flow through the rock. The permeable rock containing oil is typically found under less permeable rock that prevents the oil from flowing completely to the surface. Extraction methods involve drilling through the less permeable rock to access the oil in the porous rock formations and pumping it up. Conventional oil extraction is less expensive and requires less processing after extraction compared to oil sands (CAPP, n.d.).

Shale oil, once extracted, is also liquid at atmospheric temperature and pressure. However, unlike conventional oil that is found in more porous rock, shale oil is found in tight or low-permeability shale rock formations, making it harder to extract. Shale oil is considered unconventional because the extraction process is more complex and involves drilling horizontally and pumping fluids at high pressure to fracture the rocks and release the oil. Like conventional oil, once the oil is extracted, it does not require as much processing as oil sands (NRCAN, 2016).

Oil sands are a mixture of sand, water, and bitumen. Bitumen is a heavier type of oil that does not flow on its own. Depending on the depth of the oil sands deposit, companies recover bitumen at the surface (typically less than 75 meters underground) through open pit mining or deeper (greater than 75 meters underground) using drills. In surface mining, companies dig pits and scoop oil sands from the ground then transport it to extraction plants where they separate the oil from the sand and sell the extracted bitumen as is or upgrade it to synthetic crude oil. Deeper extraction methods involve drilling vertical or horizontal wells and injecting fluids such as steam and/or solvent to make the bitumen less thick so it can be pumped to the surface. Once at the surface, producers remove the water and/or solvent from the bitumen at a separation plant and sell the oil to an upgrader or refinery (NRCAN, 2016).

Unlike conventional oil and shale oil, which are liquid at atmospheric temperature and pressure, bitumen is heavy and thick and typically requires more processing (upgrading or diluting) after extraction. The upgrading process converts crude bitumen into synthetic crude oil, making it better quality and enabling it to flow for ease of transport. Upgrading is a process that breaks down large oil molecules into smaller ones mostly with high heat and pressure. The process also removes impurities such as sulphur and heavy metals. Once upgraded, the bitumen is sent to refineries for further processing. Refineries also accept heavy crude bitumen that has not been upgraded. To transport the bitumen, they mix it with a diluent to make a lighter bitumen blend (called dilbit) that can flow through pipelines. Once the dilbit reaches the refinery, they separate the diluent from the bitumen and refine the oil (NRCAN, 2016).

Midstream and downstream oil production involves transporting crude oil to refineries by pipeline or rail. At the refinery, the crude oil is refined into higher-value, secondary energy refined petroleum products (RPPs), like gasoline, that can be sold to the end user. Refining involves distilling oil so that lighter products separate from heavier ones. The process works by heating the crude oil in a furnace until most of the oil vaporizes into a gas. The liquids and vapour then enter a tower that separates them based on different boiling points. Heavier streams with higher boiling points collect at the bottom of the tower in liquid form, while lighter streams with lower boiling points, like kerosene, rise to the top in gaseous form. Components that have boiling points in the mid-range such as diesel are withdrawn at intermediate points in the tower (CER, 2022a).

2.1.2. Gas production

Upstream gas production also involves exploration, drilling, and conventional and unconventional extraction. Companies extract natural gas one of three ways, depending on the geology of the area. The first method is vertical drilling where an operator drills wells straight down into porous rocks that contain natural gas. The second method also occurs in porous rock and involves a drill bending at a target depth and moving horizontally through natural gas deposits. Vertical and horizontal drilling are both conventional methods. The third method is an unconventional method called hydraulic fracturing that is required for rock formations that are less porous and in tighter formations like shale. This method involves pumping fluid into a well at high pressure, causing tight rocks in the reservoir to fracture and release natural gas (CAPP, n.d.).

Midstream and downstream natural gas production involves processing natural gas into usable goods. Companies transport the extracted natural gas through gathering pipelines to processing facilities called gas plants. At the gas plants, they separate natural gas from water, impurities, and other gases such as sulfur dioxide. Some gas plants also remove natural gas liquids such as ethane, propane, and butane. Once processed, the companies transport the cleaned natural gas to local distribution companies or gas utilities through transmission pipelines and to end users through distribution pipelines. Natural gas can also be stored underground for future use (CAPP, n.d.).

2.2 Canada’s Oil and Gas Endowed Region

Oil and gas production in Canada is concentrated in Alberta, Saskatchewan, British Columbia (B.C.), and Newfoundland and Labrador. In 2020, Alberta accounted for 80% of Canadian crude oil production. Saskatchewan is the next largest oil producer, accounting for 10% of crude oil production, followed by Newfoundland and Labrador accounting for five percent. In terms of natural gas, Alberta is again the largest producer (63%), B.C. produces 35%, and Saskatchewan two percent of Canada's natural gas (CER, 2023). While B.C. is the second largest natural gas producer in Canada, oil and gas makes up a smaller proportion of the province's overall economy relative to oil and gas in Saskatchewan and Alberta (Government of B.C., n.d.). In this study, I focus on Alberta and Saskatchewan because their economies are especially dependent on the industry, and I frequently refer to them as Canada's oil and gas endowed region.

2.3 Key Policies and Actions in the Energy Transition

The *Canadian Net Zero Emissions Accountability Act* outlines Canada's commitment to creating emissions targets for 2035, 2040, and 2045 with credible, science-based reduction plans to achieve the targets ten years in advance (Government of Canada, 2023a). Because the 2030 Emissions Reduction Plan only outlines reduction plans to 2030, we do not have certainty of the policy and emissions reduction pathway for 2050. As Canada transitions to net zero, reductions in GHG emissions will impact our oil and gas endowed region. To address emissions from this highest emitting industrial sector, the federal government recently proposed a GHG cap on Canada's oil and gas industry in the 2030 timeframe, recognizing that by 2050 Canada must be net zero economy-wide (ECCC, 2022). The federal government has proposed to cap oil and gas emissions through a regulated cap-and-trade system or a modification of its existing GHG emissions pricing system for industry (the Output Based Pricing System or OBPS).

Academics, industry, government, and environmental non-governmental organizations are debating the pros and cons of a sector-specific cap on oil and gas emissions in the 2023 to 2050 timeline. The governments of Alberta and Saskatchewan generally oppose sector-specific treatment. Furthermore, some economists argue that a separate oil and gas cap would be economically inefficient because the whole economy must get to net zero by 2050 anyway. Since different firms (and therefore sectors) have different abilities and costs to reduce emissions, a sector-specific cap could make it unnecessarily costly compared to a more market-based approach where all Canadian emitters work simultaneously to reach the net zero target, with sectors with lower incremental reduction costs doing more initially.

In contrast, some climate-concerned groups support the sector-specific cap and have even called for a reduction in oil and gas production in barrels per day (bpd) to meet it. The focus on production instead of emissions was explored in a recent study by the Public Policy Forum (PPF). PPF hired the consulting firm Navius Research Inc. to conduct the analysis with their CGE energy-economy model, gTech. The study shows that an emissions cap has much lower cost consequences in the 2023 to 2050 period than a production cap, especially for Alberta and Saskatchewan (PPF, 2023).

In simulating the production cap and emissions cap for PPF, Navius Research Inc. noted that a sector specific emissions cap for the oil and gas sector becomes irrelevant by 2050, since by then all of Canada, including oil and gas, must be net zero (PPF, 2023). And since the oil and gas industry is one of the hardest-to-abate sectors with high marginal abatement costs (IEA, 2020), implementing an oil and gas specific cap could cause additional economic hardship for a sector (and region) if the cap forced GHG emissions reductions at a faster pace than would have occurred under economy-wide net zero policy.

Canada can achieve the 2050 GHG target nation-wide by using a combination of the following economically efficient policies: 1) cap-and-trade, 2) carbon tax, and 3) portfolio of sector-specific flexible regulations that are designed to be economically efficient (Jaccard, 2020). In addition to these policies, governments can also implement investment tax credit policies to help incentivize emission-reducing actions such as investments in CCS. Since the policy choice is inconsequential to the outcome in terms of GHG emissions and economic impacts if these policies are designed efficiently, my study is agnostic with respect to the specific policy choice.

2.3.1. Cap-and-trade

A cap-and-trade system is a form of carbon pricing. It is a market-based system where a regulator provides a quantity of emissions allowances that is less than the quantity of emissions expected without the policy. Each regulated entity is required to submit one allowance for each tonne of GHG emitted. Emissions scarcity under the cap drives demand in an allowance market where low-cost actions to reduce emissions are prioritized and regulated entities can buy and sell allowances from each other (ECCC, 2022). The cap would start at a specified amount and decrease gradually to zero by

2050. Firms decide in each period the extent to which they emit and purchase allowances from firms that have done more, or reduce emissions from their processes, perhaps to the extent that they have surplus allowances for sale to others.

2.3.2. GHG taxes

The Canadian GHG emissions pricing system includes a federal carbon tax on emissions from unabated fossil fuel combustion and an output-based pricing system (OBPS) for large industrial emitters. The federal carbon tax is $65/$tCO_2e$ (2023) and set to increase annually by $15/$tCO_2e$ from 2023 to 2030 (ECCC, 2021). The carbon tax is revenue neutral to government because it returns the proceeds back to Canadians through reduced personal income taxes or quarterly payments to lower income individuals. The carbon tax is designed to increase slowly in a predictable manner to give consumers and firms time to transition away from emitting GHGs.

The OBPS applies to industrial facilities with high emissions levels (>50,000 tCO_2e per year). The system is designed to incentivize emission-intensive and trade-exposed industries to reduce GHG emissions and promote innovation while maintaining competitiveness and protecting them from carbon leakage. Carbon leakage occurs when increased production costs resulting from GHG policies cause industries to lose market share to industries in other jurisdictions with more relaxed GHG policies. The OBPS evaluates emitting industries in relation to an emission standard called a benchmark. The federal government issues surplus credits to facilities that emit less than the benchmark. Any industry emissions above the benchmark must be covered by surplus credits purchased from other firms or eligible offset credits. Or, a final option is to pay the carbon tax on those emissions if that is a cheaper option than buying credits from other firms or offsetters. The carbon tax and OBPS serve as backstops that apply to any provincial government that does not have a carbon pricing system that aligns with the federal level (Government of Canada, 2018).

2.3.3. Flexible regulations

Flexible regulations are sector-specific tradable performance standards that do not define a specific pathway (fuel or technology) to comply with the standard and instead let firms (and individuals) decide through their market-based decisions on technologies, buildings, and other emissions-determining actions. The standard could, for example, be a requirement to achieve a minimum number of zero-emission vehicle sales, renewable electricity generation, or low-carbon energy in transportation. Individual firms may over- or under-comply with the minimum production or sales requirement as long as the standard is met in aggregate through a credit trading mechanism in which all emitters can participate. This flexibility mimics some of the cost reducing incentives of carbon taxes and cap-and-trade systems by allowing each firm to choose the most cost-effective compliance pathway. The ability to sell credits incentivizes firms to exceed compliance with the standard, which can spur innovation and create new revenue streams. Implementing a portfolio of sector-specific flexible regulations is an effective method to reduce GHG emissions and achieve net zero that is almost as economically efficient as carbon pricing like the carbon tax and cap-and-trade (Rhodes et al., 2021a).

2.3.4. Investment tax credits

Investment tax credits are a form of non-compulsory climate policy that supports voluntary reductions in emissions. They enable individuals or firms to deduct a certain percentage of investment costs from their taxes, which can help reduce the production or investment cost of energy transition technologies such as point source CCS and DAC with carbon storage (Rhodes et al., 2017). Because they are non-compulsory, investment tax credits are not as effective as carbon pricing or flexible regulations because they do not guarantee emissions reductions. However, this non-compulsory nature enables them to generally receive more support from the public, which can help improve the political acceptability of deep decarbonization policies (Jaccard, 2020). As such, investment tax credits alone will not achieve net zero but can be seen as an additional method to help achieve emissions reductions, especially in regions where citizens are less supportive of climate policies.

For instance, the Canadian government has taken a more technology-specific approach and announced investment tax credits as part of the next phase of supporting GHG reductions in Canadian emissions-intensive and trade-exposed industries when there is not carbon pricing facing many of their foreign competitors. These investment tax credits are additional to economy-wide carbon pricing and regulations (Government of Canada, 2022b). On the other hand, the *Inflation Reduction Act of 2022* in the U.S. is an example of investment tax credits being applied economy-wide with underling support from state level regulatory and carbon pricing policies, and from U.S. Environmental

Protection Agency regulations for electricity, vehicles, and industry (The White House, 2022).

Given that it is economically efficient for Canada to achieve net zero through one or a combination of a 1) carbon tax, 2) cap-and-trade, and 3) portfolio of sector-specific flexible regulations (with additional support from politically acceptable investment tax credits), I focus this study on the assumption that these types of policies dominate the net zero effort in Canada. While any of one or a combination of the above three policy mechanisms would have approximately the same outcome in terms of GHG emissions and economic impacts, I decided to simulate federal policy with an emissions cap within gTech as this is the easiest approach for net zero policy simulation in this model. Thus, for my net zero scenarios, I model net zero policy as an economy-wide cap-and-trade system that phases down linearly to net zero emissions from 2035 to 2050, alongside a suite of existing and announced federal and provincial policies.

2.4 Plausible Resources, Processes, and Activities

As we transition to net zero emissions there is uncertainty about what will happen to the economies that are most dependent on emissions-intensive industries like oil and gas. There are key energy sources and technologies that could play a role in how the Canadian economy takes shape on the road to net zero. Canada’s oil and gas endowed region, in particular, is rich in so many of the elements needed for the energy transition. For instance, the region has potential for DAC with carbon storage, point source CCS, hydrogen produced from natural gas with CCS, bioenergy production, electricity production with CCS, expanded mineral mining and processing, and continued production and export of oil and gas to places in the world that convert these in zero-emission processes to electricity and hydrogen.

However, in recent net zero studies, some of these possibilities have been left unexamined. I expand on these studies by exploring realistic assumptions about the deployment of point source CCS, DAC with carbon storage, hydrogen produced from natural gas with CCS, and mineral mining, and how they may coincide with growth in other sectors and processes such as electricity generation from fossil fuels with CCS. These energy sources and technologies have potential to help abate oil and gas emissions and/or provide alternative economic opportunities in Alberta and

Saskatchewan as the oil and gas industry changes in response to net zero policy. Furthermore, I investigate other key assumptions that could have effects on the energy transition in this region such as the level of climate action in neighbouring countries, and the future global demand for oil and resulting oil prices.

2.4.1. Point source CCS

Point source CCS refers to a suite of technologies that can safely capture and store CO_2 from point sources at facilities that use fossil fuels or biomass for fuel during extraction, processing, and transport. If not being used or stored on site, the captured CO_2 can be compressed and transported by pipeline for use elsewhere or injected into deep geological storage formations for permanent storage. The International Energy Agency (IEA) projects that to achieve net zero, the amount of CO_2 captured globally needs to increase by 100-fold. Retrofitting the electricity sector with point source CCS technologies can address emissions from existing facilities as well as help Canada create negative emissions through the combination with bioenergy (IEA, 2022a). Any reference to CCS in this study is referring to point source CCS.

Canada is recognized globally for its expertise in developing point source CCS technologies. Alberta and Saskatchewan have active sites with CCS technologies and expect to increase CCS deployment (CER, 2022b). Both provinces are ideal locations for CCS because of their geology for CO_2 underground storage and convenient location of facilities with point source emissions. Furthermore, in the federal Budget 2022 and 2023, the government announced an investment tax credit of 50% of the capital cost for new CCS projects (Government of Canada, 2022b; Government of Canada, 2023b). As such, we can likely expect growth in the use of point source CCS technologies on the road to net zero.

2.4.2. DAC with carbon storage

DAC with carbon storage is a CCS technology that differs from point source CCS because it captures CO_2 directly from the atmosphere through a vacuum-like technology rather than from a point emission source. The technology pulls in air, extracts CO_2 through a series of chemical reactions, and returns the residual air to the environment (Carbon Engineering, n.d.). The captured CO_2 is stored underground or can be used in food processing or combined with hydrogen to produce synthetic fuels (IEA, 2022b).

DAC with carbon storage is a negative emissions process that can help offset emissions we continue to emit or have emitted in the past. Any reference to DAC in this study is referring to DAC with carbon storage.

DAC with carbon storage is more energy intensive and expensive than point source CCS technologies because CO_2 in the atmosphere is less concentrated than CO_2 from a point emission source like a factory smokestack. Furthermore, because DAC with carbon storage has not been deployed to the same extent as point source CCS, there is uncertainty about the future cost of the technology (just as there is uncertainty about the cost of point source CCS). Firms such as Carbon Engineering based in Squamish, B.C. are starting to deploy the technology in North America (Carbon Engineering, n.d.). Alberta is also implementing pilot projects and Saskatchewan has potential to host DAC with carbon storage given its geological storage capacity (IEA, 2022b; CER, 2022b). Given the recent development in the sector, it is plausible that DAC with carbon storage could provide substantial emissions abatement and economic opportunities on the road to net zero.

2.4.3. Mineral mining

The energy transition will require minerals for solar panels, batteries, electrical wiring, and electric vehicles. Minerals also contribute to everyday products such as appliances, electronics, and fertilizer. Alberta and Saskatchewan are well positioned in terms of expertise and geology to expand mineral mining (Government of Canada, 2022c). Saskatchewan has outlined a goal to double its current mineral mining output by 2030. On top of the current production of potash, uranium, and helium, Saskatchewan has the potential to advance projects with lithium, copper, zinc, rare earth elements, nickel, and cobalt (Government of Saskatchewan, 2023). Alberta also has mineral mining potential with over 40 different mineable minerals (Government of Alberta, 2022). Both provinces have done extensive geological assessments to better understand their mining potential. Appendix A provides maps of prospective minerals in both provinces.

2.4.4. Climate policy in the U.S.

Canada and the U.S. have strong economic ties. Despite Canada and the U.S. having sizable energy production and export sectors, geographical constraints and variations in demand and costs result in substantial energy imports from each other. The main form of energy traded is oil and gas. However, efforts to decarbonize the U.S. have opened opportunities for greater electricity exports from Canada and possibly hydrogen exports in future. And because Canada and the U.S. are dependent on each other for trade, both are vulnerable to market disruptions and policy developments in the other country (Government of Canada, 2019).

In August 2022, the U.S. passed the *Inflation Reduction Act of 2022* to help achieve the country's net zero by 2050 target. The act outlines funding, programs, and incentives to accelerate the clean energy transition (The White House, 2022). If both countries adopt stringent climate policy, the market share of zero- and low-GHG technologies may increase, which could decrease their costs at a faster rate. Stringent climate policy could also affect the economies of the two provinces, impacting trade dynamics. I explore how stringent climate policy in both countries could affect Alberta and Saskatchewan through incorporating policies that cause the U.S. to achieve net zero by 2050.

2.4.5. Hydrogen produced from natural gas with CCS

Hydrogen is commonly used for petroleum refining and fertilizer production. Potential emerging uses include transportation, electricity generation, building heat, and high-temperature processes in industry. For instance, natural gas utilities are interested in blending natural gas and hydrogen (up to 15%) for distribution to buildings, and in cases where specialized pipes are installed (for directly serving some industries perhaps), the hydrogen content could reach 100% (Government of Alberta, 2021a). If hydrogen is produced from natural gas (or another fossil fuel) the production process must include CCS to be part of the net zero future. For the remainder of the report, when I refer to hydrogen, I am referring to hydrogen produced from natural gas with CCS.

Given Alberta's existing natural gas reserves, infrastructure, and extensive pipelines capable of transporting a blend of hydrogen and natural gas, the province can play a lead role in Canada's clean hydrogen economy. The government of Alberta has created a Hydrogen Roadmap (Government of Alberta, 2021a) to expand the province's hydrogen sector and has outlined plans in its provincial Budget 2023 to foster investment (Alberta Energy Regulator, 2023). Saskatchewan is also working on developing potential hydrogen hubs in the province (Saskatchewan Research Council, 2022).

2.4.6. Global oil price

The global oil price has, of course, significant economic impacts on our oil and gas endowed region. However, there is uncertainty about this price as countries transition to net zero. The IEA predicts that there will be considerably less demand for oil in a net zero future and therefore the price will be lower (IEA, 2022c). On the other hand, if Canada achieves net zero by 2050 but other significant countries do not, the oil price could remain high. I explore how different future global oil prices could impact our oil and gas endowed region under net zero policy in 2050.

2.5 Recent Assessments

Since the Canadian *Net-Zero Emissions Accountability Act* was enacted in 2021, several studies have investigated potential futures for the Canadian economy in a net zero world. Two studies in particular use the same modeling tool and explore similar policy scenarios and economic metrics related to Canada's oil and gas endowed region.

2.5.1. Clean Energy Canada

Clean Energy Canada (CEC) recently released a report looking at the future of jobs in Canada in a net zero world, with emphasis on clean energy versus fossil fuel jobs. Navius Research Inc. conducted the analysis and simulated the effects of three policy scenarios: 1) current policies, 2) net zero policies, and 3) a scenario where climate policies are retracted (CEC, 2023). I model similar current and net zero policy scenarios.

Relevant findings for all of Canada include that there may be 1.5 million fewer fossil fuel-related jobs and two million more clean energy-related jobs in 2050 relative to 2025 under net zero policy. Under optimistic assumptions for DAC availability and cost, the sector could create between 125,800 and 177,300 jobs by 2050, while providing 259 Mt of emissions reductions for Canada. These findings provide insight into potential decreases in employment in the oil and gas industry and the potential significance of DAC as an economic opportunity.

While this study explores uncertainty with the energy transition in terms of economic metrics like jobs, there are key differences that separate our studies. The main difference is that the CEC study looks at a climate policy rollback scenario as its third scenario. While this scenario is useful for comparison purposes, it does not account for the negative economic impacts that will result from climate change worsening without climate policy. I instead focus on one side of the ledger and look at the economic effects related to emissions reductions.

Secondly, the study only looks at effects of net zero on energy-related employment, with a particular focus on clean and renewable energy jobs. My study looks beyond energy-related jobs and seeks to understand the effects of net zero policy on the economy more broadly, especially in on our oil and gas endowed region. The findings about job losses and the importance of DAC serve as useful insights for me to explore further and compare against through my analysis where I research new possible economic development under net zero policy.

2.5.2. Public Policy Forum

The Public Policy Forum (PPF) also recently released a report exploring the effects of net zero policy on economic activity in Canada. The study compares the effects of net zero policy focused strictly on GHG reduction versus an explicit requirement to phaseout Canada's oil and gas production (PPF, 2023). Navius Research Inc. conducted the analysis and simulated three policy scenarios: 1) announced policies (similar to CEC current policies), 2) net zero policies, and 3) net zero policies with an oil and gas production phase-out. I model the same announced policy and net zero policy scenarios, but not the production phase-out scenario.

Relevant findings from the study include that jobs increase in all scenarios between 2020 and 2050 as Canada's population and economy grow. In terms of the energy transition, employment grows in biofuels, electricity, hydrogen, and CCS. The results also suggest that DAC with carbon storage and point emission source CCS are crucial to minimize the cost of achieving net zero and that economic impacts of net zero policy depend on the future global oil price, DAC availability, and the extent to which CCS cost declines.

The basis of my study relates to some of the key insights from the PPF study. These insights include that 1) the economic impacts of net zero policy are more significant in Canada's oil and gas producing region, 2) there are different potential net zero pathways for Canada, some of which include continued oil and gas production, and 3) these pathways, especially the ones including continued oil and gas production, depend on factors within our control, such as domestic policy design, and factors outside our control, such as the global oil price. These key conclusions inclined me to probe further into potential pathways to net zero for our oil and gas endowed region. Unlike the PPF study, I do not focus on an oil and gas production phaseout, which makes it unnecessarily costly for Canada to achieve net zero. Instead, I expand on the baseline net zero scenario by integrating plausible developments in point source CCS, DAC with carbon storage, hydrogen with CCS, and mineral mining.

Because DAC with carbon storage is not yet a commercial technology and typically has a large impact on modeling results, the technology was explored through a sensitivity analysis by Navius in its research for PPF, which thus showed the potential effects of net zero on the economy with and without the technology. While the PPF study explores a range of uncertainty assumptions such as different cost and availability assumptions for global oil price, availability and cost of DAC with carbon storage and point source CCS, and level of climate policy implemented in the U.S., I use their baseline (reference) scenario in my basic net zero scenario – what they refer to as the intermediate sensitivity that includes a medium oil price, DAC as unavailable, declining costs for CCS, and median policy in the U.S.

I chose to select this baseline scenario from the PPF study to represent my initial net zero scenario. This is not to discount the PPF's efforts to explore DAC with carbon storage and other uncertainties, which provide important insights and takeaways such as the contribution of the technology to the cost of achieving net zero. Then, in my second net zero scenario, I include DAC with carbon storage as one of the key plausible technologies in a net zero future, one that has particularly good opportunities in a region where the same geological conditions that provide plentiful oil and gas also provide ideal locations for geological storage of CO_2.

2.6 Need for Research

The CEC and PPF studies follow similar structures for their analyses. The studies analyze three scenarios: 1) current/announced policy, 2) net zero policy, and 3) a scenario tailored to their research question (policy rollback and oil and gas production phaseout). I follow a similar structure for my analysis. While the scenarios modeled in the CEC and PPF studies are possible realities given the unpredictable nature of politics and climate policy in Canada, my goal is to simulate a plausible scenario which explores the full potential of economic activity in a net zero future.

Both studies used Navius' general equilibrium model called gTech. Such models can be useful to explore key interactive effects that happen during periods of long-term transition, such as the energy transition implied by a net zero future. However, while energy-economy models like gTech will automatically simulate growth in some technologies, processes, and sectors related to the energy transition, they generally require additional exogenous assumptions to explore the full range of plausible economic activity that would occur under the major transformation that is implied by a multi-decade transition to a net zero economy.

gTech includes zero-emission energy and process options such as renewables, bioenergy, and point emission source CCS technologies. gTech also includes new technologies for clean energy production and consumption as well as new GHG extraction options such as DAC with carbon storage. However, like any energy-economy model, gTech is constrained in its portrayal of the full potential of the energy transition when applied conventionally. To fully capture the possible range of economic opportunities, these models often require additional assumptions. The reason is that model designers and users are reluctant to include and fully unconstrain technologies, processes, and new industrial activities that are not currently located in a given region and whose potential development is uncertain.

For instance, in response to the worldwide need for a dramatic increase in the production of critical minerals for the energy transition, we can anticipate that Canada will need to develop and expand its mineral sector. However, while extensive geological assessments confirm that Alberta and Saskatchewan have potential to mine many of the critical minerals needed, the minerals are primarily still prospective and not yet commercial because of the lengthy exploration and regulatory processes involved with mining and extraction. Given this, there is still some uncertainty about the development of this sector and many energy-economy models in North America do not include a critical mineral sector.

Likewise, if a region does not manufacture specific energy using equipment, like heat pumps, it is assumed this lack of production will continue through the entire multi-decade simulation. Also, if a region does not currently have extensive development of new energy transition technologies, like DAC with carbon storage, it is difficult for such a technology to achieve high deployment despite its advantages over other decarbonization options during a period of several decades. If, however, these types of plausible developments are included in such models, economic activity in Canada's oil and gas endowed region could be much greater than what has been portrayed in recent net zero energy-economy analyses such as the PPF study.

Thus, the goal of my research is to focus on the region in Canada (comprising Alberta and Saskatchewan) that is most likely to be impacted by the energy transition and to identify and simulate the development of all resources, processes, and activities that could plausibly emerge as part of the energy transition, yet were underrepresented or developed in recent transition modeling, such as the PPF study. To keep the comparison as clear as possible, I keep constant other key variables from the PPF study, such as the announced and net zero policy assumptions. Then, in an additional scenario, I expand on the net zero scenario by promoting development of key plausible transition-related investments in our oil and gas endowed region. My study is not intended to forecast or dictate the right pathway, rather it may provide a useful illustration of what the future of this region could look like given plausible assumptions about the future economy and political landscape in Canada and the U.S.

3. Methodology

3.1. Energy-Economy Modeling

Models help simulate the dynamics of complex nonlinear systems in the world around us (Oreskes, 2003). Energy-economy models do this in the context of questions we have about relationships between energy and the economy such as how a policy or technology could affect GHG emissions or GDP in a region (Rhodes et al., 2022).

Energy-economy models are characterized by having aspects of behavioural realism, technological detail, and/or macroeconomic feedbacks (Jaccard et al., 2003). Behavioural realism accounts for human preferences such as whether decisions are based solely on minimizing financial costs or if other non-financial factors are important in technology choices. (Rivers & Jaccard, 2006). These non-financial factors are sometimes referred to as intangible costs, an example being the extra perceived psychosocial cost of buying a brand of personal vehicle that confers less social status in the eyes of the buyer. Technological detail refers to the level of detail a model includes, which can help with exploring emerging technologies. An example is how a near-commercial technology's cost declines over time as it penetrates the market (Mundaca et al., 2010). Macroeconomic feedbacks account for interactions in the economy, such as how the equilibrium of prices, demand, and supply levels of goods in the economy are affected by a policy (Nikas et al. 2019).

3.1.1. Bottom-up models

Bottom-up models are considered technologically explicit (Rhodes et al., 2021b). Current and emerging technologies are included as well as their market shares, capital and operating costs, emissions profiles, and energy use (Rivers and Jaccard 2006). Bottom-up models are useful to help determine potential impacts of emissions from future technologies and energy demand (Herbst et al., 2012) and to show possibilities for different technologies to meet environmental goals (Jaccard et al., 2003). However, conventional bottom-up models are criticized for their lack of behavioural realism if their technological evolution is based on the assumption that competing technologies are perfect substitutes for each other and that financial costs are the only decision factor when simulating technology choices (Rivers and Jaccard, 2006). In reality, there are other purchasing decisions such as consumer preference, higher chance of premature failure, and differing financing costs between consumers (Jaccard et al., 2003). These models have also traditionally not included macroeconomic feedbacks because energy sector technologies are not interacting with the rest of the economy (Rhodes et al., 2021b).

3.1.2. Top-down models

Top-down models provide a more aggregated approach in focusing on interactions between the energy system and the economy (Assoumou et al. 2018). CGE models are a type of top-down model that assesses links between economic sectors to determine how policies may impact the economy through macroeconomic equilibrium feedbacks (Nikas et al., 2019). Top-down models can also include behavioural realism because the parameters are based on historical data, which means they can include intangible costs consumers include when making technology purchasing decisions (Rivers and Jaccard, 2006).

A limitation of top-down models is that historical responses to price changes may not be indicative of future responses, especially if the range of technology options has changed recently (such as the advent of electric vehicles). Conventional top-down models also typically lack technological detail. They can be useful to simulate effects of large-scale policies like taxes, but the absence of technological detail makes them less suitable to model technology-specific policies like targeted subsidies (Jaccard & Dennis, 2006).

3.1.3. Hybrid models

Hybrid models combine strengths of bottom-up models (technological detail) and top-down models (equilibrium feedbacks and behavioural realism). Hybridization occurs through adding technological detail to a top-down model or incorporating behavioural realism and/or equilibrium feedbacks to a bottom-up model (Rivers & Jaccard, 2006). gTech, the model I use for this study, is one type of hybrid energy-economy model.

3.2. gTech

As a control for the study, I use the same general equilibrium energy-economy model as the PPF and CEC studies. gTech is owned by Navius Research Inc. and is based on elements from three models: CIMS, oiltrans, and GEEM. The model is founded in a CGE (top-down) framework from GEEM (a general equilibrium model) that enables it to account for the whole economy, including how sectors and regions interact with each other and the rest of the world. gTech is considered a hybrid model because it can explicitly simulate technological changes. The model derives this capacity from the hybrid model CIMS, an open-source model owned by the Energy and Materials Research Group (EMRG) at SFU. Elements from oiltrans, another model developed by Navius Research Inc., are incorporated to include the representation of energy supply such as liquid and gaseous fuels (Peters & Riehl, 2021).

3.2.1. Macroeconomic dynamics

gTech is a macroeconomic model that can provide insights about how policies may affect the economy. Key dynamics in gTech include comprehensive coverage of economic activity, full equilibrium dynamics, labour and capital markets, sector detail, interactions between regions, and household dynamics (Peters & Riehl, 2021).

gTech accounts for economic activity in Canada based on Statistics Canada national accounts and forecasts how government policy could affect economic metrics like GDP. To represent full equilibrium dynamics in labour and capital markets, the model always resolves to long-run equilibrium. Furthermore, the model can simulate how policies affect over 95 sectors in the economy, as well as ripple effects in the economy, such as how the electricity sector can pass policy compliance costs to households who may change their demand for electricity and other goods or services. gTech also measures equilibrium unemployment, and household earning and spending. Lastly, gTech accounts for how Canadian provinces and territories, the U.S., and the rest of the world interact with each other through trade of goods and services, capital movement, taxation (in Canada), and transfers between regions (Peters & Riehl, 2021).

3.2.2. Technological choice

gTech has 95 sectors and 300 technologies across 70 end-uses. Factors affecting technology choice include capital and energy costs, time preferences, cost dynamics, technology preferences, and policy (Peters & Riehl, 2021).

Energy costs in gTech are based on external prices for globally traded energy commodities, model-determined prices for energy commodities whose prices results from market interactions in Canada (or Canada and the U.S.), and energy consumption by the technologies in the model. gTech accounts for the trade-off between near-term capital costs and long-term energy operating costs (time preference of investors and consumers) through a behaviourally estimated discount rate that ranges from 8-25% depending on the technology choice being simulated. gTech also includes how costs for technologies decline over time in response to cumulative production and related innovation through a declining capital cost function. Furthermore, gTech accounts for preferences consumers have for technologies aside from purchasing cost by quantifying them as intangible non-financial costs that are added to a technology-choice algorithm. Lastly, gTech uses a market share equation where technologies with the lowest net-costs (including non-financial) achieve the greatest market share and those with higher net-costs capture less, but the outcome is rarely winner-take-all. Thus, gTech can be used to simulate the combined effects of incentive programs, regulations, carbon pricing, other tax policy, and flexible regulations on technology choice (Peters & Riehl, 2021).

3.2.3. Energy supply markets

gTech includes all major energy supply markets such as electricity, RPPs, and natural gas. The markets are characterized by resource availability and production costs by province, as well as costs and constraints of transporting energy between regions. Low carbon energy sources such as renewable electricity and bioenergy can be introduced in each fuel stream in response to policy. gTech also accounts for availability and cost of bioenergy inputs (Peters & Riehl, 2021).

3.3. Hybrid Models in Canada

To put my choice of gTech in a broader context, I constructed Table 1 from information in several tables from Rhodes et al. (2021). The table surveys energy-economy hybrid models in Canada and shows how they may incorporate the aspects I need to answer my research question. These include 1) the ability to simulate to 2050, 2) full equilibrium dynamics, 3) inclusion of near-commercial technologies such as DAC with carbon storage (DAC + CS) and point source CCS 4) regional and national jurisdiction in Canada and international for the U.S., and 5) availability of the model for public use. Cells highlighted in blue indicate that the model adequately incorporates the aspect. N/A stands for “not available” and is treated as not meeting the criteria. While gTech’s code and assumptions are not available to the public, I was granted access to the model for research purposes.

Table 1. Hybrid Models in Canada

Model	Owner	Model type	Simulation target	Full equilibrium	Near-commercial technologies	Jurisdiction	Public use
gTech	Navius Research	Optimization/ linear programming, CGE (Hybrid)	2030, 2050	Yes	DAC + CS, point source CCS	Provincial, national, US, international	No - granted access
CIMS	SFU EMRG	Hybrid	2030, 2050	No	DAC + CS, point source CCS	Regional, provincial, national	Yes - on request
CIMS-Urban	SFU EMRG	Hybrid	2030, 2050	No	No	Municipal	Yes - on request
E3MC	Systematic Solutions, Inc.	Input-output, hybrid, system dynamics	2050	No	Point source CCS	Provincial, national	No
ENERGY 2020	Systematic Solutions, Inc.	Hybrid, system dynamics	2050	Yes	Point source CCS	Provincial	No
Energy Policy Simulator	Energy Innovation, LLC	Input-output, hybrid, system dynamics	2050	No	DAC + CS, point source CCS	Municipal, provincial, national, US, international	Yes
GCAM	University of Maryland, Joint Global Change Research Institute	Integrated assessment model, hybrid	2100	N/A	DAC + CS, point source CCS	Regional, national, international	No
MAPLE-C	US Energy Information Administration	Hybrid, bottom-up, general equilibrium	N/A	Yes	Yes	N/A	N/A
MESSAGE - MACRO	The International Institute for Applied Systems Analysis Energy Program	Hybrid - bottom-up, partial equilibrium	N/A	Yes	Yes	N/A	N/A
NATEM-TIMES	Energy Super Modelers and International Analysts Consultants	Optimization/ linear programming, hybrid	2050	No	Point source CCS	Municipal, provincial	No

Note. Adapted from Rhodes, E., Craig, K., Hoyle, A., & McPherson, M. (2021). *Improving Climate Policy Projections: A Pan-Canadian Review of Energy-Economy Model*. University of Victoria. Copyright 2021 by Rhodes et al.

3.4 Modeling Assumptions

I compare three scenarios in this analysis: 1) announced policy, 2) policies to achieve net zero by 2050, and 3) policies to achieve net zero by 2050 with a focused exploration of plausible opportunities for economic development in key sectors related to the energy transition. The first two scenarios are already established in gTech and I describe them further in section 4 (scenario design). In the following section, I describe the process for creating the third scenario.

In my third scenario, I seek to include more a realistic representation of energy transition opportunities in Canada’s oil and gas endowed region. While the region is suitable for many of the elements needed for the energy transition, my goal was to promote growth in sectors and technologies that have been underrepresented in recent net zero studies. I began by conducting a literature review to better understand what energy sources, resources, and technologies have potential to emerge or expand in Canada’s oil and gas endowed region on the road to net zero. My research revealed that the region is well positioned in terms of expertise, resources, and infrastructure for DAC with carbon storage, point source CCS, hydrogen produced from natural gas with CCS, bioenergy production, electricity production with CCS, continued production and export of oil and gas (to places in the world that convert these in zero-emission processes to electricity and hydrogen), mineral mining, and renewables such as wind, solar, and geothermal (Delphi Group et al., 2021; SaskPower, 2022; Jaccard, 2006).

Renewables included in gTech are wind, solar, run-of-river and large hydro, and nuclear in some provinces. For the intermittent renewables, the model also includes energy storage and stationary batteries, however the model cannot quantify economic activity associated with these technologies. A key element missing from the renewable sector in gTech that is relevant to this region is geothermal energy. While creating a geothermal technology with great expansion capability in the model may contribute to a expanded use of renewable energy in the economy, I felt this technology was beyond my level of expertise and sat at the edge of the scope of technologies I should include. Furthermore, given the focus of previous net zero studies on clean and renewable energy using similar policy scenarios in gTech, such as the study by CEC (2023), I concluded there has been adequate representation of renewables and settled on maintaining its existing set of options.

Similarly, after discussing with lead researchers at Navius about the representation of biofuels in the model, I concluded that the potential growth of biofuels is mostly already accounted for in the basic net zero scenario. gTech represents biofuels in the form of liquid and gaseous biofuels as well as a limited amount of solid wood fuels.

The model differentiates between first generation bioenergy, which is already commercialized, and second generation, which is produced from woody or grassy biomass through methods that are under commercialization. Further evidence of biofuels' potential being adequately accounted for in the model is provided by Navius' annual reports on the role of biofuels in Canada, which involves ensuring there is up-to-date information and representation of biofuel potential in the model.

As previously mentioned, despite the need for rapid expansion of critical minerals for the energy transition, the sector is currently underrepresented in most energy-economy models in North America because the sector is still developing. Likewise, point source CCS, DAC with carbon storage, and hydrogen with CCS still have great uncertainty about growth potential, cost, and/or availability and are often explored through uncertainty analyses in modeling studies rather than as included in baseline or reference scenarios.

However, my research and discussions with experts convinced me that increased opportunities in these sectors are plausible given their suitability to the region. For instance, federal and provincial governments recognize the need for these sectors and are investing to promote their uptake in the energy transition. Thus, I settled on increasing mineral mining output potential, allowing growth in point source CCS as a GHG reduction option, enabling DAC with carbon storage, and promoting growth in hydrogen production from natural gas with CCS. Table 2 outlines my decision-making process for selecting the sectors on which I focused for plausible growth in Canada's oil and gas endowed region in a net zero future.

Table 2. Decision-Making Process for Growing Sectors

Energy source	Rationale	Change(s)/assumption(s)	Change?
Mineral mining	Region anticipates growth in the sector by 2050	Manually increase growth in mineral mining based on provincial targets	Yes
Hydrogen produced from natural gas with CCS	Use region's existing natural gas reserves, export/transport infrastructure, and CCS technologies	Increase investment tax credit to reduce cost of production	Yes
DAC with carbon storage	Region has pilot projects, good geology for storage, and anticipates more development	Assume available and increase investment tax credit to reduce cost of production	Yes
Point source CCS	Region has existing projects, good geology for storage, and anticipates more development	Assume available and increase investment tax credit to reduce cost of production	Yes
Bioenergy	Region has vast agricultural land and can use current export/transport infrastructure	Adequately represented in gTech and explored in recent studies	No
Renewables (geothermal, solar, wind)	Region is suitable in terms of geology and climate	Adequately represented in gTech and explored in recent net zero studies	No

An additional assumption I include is stringent climate policy in the U.S. to reflect a realistic scenario where both countries are working towards net zero. This assumption is justified given the recent net zero by 2050 target from the U.S. and the *Inflation Reduction Act of 2022*, which outlines incentives to help achieve this target (The White House, 2022). And, even if the U.S. federal government does not fully implement policies that achieve net zero in 2050, there is substantial implementation of policies at the state level that collectively can have similar technological and industrial effects. Overall, the combination of these assumptions have potential to coincide with and support emissions reductions in the oil and gas industry as well as potentially provide alternative or supplemental industries in the region as Canada and the U.S. transition to net zero. I next discuss the specific changes I made to the model to simulate the effects of these assumptions.

3.4.1. Mineral mining changes

To stimulate growth for mineral mining in Alberta and Saskatchewan, I approximated the effect of new mineral development by manually increasing the resource endowment for existing metallic and non-metallic minerals to ultimately increase output. Saskatchewan currently has a productive mineral mining sector and expects further growth in existing metallic and non-metallic minerals (Government of Saskatchewan, 2023). Alberta primarily mines non-metallic minerals but has potential to mine metallic minerals such as lithium (Government of Alberta, 2022).

I assume metallic mineral output doubles by 2050 relative to 2020 for both provinces. While Saskatchewan has set a goal to double mineral output by 2030 and Alberta's metallic minerals could more than double their current production, I chose a doubling for both provinces by 2050 to account for uncertainty with the exploration and regulatory processes involved in mining and extraction.

Saskatchewan currently mines important non-metallic minerals such as potash and expects growth in the sector. I doubled non-metallic mineral output in 2050 in Saskatchewan relative to 2020. Alberta's current non-metallic minerals consist mainly of sand, gravel, and limestone. When I tried to increase non-metallic mineral output for Alberta, there was not enough demand for existing minerals to increase output more than 25% above 2020 levels in 2050. This is evidence of the constraints of general equilibrium models when trying to manually grow a sector – unless the user creates a new external demand for exports. It also is a limitation of growing existing minerals in the model and not creating new critical mineral commodities such as lithium. However, this was beyond my level of expertise.

Because mineral mining has long been overshadowed by oil and gas in Alberta, there is less certainty and development in mineral mining compared to Saskatchewan. Furthermore, many of the prospective minerals for Alberta are metallic. Thus, a 25% increase in non-metallic mineral production in Alberta is certainly plausible over the next decades of the energy transition, especially given all the forecasts by independent researchers of a dramatic increase in global mineral demand because of the energy transition.

3.4.2. Point source CCS

To simulate potential growth in DAC with carbon storage, point source CCS, and hydrogen with CCS in a net zero future I updated the relevant investment tax credit policies outlined in Canada's Budget 2022 and 2023, which has the effect of reducing firm production costs. If the energy sources and technologies are even cheaper, they will receive more market share and thus contribute more to the net zero economy. Because there was readily available information for the investment tax credit policies and more uncertainty around their growth and uptake, I was less confident about manually growing output for these sectors by a specified amount. Instead, I took a more internal approach and used the tax credits to simulate growth in these sectors by letting the model allocate changes in response to the policies.

I assume CCS technologies are available with a reference level declining cost. CCS technology costs are based on studies from the Global CCS Institute (2021) and the IEA (2021). There are several CCS technologies, each with their own costs. To account for declining capital costs for these technologies, I use existing values for current (first of a kind) and future (nth of a kind) costs in gTech. Navius Research Inc. presents the costs as levelized incremental costs for each CCS technology using a 15% discount rate and 30-year lifespan. The full list of CCS technologies and cost assumptions is in Appendix B.

The federal government recently announced an investment tax credit of 50% of the capital cost for new CCS projects (Government of Canada, 2022b). The policy helps reduce the cost of CCS projects in Canada, alongside other climate policies, and is included in gTech. To account for the high capital costs and the expected demand by 2050, I increased the CCS investment tax credit according to the increase outlined in Canada's federal Budget 2023 (Government of Canada, 2023b). Budget 2022 outlines $2.6 billion over five years starting in 2022-2023, with an annual cost of $1.5 billion in 2026-2027 until 2023. Budget 2023 announced an additional $520 million over five years starting in 2023-2024, which I have added to the existing policy based on Budget 2022.

3.4.3. DAC with carbon storage

DAC with carbon storage is covered under the CCS investment tax credit. I assume DAC is available at an initially high but then declining cost to account for uncertainty in uptake and cost over the next two decades. The high-cost estimate for DAC is based on the highest value reported in Keith et al. (2018), Fasihi et al. (2019), and Larsen et al. (2020). Like the CCS technology costs, Navius Research Inc. uses current (first of a kind) and future (nth of a kind) costs to account for the declining capital costs of the technology. Costs are annualized using a 15% discount rate and 20-year life span. Table 3 shows the different cost options for DAC with carbon storage. I use the current high levelized cost of DAC of $1570 per tonne of CO_2e reduced and the future minimum high cost of $217 per tonne of CO_2e reduced.

Table 3. Levelized Cost of Carbon Capture from DAC (2020 CAD/tCO_2e reduced)

Assumption	**Current (first of a kind)**	**Future minimum (nth of a kind)**
Low	410	120
Reference	734	167
High	1570	217

3.4.4. Hydrogen production from natural gas with CCS

For hydrogen produced from natural gas with CCS, I created a policy that helps reduce the cost of production through an investment tax credit, as opposed to manually increasing output. The tax credit amount is in line with the Clean Hydrogen Investment outlined in Canada's Budget 2023 (Government of Canada, 2023b). The tax credit applies to all hydrogen production that does not produce emissions. In the case of Alberta and Saskatchewan, this policy typically only applies to the production of hydrogen from natural gas with CCS. The tax credit amount in budget 2023 is $5.6 billion over five years, beginning in 2023-2024 and an additional $12.1 billion between 2028-2029 and 2034-2035. Furthermore, the CCS tax credit has potential to help promote growth in this sector as well.

3.4.5. Climate policy in the U.S.

For my stronger climate effort simulation, I applied policies that cause the U.S. to achieve net zero by 2050. In particular, within gTech I simulate an economy-wide cap-and-trade system that starts in 2030 and phases down linearly to net zero in 2050 to keep it consistent with the Canadian net zero policy I simulate. The assumption is based on efforts outlined in the *Inflation Reduction Act of 2022* to achieve net zero emissions by 2050 through an equivalent portfolio of pricing, regulatory, and investment tax credit policies at the federal and state level.

3.4.6. Oil price uncertainty

Because global oil prices are a function of global climate effort, international conflict, and innovations in exploration and extraction, oil prices are unpredictable and often volatile (and have been for the last five decades). Given that oil prices have a significant impact on the economies of oil and gas endowed regions, I test alternative oil price scenarios, with low, reference, and high oil price assumptions in 2050. Navius Research Inc. uses West Texas Intermediate (WTI) oil forecasts that are based on the Canada Energy Regulator's *Canada's Energy Future* reports (CER, 2018; CER, 2021). In 2050, the low oil price is \$35.1 (2020 USD/barrel), the reference price is \$64.1, and the high price is \$88.0. The full breakdown of the oil price forecast assumptions in gTech from 2025 to 2050 is in Appendix C.

3.5 Land-Use, Land-Use Change, and Forestry Assumptions

Lastly, an existing assumption Navius Research Inc. uses in gTech is the inclusion of land-use, land-use change, and forestry (LULUCF) offsets in GHG emissions reporting. A recent report by Natural Climate Solutions Canada indicates what emissions offsets from LULUCF will be available on the path to net zero (Drever et al., 2021). Navius adds the emissions offset assumptions as an external input to the model. 30 $MtCO_2e$ are offset through LULUCF in 2030, rising to 105 Mt CO_2e in 2050.

4. Scenario Design

As noted above, I modeled three scenarios: 1) Announced Policy (A*nnPol*), 2) Announced Policy with Net Zero (*NetZero*), and 3) Announced Policy with Net Zero and Plausible Growth in Key Sectors (*NetZero+*). These are summarized in Table 4. The full list of policies I modeled is in Appendix D.

Table 4. Scenario Overview

Scenario	Assumptions	Policies Represented
Announced Policy (*annPol*)	DAC with carbon storage unavailable, point source CCS available and reference cost, baseline policy in the U.S., reference oil price	Existing and announced federal and provincial policies from *A Healthy Environment and Healthy Economy (HEHE)* and the *2030 Emissions Reduction Plan.*
Announced Policy with Net Zero (*NetZero*)	Same as *annPol*	Same as *annPol* with policies that achieve net zero.
Announced Policy with Net Zero & Plausible Growth in Key Sectors (*NetZero+)*	DAC with carbon storage available and high cost, point source CCS available and reference cost, stringent climate policy in the U.S., reference oil price	Same as *NetZero*

4.1 Announced Policy (*annPol*)

This policy scenario includes the same assumptions and policies as the PPF intermediate sensitivity announced policy scenario. In this scenario, DAC with carbon storage is unavailable, point source CCS is available with a reference declining cost, the U.S. has baseline climate policy, and there is a reference global oil price. The policies in this scenario include existing and announced federal and provincial policies as of October 2022 from *A Healthy Environment and Healthy Economy* (Government of Canada, 2021) and the *2030 Emissions Reduction Plan* (Government of Canada, 2022a). Examples of policies include a carbon price that rises to $170/tCO2e by 2030 and the Clean Fuel Regulation.

While the federal government is obliged to set emissions reductions plans in five-year increments to achieve net zero by 2050, I assume in this scenario that the government does not implement new policies beyond those outlined in the 2030 Emissions Reduction Plan. As noted in the PPF (2023) study, this announced policy scenario is not a likely scenario because Canada will likely implement climate policy at higher stringencies beyond 2030. And, under climate-sincere leadership, we can assume the federal government will continue to work towards achieving net zero. However, this scenario is useful for providing insight into the current trajectory for emissions and economic activity under announced policy and for comparison with net zero policy. Moreover, there is a chance that a change in Canada's federal government could lead to a decade of negligible climate effort, as has happened in the past.

4.2 Announced Policy with Net Zero (*NetZero*)

NetZero has the same key assumptions as the *annPol* scenario. While *NetZero* includes the same *A Healthy Environment and Healthy Economy* and *2030 Emissions Reduction Plan* policies, it also includes additional policies and policy stringencies to achieve net zero. Thus, to keep the policy scenario consistent with the intermediate sensitivity net zero scenario from the PPF study, I simulate sector-specific and economy-wide emissions constraints in the model that together achieve net zero. In particular, I approximate federal policy to achieve net zero by 2050 by simulating an economy-wide emissions cap-and-trade system in gTech, as this is the easiest way for a modeler to simulate any set of economically efficient policies that achieve net zero in a specific period. The emissions cap phases down linearly to net zero from 2035 to 2050. As noted earlier, the purpose of this scenario is to understand the potential effects of a net zero outcome on economic activity and emissions in Canada's oil and gas endowed region. The scenario also provides a baseline to probe further into plausible opportunities arising under the energy transition.

4.3 Announced Policy with Net Zero and Growth in Key Sectors (*NetZero+*)

In *NetZero+*, assumptions include DAC with carbon storage as available with a high declining cost, point source CCS as available with a reference declining cost, stringent climate policy in the U.S. that achieves net zero by 2050, and a reference global oil price. Overall, *NetZero+* has the same policies as *NetZero*. The purpose of this scenario is to expand on the PPF net zero scenario by exploring realistic growth in emerging sectors in our oil and gas endowed region in 2050 under the energy and economy transition implied by net zero policy in Canada and elsewhere.

5. Results

Through this study, I seek to understand 1) the range of effects of net zero on Canada's oil and gas endowed region and 2) additional economic opportunities for the region from plausible growth in key industrial sectors and activities related in some way to the energy transition. The metrics I focus on are GHG emissions, GDP, and jobs. I begin by discussing key takeaways from the region, then narrow down the analysis to provide more province-specific insights. Lastly, I explore the effects of different global oil prices in the region in 2050.

To distinguish between the two net zero scenarios, I will often refer to *NetZero* as the PPF net zero scenario, which is based on the intermediate sensitivity assumptions from the PPF study. It is important to note that while my baseline net zero scenario (*NetZero*) is modeled after the PPF net zero scenario, Navius has made some adjustments to the base model since the PPF study so there may be slight differences with the version I simulate. Furthermore, my use of just one of the PPF scenarios ignores the impressive range of uncertainties explored in the PPF study via sensitivity analysis. Nonetheless, I believe that my reliance on the PPF intermediate scenario provides the desired comparison.

5.1 Key Insights

Key insights include that 1) there is economic growth in all scenarios out to 2050 as the population and economy grow, 2) there is more economic activity in the sectors I adjusted but also ripple effects throughout the economy, and 3) there are key differences between the provinces that provide insight into the potential for diversified economic development as well as some of the challenges I faced when conducting the study.

Throughout the process of executing and then analyzing the simulation outputs, I became more aware of challenges in using a general equilibrium model, such as gTech, for this type of study. In particular, exogenous stimuli to an economy caused by entirely new demands for materials and equipment during the net zero energy transition are a challenge to execute fully in a general equilibrium framework. With each new industrial activity I tried to introduce, the model simulations would, quite naturally, return to baseline population growth and activity rates thanks to the equilibrating role of price adjustments, factor substitutions, and structural change. As noted in the discussion below, this caused me to use various override techniques to approximate the effect of the plausible activities and cost trajectories I was including in my key scenario.

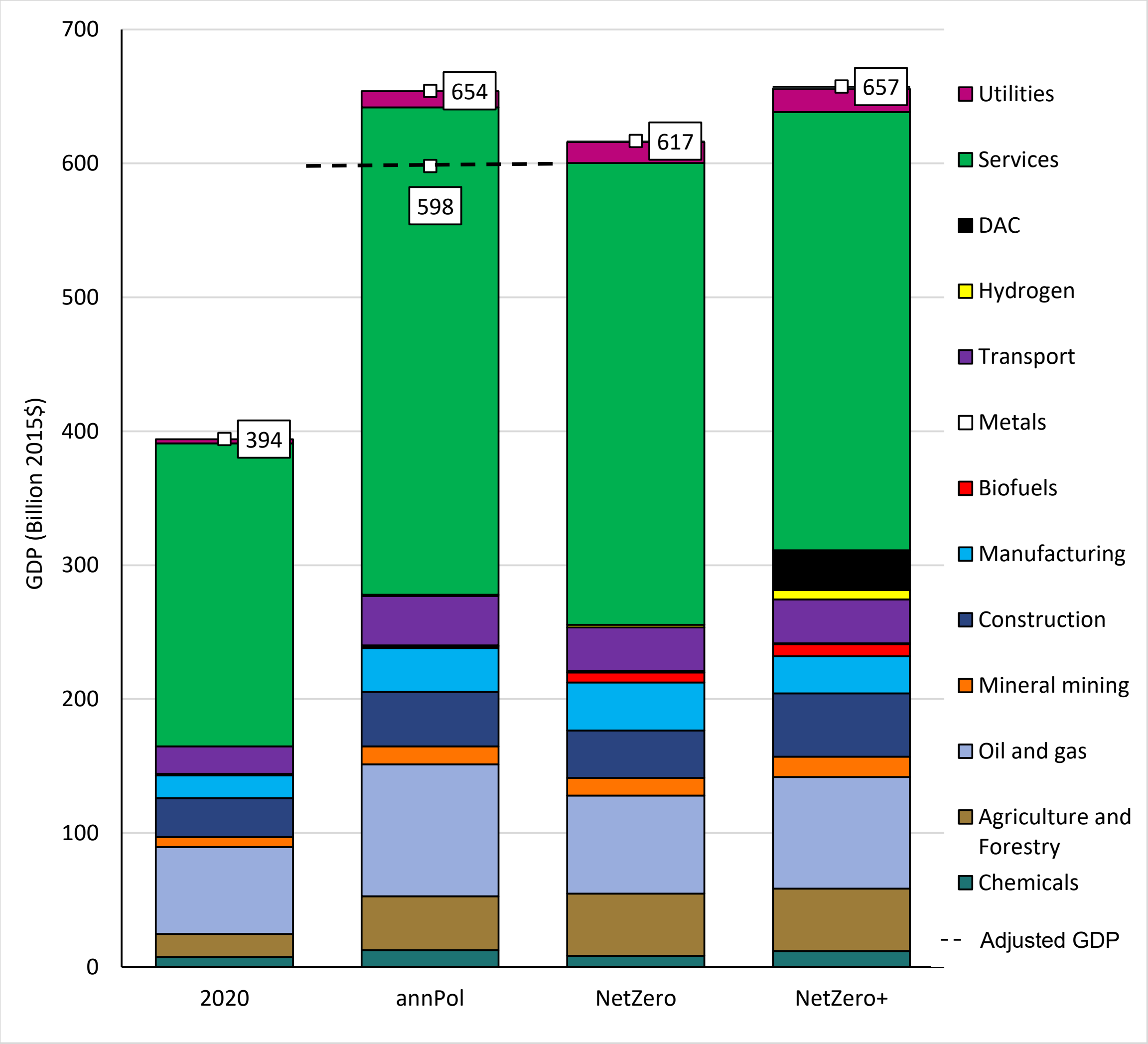
5.2 Insights for the Region

Figure 1 shows GDP for the region in 2020 (left column) as well as in 2050 for the three simulated scenarios. At the regional level, the results provide the desired outcome of representing more plausible economic activity in Canada's oil and gas endowed region during the energy transition. While I compare the net zero scenarios relative to an announced policy scenario, this latter scenario is not intended to serve as a plausible scenario. If we do not globally implement rising-stringency climate policy past 2030, the worsening effects of climate change will also affect economic activity and these economic effects are not reflected in *annPol*.

For example, a recent study by the Canadian Climate Institute estimates that if we in Canada and the rest of the planet continue emitting GHGs, such as what would occur in *annPol*, the GDP value could be three percent lower by mid-century and up to 12% lower by the end of the century relative to a scenario where climate policy achieves a stable climate (Sawyer et al., 2022b). Indeed, the Intergovernmental Panel on Climate Change suggests that the economic impacts of climate change could be even greater than this by mid-century (Calvin et al., 2023).

Thus, I rarely refer to the *annPol* scenario when discussing the results. Instead, its purpose is as a comparison tool to isolate the effects of net zero policy, thus providing an initial baseline. As a reminder of the limitations of the *annPol* scenario, I have added a dashed line on *annPol* in the GDP figures, which shows the estimated effect of climate change without GHG reductions on GDP by mid-century from the Canadian Climate Institute study. I calculate the three percent loss according to the *NetZero* (climate policy scenario achieving a stable climate) GDP value in 2050. The estimate is approximate and from a study using different scenarios and assumptions, and therefore should be interpreted accordingly.

Figure 1. GDP in Alberta and Saskatchewan in 2050



When looking at the region as a whole, the first takeaway, which is in line with the PPF study results, is that while the rate of growth may differ, the economy of the region is projected to continue growing in all scenarios relative to current levels in 2020. Net zero policy may somewhat slow growth for our oil and gas endowed region relative to a global continuation of unabated fossil fuel combustion (unadjusted *annPol)*, but this effect could be more than offset by plausible opportunities arising in the energy transition *(NetZero*+). As one can see, when I account for plausible growth in key sectors, the simulated GDP growth in *NetZero*+ exceeds both the unrealistically high and downward corrected GDP values in *annPol* in 2050.

Secondly, the economic structure of the region does not change dramatically between the two net zero scenarios although there is some shuffling between industries. While there is obviously more economic activity in the sectors I projected to grow, there are also ripple effects in other sectors. For instance, with more activity in DAC, mineral mining, CCS, and other related sectors, there is more activity in the construction sector relative to *NetZero.*

Furthermore, oil and gas still make up a significant portion of the region's economy in a net zero 2050. Fossil fuels and GHG emissions are related, but they are not linked one-to-one, meaning that oil and gas production can realistically continue in a net zero future if these primary energy inputs are converted to electricity, hydrogen, and synthetic fuels with near-100% CCS, with perhaps some residual emissions offset via technologies like DAC with carbon storage and bioenergy with carbon capture and storage (BECCS). When I promote growth in CCS, DAC, and zero-emission hydrogen production from natural gas, there is more economic activity in the oil and gas sector. As such, one can note an associated increase in economic activity in utilities (primarily in electricity generated from fossil fuels with CCS) and hydrogen between the two net zero scenarios. This provides insight into the potential for the oil and gas industry to reinvent itself away from unabated burning of fossil fuels and to contribute and perhaps thrive in a net zero world, especially by producing zero-emissions electricity and hydrogen.

Most of the differences in economic activity between scenarios are intuitive and based on changes I made in *NetZero+.* However, there are some results that are less straightforward and require a deeper analysis to understand. One example is that the region sees changes in emissions, GDP, and jobs for services and manufacturing between the two net zero scenarios. The decrease in activity in services is likely the result of changes I simulated as well as the effects of the full-equilibrium dynamics of the model. Minor shuffling of capital and labour between sectors could be attributed to the model trying to achieve equilibrium after I changed values to account for growth in certain sectors.

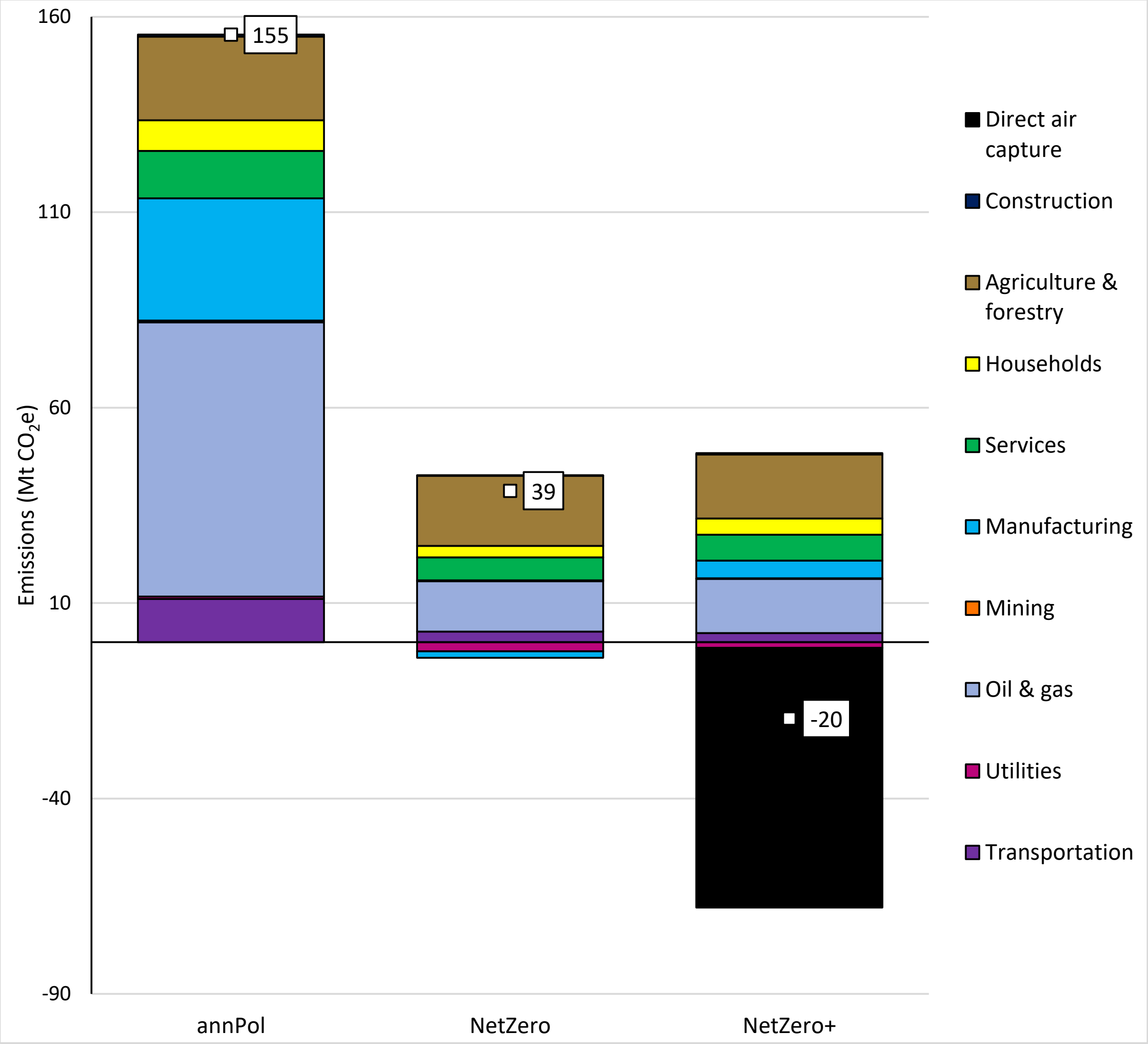
Alternatively, the change in manufacturing is the result of an interesting interplay between the growth I simulated for the key Canadian sectors and interactions with the U.S. economy. The main decreases in manufacturing are seen in machinery and electric products, which are important elements of the energy transition. In the PPF net zero scenario, Canada has policies to achieve net zero but the U.S. does not. As such the U.S. is not incentivized to manufacture products that help achieve net zero and it is more economical for Canadian firms to manufacture their own machinery and electric products. In *NetZero+,* I assume stringent climate policy in the U.S. and promote growth in key sectors. As a result, it becomes more expensive to produce manufactured goods because capital and labour are directed to the new and emerging sectors in which I triggered growth, such as mineral mining. At the same time, widespread production of manufactured goods in the U.S. reduces the cost of manufacturing machinery and electric products, which enables firms in Alberta and Saskatchewan to import lower cost versions of these products from the U.S.

However, while both provinces are in substantial ways similarly affected by the net zero energy transition, there are some notable differences. These differences highlight the potential for diversified economic development in the two provinces as well as some of the underlying challenges I faced when conducting the study. I next explore province-specific changes in emissions, GDP, and jobs in 2050. In response to the net zero policies I simulate in *NetZero* and *NetZero+*, each province acts to achieve net zero in Canada through the cheapest path.

5.3 Emissions in Alberta

In Figure 2, I break out emissions by sector for Alberta in 2050 for the three scenarios. While in *NetZero,* Alberta is the highest emitter in Canada, in *NetZero+*, the province is the lowest emitter, with negative emissions. The main driver for the change in emissions is the assumption that DAC is available. Recall that the intermediate sensitivity in the PPF net zero scenario assumes DAC is unavailable. With DAC available and with the CCS tax credit reducing production costs, the technology contributes to the Canadian economy and is dominant in Alberta. Similarly, emissions abatement from point source CCS technologies is significantly higher between the two net zero scenarios and is dominant in Alberta.

Figure 2. Emissions in Alberta in 2050



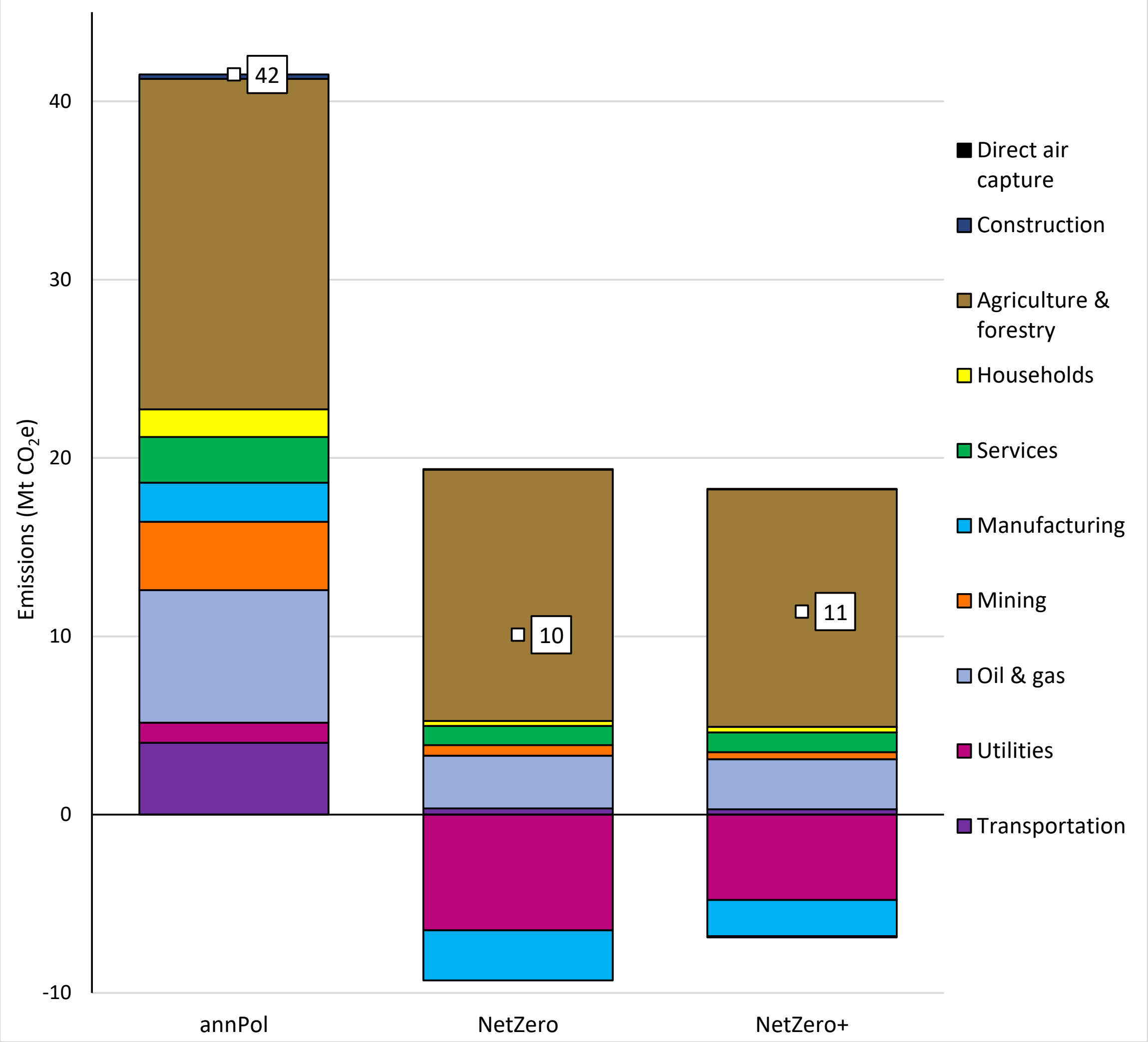
To reflect anticipated growth while also accounting for uncertainty, I promoted growth in DAC with carbon storage and point source CCS by simulating a tax credit policy that helps reduce production costs. As such, the model determined internally where industry was likely to allocate the two technologies based on cost and suitability. While evidence shows that Saskatchewan has potential to have significant DAC with carbon storage and point source CCS uptake on the road to net zero, Alberta is considered a more suitable location given existing conditions in the model such as geological storage and prospects for CO_2 pipelines linking sources and storage sites. Geological storage for CO_2 in gTech is based on availability and proximity to depleted oil beds and is assumed to be concentrated in Alberta. As a result, the model did not distribute DAC with carbon storage and point source CCS evenly between the two provinces, even though both have substantial storage potential since they both are in the Western Sedimentary Basin. Nonetheless, this provides insights into the potential for DAC with carbon storage and point source CCS as economic opportunities in Canada's oil and gas endowed region comprised of Alberta and Saskatchewan.

This also reflects the challenges of modeling discussed earlier, where if a region does not currently have extensive development of a new energy transition technology or the infrastructure to support the development, it is difficult for the technology to achieve deployment in a given model simulation. While the goal was to overcome these types of challenges by enabling growth in key sectors, I was constrained by the inherent nature of CGE models - the equilibrium interconnectedness of the economy. To adequately represent plausible growth in DAC with carbon storage and point source CCS in both provinces, I may have needed to further adjust the underlying storage capacity assumptions. I explore these interactions further by looking at changes in emissions in Saskatchewan.

5.4 Emissions in Saskatchewan

Figure 3 shows emissions by sector for Saskatchewan in 2050 for the three scenarios. Despite growing sectors that contribute to emissions abatement in *NetZero+,* such as point source CCS, and hydrogen with CCS, there are fewer negative emissions and overall emissions are slightly higher (11 Mt) relative to *NetZero* (10 Mt).

Figure 3. Emissions in Saskatchewan in 2050



While the breakdown of emissions is relatively similar between the two net zero scenarios, there are discrete shifts between mineral mining, utilities, and manufacturing because of the changes I made in *NetZero+*. In *NetZero,* electricity generation (utilities) and manufacturing generate negative emissions through BECCS, a process that uses biomass as fuel and captures and stores the resulting emissions.

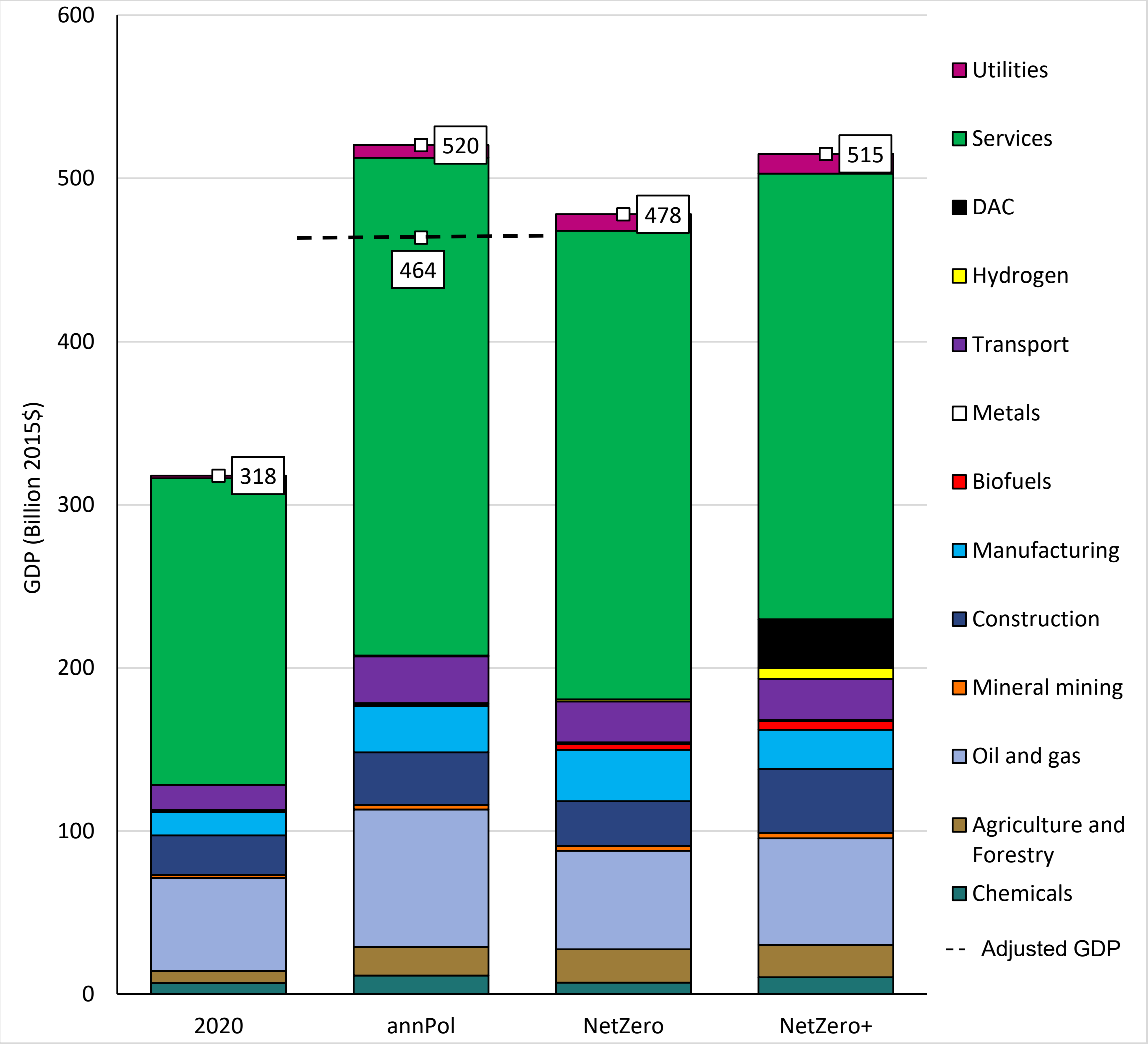
According to the model simulations, in a net zero economy, bioenergy is also a major fuel source for mineral mining operations. When I increase output for mineral mining in *NetZero+*, the sector requires more bioenergy to meet the output requirements while also reducing emissions. The net zero policies I model are designed to achieve net zero while also minimizing Canada-wide GHG emission reduction costs. With the combination of growth in mineral mining and the net zero policies, it is more economical for firms to use bioenergy for mineral mining and shift to using renewables for electricity generation, which is zero-emissions instead of negative, and decrease manufacturing output. As a result, emissions are lower for mineral mining (despite output increasing), and there are fewer negative emissions from utilities and manufacturing.

As mentioned above, given the underlying assumptions in the model, Saskatchewan is considered less suitable for DAC. Therefore, firms address the residual emissions in the Saskatchewan economy by relying on the small amount of DAC with carbon storage in Saskatchewan while also paying for an extensive amount of DAC in Alberta. This can occur because the net zero policies I simulate are designed to minimize Canada-wide GHG emissions reduction costs while also allowing for emission-credit trading between regions to achieve the emissions goals. Some of the residual emissions may also be offset by the LULUCF offset assumptions included in the model. These types of interactions are increasingly apparent when exploring changes to GDP and jobs.

5.5 GDP in Alberta

Figure 4 shows the breakdown of GDP by sector in Alberta under the three scenarios in 2050. I include a dotted line across the *annPol* column as in the earlier GDP figure to show one estimate of the highly uncertain GDP reductions likely from wildfires, droughts, floods, storms, diseases, and other catastrophic events that scientists agree are already happening because of climate change and that will intensify in the coming decades without net zero policy. My simulated GDP results for Alberta are similar to the emissions findings in terms of how the scenarios compare to each other. GDP grows substantially from 2020 to 2050 in all scenarios. While the *NetZero* simulated future still has economic growth, but slightly less, *NetZero+* sees virtually the same growth as the unadjusted *annPol* and more growth than the more realistic *annPol*, albeit in a far more sustainable, lower-risk future.

Figure 4. GDP in Alberta in 2050



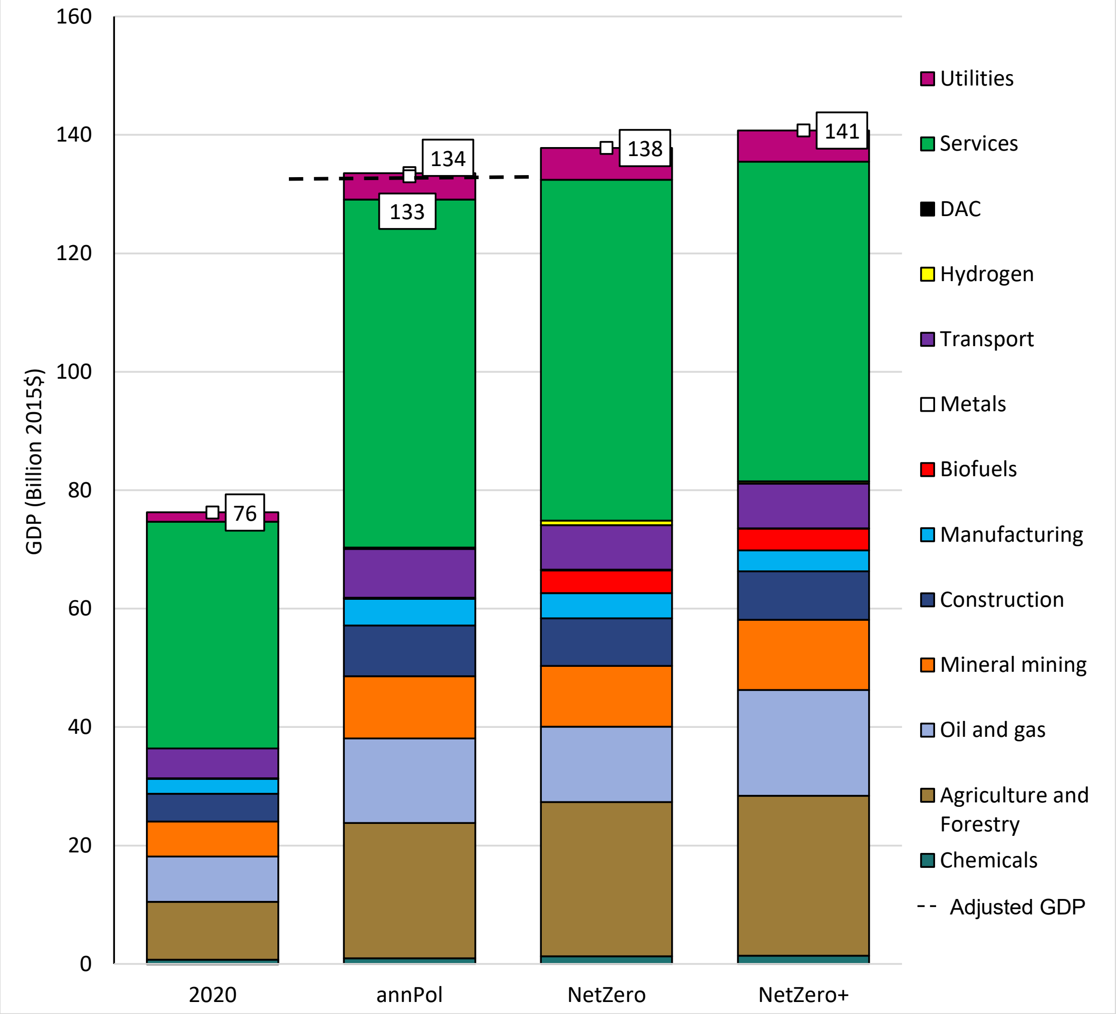
With the addition of plausible growth in key sectors, the overall GDP value in 2050 is three percent higher than the PPF net zero scenario. In particular, the GDP value is higher for oil and gas, construction, DAC with carbon storage, and hydrogen with CCS. The changes in DAC with carbon storage and hydrogen with CCS can be explained by the growth I simulated in these sectors as well as the abundance of geological storage capacity and natural gas deposits. Alberta has a more dominant oil and gas industry, and as a result more natural gas production – the main input for this type of hydrogen. While making hydrogen can be a relatively expensive process initially, the combination of net zero policy, as well as the investment tax credits for CCS and hydrogen potentially reducing production costs for hydrogen and CCS, make the energy source more economical in a net zero 2050 in Alberta.

The differences in GDP in oil and gas and construction are likely the effects of the assumptions I made in *NetZero+*. For instance, I simulated policies that aim to reduce production costs for sectors that help decarbonize and sustain the oil and gas sector in a net zero world – DAC with carbon storage, point source CCS, and hydrogen with CCS. Likewise, with an increase in activity in these sectors, there will likely be a need for more construction projects and therefore more GDP generated from the industry.

5.6 GDP in Saskatchewan

Similar to its emissions simulations, the changes in GDP in Saskatchewan are more nuanced. Figure 5 shows the breakdown of GDP by sector in the three scenarios in 2050. GDP grows substantially from 2020 to 2050 in all scenarios and grows the most in *NetZero+*, even compared to the unadjusted *annPol*. Saskatchewan generates noticeably more GDP from biofuels and agriculture under net zero policy relative to the announced policy scenario in 2050. Given that the unadjusted *annPol* scenario does not account for the negative economic effects that would occur as a result of the increasing consequences of climate change, it is interesting that *NetZero* has a higher GDP value in 2050. With the addition of plausible growth in key sectors, the GDP value in 2050 is two percent higher in *NetZero+* than in *NetZero*. In particular, the GDP values for mineral mining, oil and gas, and agriculture are higher.

Figure 5. GDP in Saskatchewan in 2050



Mineral mining is explained by the increase in output I simulated for the sector. On the other hand, there is likely more GDP from oil and gas because of the CCS investment tax credit. As such, it is more economical for firms in Saskatchewan to rely on these abatement technologies to offset emissions and sustain production.

In the two net zero scenarios, agriculture is dominant in Saskatchewan and accounts for over 27% of Canada's GDP from agriculture. With an increasing need for biofuels in North America to achieve net zero emissions, Saskatchewan's agricultural land, especially for inputs to ethanol such as corn and canola, increases in value. Furthermore, the agriculture sector provides inputs for other sectors like chemicals, manufacturing, biofuels, mineral mining, and oil and gas. In *NetZero*, the province is incentivized to expand agriculture. Moreover, with the addition of growth in other sectors such as mineral mining and oil and gas in *NetZero+*, there is even more demand for agricultural land and outputs, and therefore, more economic activity in the sector.

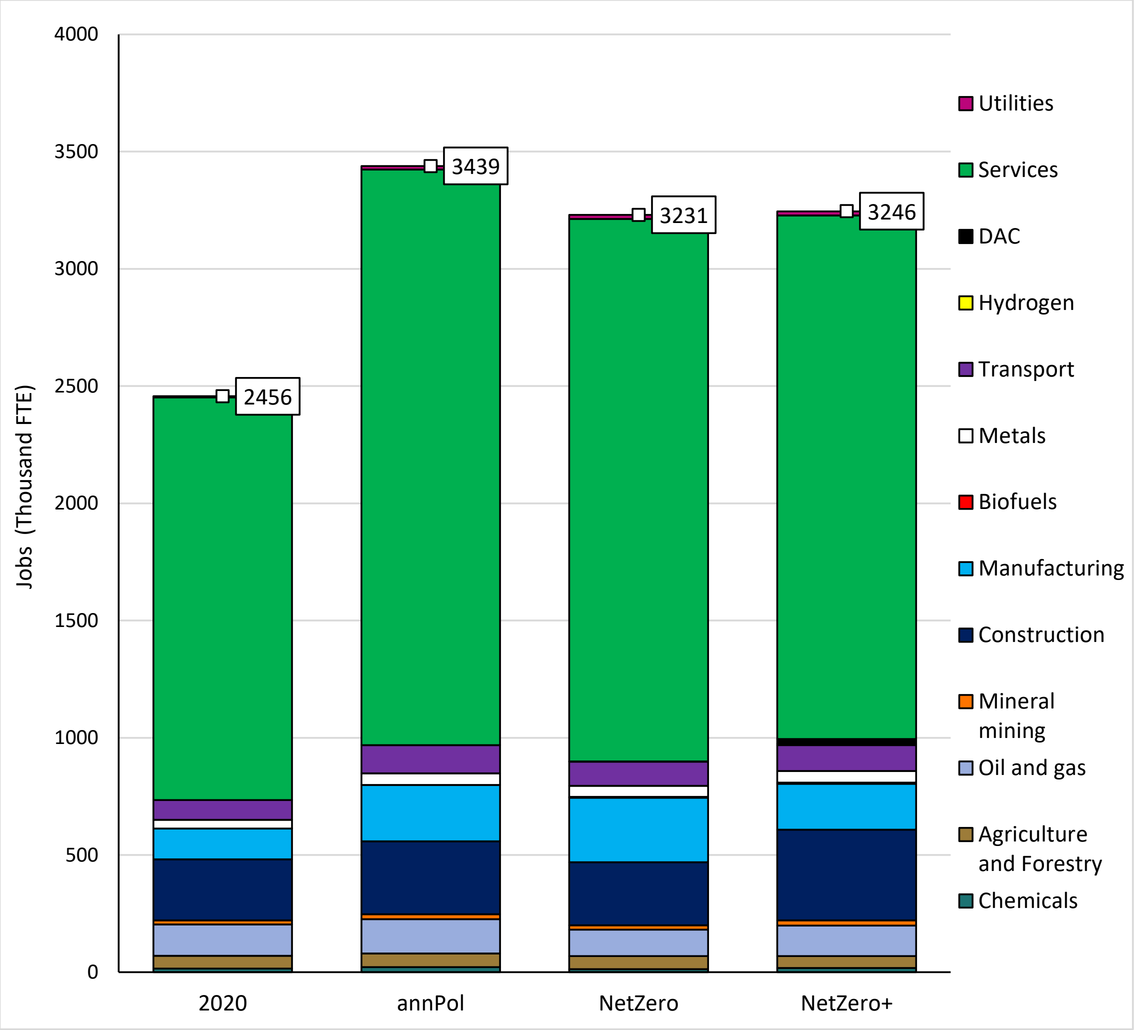
Finally, GDP being lower for hydrogen is further evidence of some of the challenges I faced when conducting this study. Because I did not exogenously set economic growth in each province, the model internally allocated growth based on suitability and cost. The combination of existing assumptions in the model, such as less natural gas in Saskatchewan relative to Alberta, net zero policies that aim to minimize the cost of achieving net zero, and the growth I promoted in other sectors, resulted in it being more economical to reduce hydrogen production and use the natural gas inputs for other industries in Saskatchewan. However, these results may suggest that hydrogen with CCS has lower prospects in Saskatchewan relative to other economic opportunities on the path to net zero. To explore these GDP changes further, I next discuss changes to employment in 2050.

5.7 Jobs in Alberta

Figure 6 shows jobs in Alberta in 2050 for the three scenarios. Similar to the emissions and GDP findings, the most noticeable differences in jobs between the two net zero scenarios are seen in DAC, transportation, construction, and oil and gas. While there are fewer overall jobs in services and manufacturing in 2050, the increases in the above sectors result in an overall increase in the number of jobs in the Alberta economy.

As previously discussed, changes to DAC and oil and gas are explained by the growth assumptions I simulated. While there are slight changes to emissions and GDP for transportation and construction, the changes are most obvious when looking at employment. The increase in transportation and construction jobs are related and are the result of increased activity in mineral mining, oil and gas, hydrogen, and CCS. The main increase in transportation jobs is seen in ‘other transportation’, which is transportation related to on-site transportation for sectors like mineral mining and oil and gas. Likewise, the energy transition will require construction to establish new projects, facilities, and sites related to the sectors I grew. As such, the construction sector has potential to create significant economic opportunities for Alberta on the road to net zero.

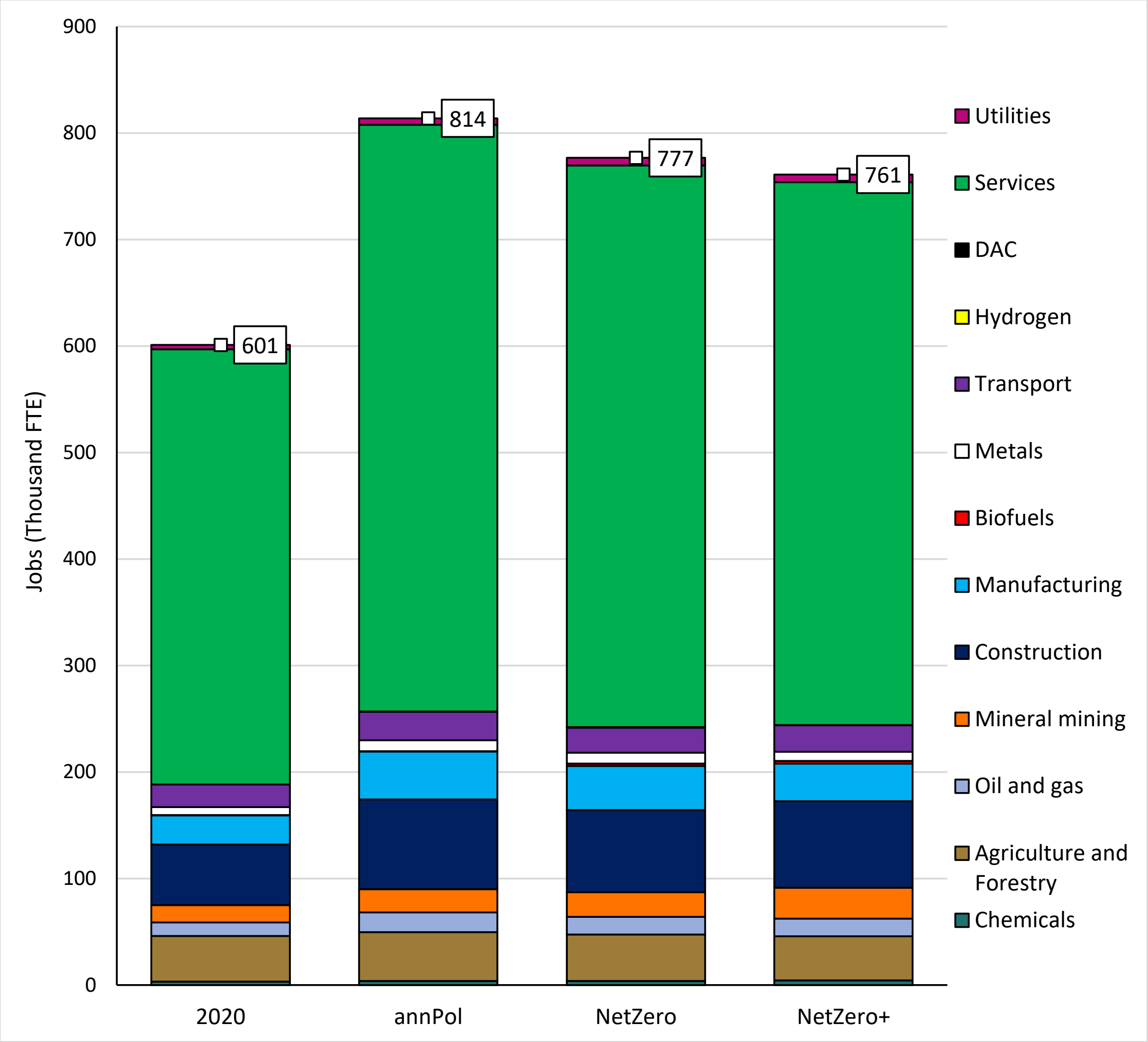
Figure 6. Jobs in Alberta in 2050



5.8 Jobs in Saskatchewan

Figure 7 shows jobs in Saskatchewan in 2050 for the three scenarios. Similar to the other metrics analyzed, changes in mineral mining jobs are a direct response to the growth I simulated. Likewise, changes to construction and transportation are responses to the increased activity in sectors that require construction and transportation.

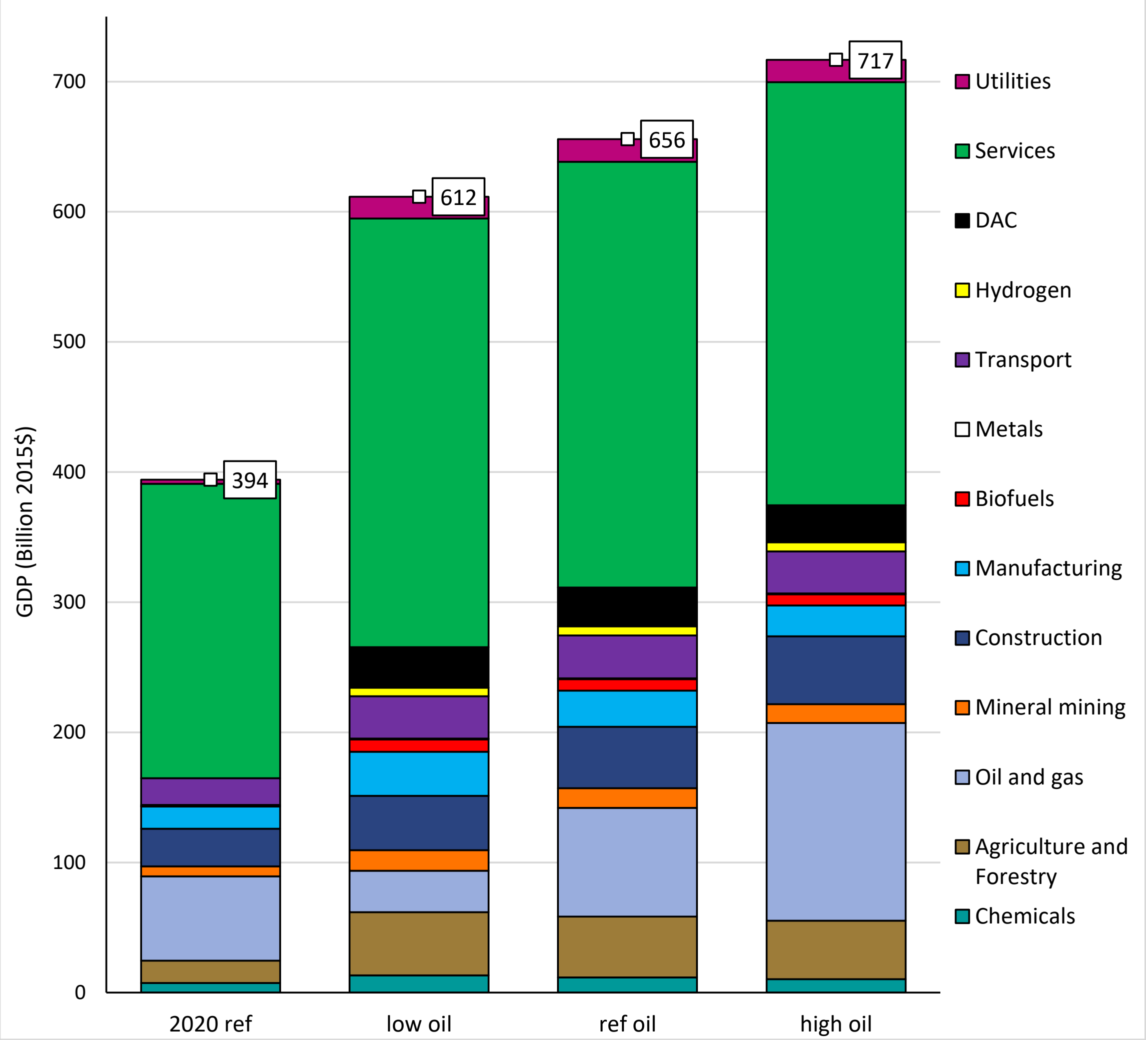
Figure 7. Jobs in Saskatchewan in 2050



5.9 Exploring Oil Price Uncertainty

Lastly, I explored uncertainty around future global oil prices. Obviously, oil price has a significant impact on economic outcomes for Canada's oil and gas sector. Given the significance as well as uncertainty of future global oil prices, the following analysis explores how economic activity may change in response to different oil prices in 2050. I explore how a low and high oil price could influence economic activity in our oil and gas endowed region when there is net zero policy. Figure 8 shows the breakdown of GDP in the region under the three oil price assumptions in *NetZero+* in 2050. Both provinces see more GDP from oil and gas and related industries under a higher global oil price.

Figure 8. GDP in the Region in 2050 Under Different Oil Prices in NetZero+



A higher oil price is typically associated with ongoing high demand for refined petroleum products which are combusted without CCS, causing GHG emissions. However, in a net zero 2050 future that still has high oil demand and high oil prices, the use of oil must be associated with one or more of the following processes and products: 1) ongoing conversion of oil to electricity or hydrogen with point source CCS, 2) ongoing use of oil as a material feedstock for the production of non-energy (recyclable) products like lubricants, plastics, asphalt, concrete, and other material goods, and 3) ongoing combustion of RPPs whose GHG emissions are offset by DAC with carbon storage. As expected, a higher oil price results in more economic growth for Alberta and

Saskatchewan because it causes more economic activity in the oil and gas industry and overall economy.

5.10 Summary of Results

My simulation results provide a plausible depiction of economic opportunities that could arise in Canada’s oil and gas endowed region under the energy transition. The first takeaway of my study is that the energy transition does not halt economic growth. While *NetZero* still achieves healthy economic growth, it should be viewed alongside *NetZero+,* a scenario that accounts for growth in key sectors needed in the energy transition while also considering climate action in the U.S.

The simulation outputs reveal that there is obviously more economic activity in the sectors I adjusted but also ripple effects in the rest of the economy. For instance, in a net zero 2050, there is potential for continued oil and gas production if firms decarbonize their processes, produce zero-emission electricity and hydrogen with CCS, and/or offset some emissions with DAC or BECCS. When I simulated growth in related sectors, the oil and gas industry saw more economic activity relative to *NetZero,* primarily through its contribution to zero-emissions electricity generation and hydrogen production. And, as expected, a higher oil price results in more economic growth for the region because it causes more economic activity in the oil and gas industry and overall economy.

Overall, the economic structure of the two provinces does not differ when I account for plausible growth in key sectors but there are notable shifts between sectors with the additional assumptions I include in *NetZero+*. While most of the changes can be directly associated with newly favoured sectors and assumptions I added, some changes, such as those in manufacturing and services, are the results of more complex interactions within an economy that is perpetually re-adjusting towards equilibrium.

Lastly, both provinces are in substantial ways similarly affected by the net zero energy transition, but there are some key differences. For instance, Alberta saw more economic activity in oil and gas related sectors such as DAC with carbon storage, point source CCS, and hydrogen with CCS, and related industries like construction and transportation given the province’s existing infrastructure, resources, and expertise. On the other hand, Saskatchewan also saw more economic activity in oil and gas related sectors as well as in sectors needed for the energy transition such as mineral mining and agriculture. These findings provide insight into the potential roles these provinces can play as well as the diversified opportunities in a net zero world. I explore study limitations in the following section.

6. Limitations and Further Research

6.1 Modeling Method

While I have discussed some of the limitations of this study throughout the report, the section summarizes the main limitations and provides insight on how to potentially address them moving forward. To begin, modeling in general is limited because models provide a simplification of the real world and cannot accurately reflect reality or predict the future. This will always be a limitation of modeling, and as such, the outputs from this study should be viewed as possible scenarios that could occur rather than fact.

My goal of this study was to overcome some of the limitations of recent net zero studies by exploring a plausible growth scenario in the energy transition to net zero. I chose to use the same CGE model, gTech, for ease of comparison between studies, especially in terms of long-run GDP changes, as well as to explore key elements of the energy transition that are missing in technologically vague energy-economy models, such as the availability of DAC and interactions with the U.S. While gTech was an appropriate model to use for these reasons, there were also challenges.

As noted in the energy-economy model section, everything is connected in the economy in a CGE model – inputs must equal outputs and supply must equal demand. When increasing output (supply) of a sector, a lack of demand farther down the supply chain can limit how much a sector can grow. For instance, when I tried to increase non-metallic mineral mining in Alberta, the model would not let me increase output in Alberta by more than 25% above 2020 levels in 2050 because there was not enough demand for sand and gravel (the existing non-metallic mineral resources in Alberta) in 2050. To account for these dynamics, I would likely have needed to change the demand side as well or simulate material trade linkages with other jurisdictions. However, changing demand may have had ripple effects and unintended reactions in other industries. For reasons like these, CGE models can be challenging to apply and interpret (Böhringer et al., 2003).

6.2 Simulation Assumptions

There are also limitations in how I conducted the study. I grew the existing mineral mining output in gTech to simulate how a mineral mining sector could potentially contribute to the net zero economy. While I grew the output by a realistic amount, I did not account for growth in emerging mineral resources such as lithium. This likely contributed to why I could not grow the Alberta mineral sector to the desired output. Future research could integrate the emerging critical minerals outlined in the *Canadian Critical Minerals Strategy* as well as the associated demand into gTech.

Another consideration worth exploring further is the use of tax credits versus manually growing output for certain sectors. Both approaches had their associated challenges, and one is not necessarily better than the other. For mineral mining, I manually increased output in 2050 for Alberta and Saskatchewan to levels I deemed plausible through my literature research. On the other hand, I simulated growth for DAC with carbon storage, point source CCS, and hydrogen with CCS through the economy-wide investment tax credits that the federal government has proposed. While manually increasing output is more likely to guarantee the desired growth in the sector and province, I was less confident when manually changing output for these sectors and wanted to incorporate some credibility for my assumptions by simulating existing or proposed policies, especially for DAC. While I may not have achieved the plausible outcome in both provinces for certain sectors, this approach of simulating interactions internally through tax credits enabled some interesting insights about differences in economic opportunities between the provinces.

6.3 Other Limitations

There are also other underlying challenges of applying a general equilibrium model to address my research question. For instance, between provinces, there is no movement of labour based on changes in wages. If wages in Alberta decrease because there is less demand for employment in oil and gas, the model does not account for labour moving from Alberta to another region in response to this wage change. On the other hand, the model assumes perfect mobility between occupations within the region or province being modeled. Thus, if wages change within an occupation, the model assumes labour will move to that occupation and not create unemployment. These assumptions may not provide an accurate representation of how employment will change or move under net zero policy, especially in our oil and gas endowed region.

Furthermore, there are limitations associated with the structure of the CCS tax credit policy. Under the proposed policy, enhanced oil recovery does not qualify for the tax credit because it reuses CO_2 rather than storing it. When conducting this study, gTech did not differentiate CO_2 that is stored and CO_2 that is reused for enhanced oil recovery. The distribution of what makes up the oil and gas industry in 2050 would likely look different if the CCS tax credit in the model did not apply to enhanced oil recovery.

A final noteworthy limitation is the quantitative nature of energy-economy analyses. Given that I used a quantitative modeling tool, I only looked at quantifiable metrics such as jobs, GDP, and GHG emissions. I did not assess qualitative metrics or considerations that are an important part of the energy transition. Some of these qualitative considerations include individual and community identity associated with certain industries that may decline on the road to net zero, family hardships associated with shifting industries or locations, and negative environmental and social impacts of new industries such as mineral mines.

7. Conclusion

In this study I explored the possible effects of net zero on economic activity in Canada's oil and gas endowed region. To this end, I applied a quantitative energy-economy model to explore the 1) effects of net zero policy in our oil and gas endowed region and 2) potential economic opportunities for this region under net zero policy by promoting growth in some of the emerging energy resources and technologies.

The sectors, processes, and technologies I explored include DAC with carbon storage, point source CCS, hydrogen produced from natural gas with CCS, bioenergy production, electricity production with CCS, and expanded mineral mining. Notably, to account for underrepresentation in recent studies, I simulated growth in DAC with carbon storage, point source CCS, and hydrogen produced from natural gas with CCS to better represent plausible opportunities in these sectors as well as how they could contribute to creating opportunities in other processes such as electricity production from fossil fuels with CCS.

The goal of this study was to address some of the limitations of recent energy-economy analyses and provide a plausible portrayal of economic opportunities arising from the energy transition. For ease of comparison, I used the same general equilibrium energy-economy model, gTech, that had been used in other recent GHG reduction simulations for Canada's oil and gas endowed region. However, throughout the process of executing and then analyzing the simulation outputs, I became more aware of challenges in using a general equilibrium model for this type of study. In particular, applying exogenous stimuli to an economy caused by entirely new demands for materials and equipment during the net zero energy transition are a challenge to execute fully in a general equilibrium framework. Nonetheless, this study still provides useful insights and serves as an important starting point to explore realistic representations of the effect of plausible economic opportunities in the energy transition.

While *NetZero* still achieves healthy economic growth, it should be viewed alongside *NetZero+,* a scenario where the region is able to position itself for the economy of the future. Representing realistic growth in the key sectors provides an assessment of what could happen in this region triggered by the energy transition, notably more economic growth than what has been portrayed in recent studies. While the overall structure of the economies of Alberta and Saskatchewan remains relatively similar, Alberta could see more economic activity in oil and gas related sectors such as DAC with carbon storage, point source CCS, and hydrogen produced from natural gas with CCS. At the same time, growth in these sectors can also spur more activity in construction and transportation. On the other hand, Saskatchewan could maintain economic activity in oil and gas related sectors as well as grow alternative and important sectors needed for the energy transition such as mineral mining and agriculture.

This study highlights the important role Canada's oil and gas endowed region can play in the energy transition. On one hand, the region has potential to reinvent its oil and gas industry and energy system away from unabated combustion of fossil fuels by using oil and gas with CCS to create zero-emissions electricity and hydrogen. On the other hand, the region could also benefit from expanding other sectors like minerals and agriculture that contribute to the inputs we need for the energy transition with biofuels and solar panels. Ultimately, despite previous narratives recounting the negative effects of the energy transition for this region, it has potential to not only participate but also thrive in a net zero future. Net zero does not necessarily mean the end of the current resources, expertise, and infrastructure in Canada’s oil and gas endowed region. Old and new energy sources and technologies can exist on the path to net zero and in the ultimate net zero future. And while stringent economy-wide policy is necessary to achieve net zero by 2050, both provinces are equipped to navigate the energy transition.

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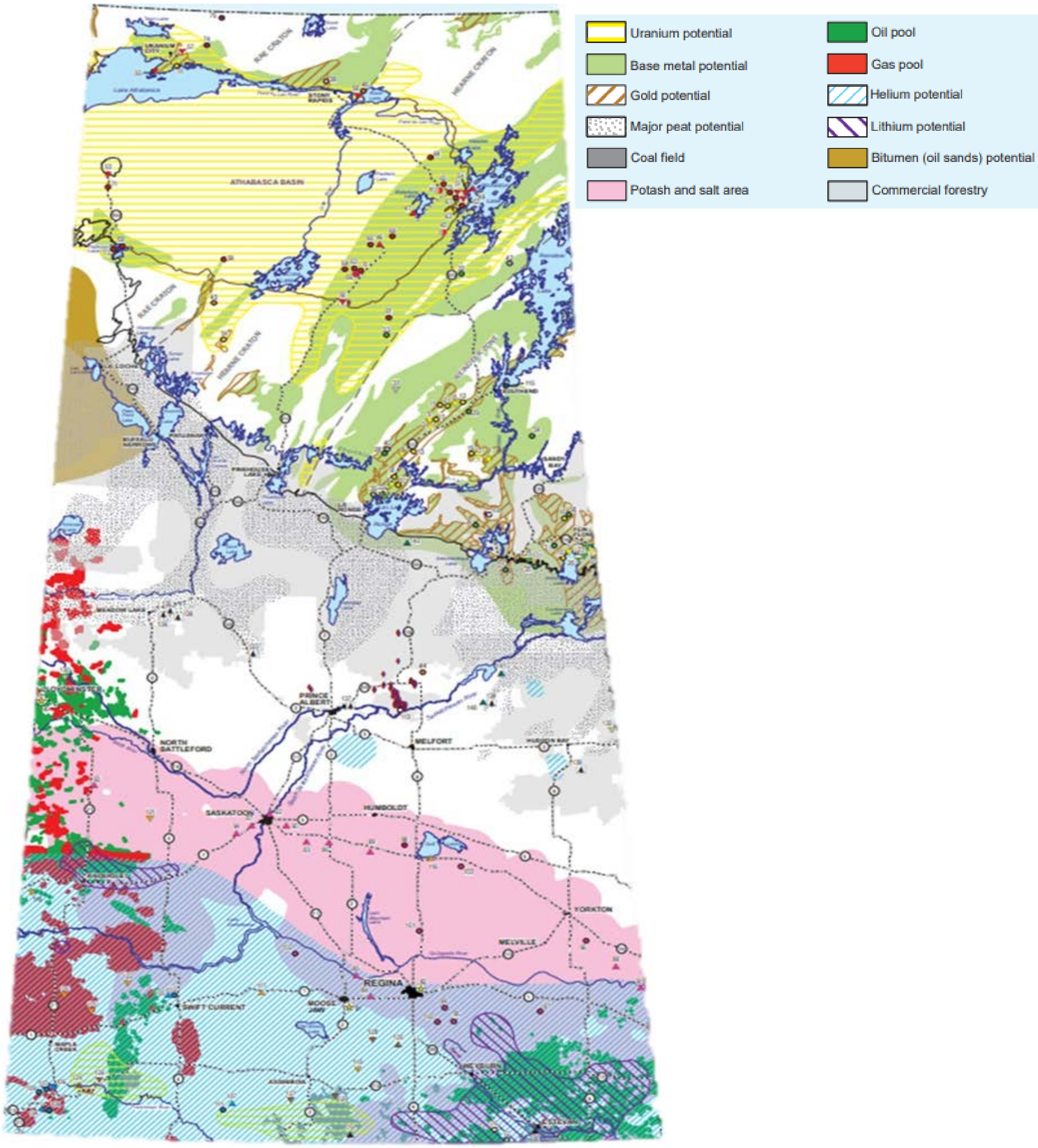
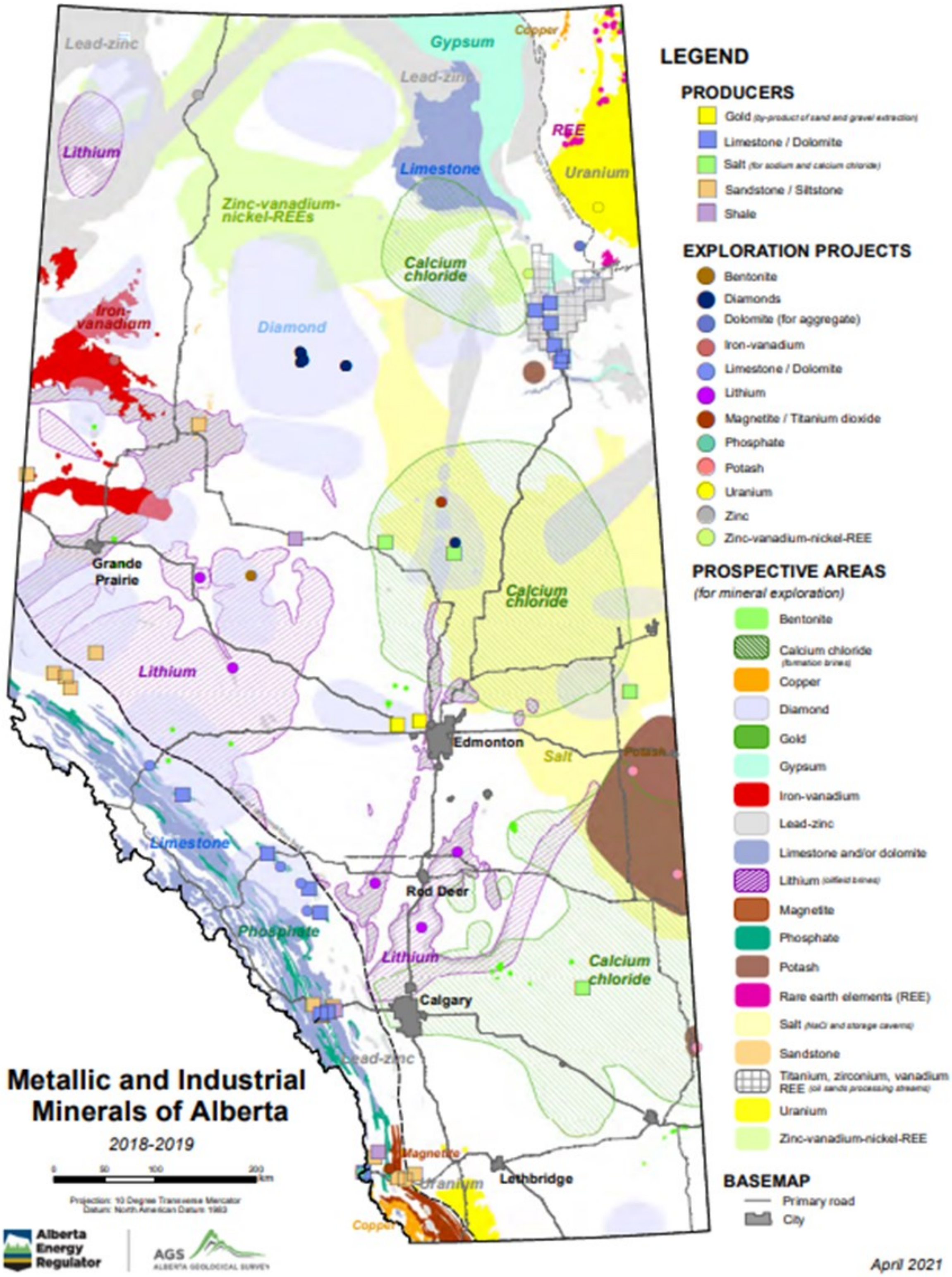
Appendix A - Prospective Minerals

Figure A.1. Map of Prospective Minerals in Saskatchewan



Note. Adapted from Government of Saskatchewan. (2021). Resource Map. https://er-saskatchewan.hub.arcgis.com/maps/ae2640f3ecf64e69a317d25cece224d2. Copyright 2021 Government of Saskatchewan

Figure A.2. Map of Prospective Minerals in Alberta



Note. Adapted from Alberta Energy Regulator. (2021, April). *Minerals of Alberta*. Alberta Geological Survey. https://ags.aer.ca/publication/map-590. Copyright 2021 by Alberta Energy Regulator.

Appendix B - CCS Technologies and Costs in gTech

Table B.1. Current CCS Technology Costs in gTech

CCS Technologies current (first of a kind)	**Levelized reference cost (2020 CAD/tCO_2 captured)**
Co-generation (natural gas with CCS)	221.2
Cement heat (coal with CCS)	151.3
Cement heat (natural gas with CCS)	221.1
Industrial heat (coal with CCS)	141.7
Industrial heat (natural with CCS)	221.2
Low-temperature industrial heat (coal with CCS)	147.7
Low-temperature industrial heat (natural gas with CCS)	221.2
Hydrogen with CCS production (with CCS)	100.5
Formation CO_2 (with CCS)	49.0
Electricity generation (new coal with CCS)	146.4
Electricity generation (new combined cycle gas turbine with CCS)	215.6

Note. Adapted from Förg et al. (2023). *Analyzing Net Zero Pathways for Canada*. Navius Research Inc. https://www.naviusresearch.com/publications/net_zero_pathways/. Copyright 2021 by Navius Research Inc.

Table B.2. Future CCS Technology Costs in gTech

CCS Technologies Future (nth of a kind)	**Levelized reference cost (2020 CAD/tCO_2 captured)**
Co-generation (natural gas with CCS)	127.0
Cement heat (coal with CCS)	87.2
Cement heat (natural gas with CCS)	106.7
Industrial heat (coal with CCS)	75.1
Industrial heat (natural gas with CCS)	126.4
Low-temperature industrial heat (coal with CCS)	75.1
Low-temperature industrial heat (natural gas with CCS)	126.4
Hydrogen with CCS production (with CCS)	96.5
Formation CO_2 (with CCS)	27.0
Electricity generation (new coal with CCS)	106.2
Electricity generation (new combined cycle gas turbine with CCS)	150.7

Note. Adapted from Förg et al. (2023). *Analyzing Net Zero Pathways for Canada*. Navius Research Inc. https://www.naviusresearch.com/publications/net_zero_pathways/. Copyright 2021 by Navius Research Inc.

Appendix C - WTI Oil Price Assumptions

Table C.1. WTI Oil Price Forecast Assumptions in gTech (2020 USD/barrel)

Sensitivity	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Low	39.5	37.1	36.2	35.9	35.6	35.1
Reference	68.9	67.8	66.2	65.7	65.1	64.1
High	97.5	93.1	90.9	90.2	89.5	88.0

Note. From Förg et al. (2023). *Analyzing Net Zero Pathways for Canada*. Navius Research Inc. https://www.naviusresearch.com/publications/net_zero_pathways/. Copyright 2021 by Navius Research Inc.

Appendix D - Policies Modeled

Table D.1. Announced Policies Modeled

Policy	**Jurisdiction**
Federal Fuel Charge	National
Output-Based Pricing System	National
GHG Emissions Cap on Oil and Gas Sector	National
75% Reduction in Oil and Gas Methane Emissions	National
Low Carbon Electricity Standard	National
Waste Methane Capture	National
Low Carbon Fuel Regulations	National
Light-Duty Vehicles Emissions Standard	National
Medium-and Heavy-Duty Vehicle Emissions Standard	National
National Net Zero Emissions Building Strategy	National
CCS Investment Tax Credit	National
Canada Infrastructure Bank Spending	National
Net Zero Accelerator	National
Zero Emissions Vehicle Tax Write-Off	National
Incentives for Zero Emissions Vehicle Program	National
Funding for Charging Stations	National
Large Truck Retrofits	National
Interest-Free Home Retrofit Loan	National
Residential Efficiency Retrofits	National
Replace Home-Heating Oil	National
Community Buildings Upgrade	National
Hydrogen Projects	Alberta
Ontario Steel Plant Upgrades	Ontario

Table D.2. Legislated Policies Modeled

Policy	Jurisdiction
Carbon Pollution Pricing Backstop	All provinces/territories except B.C., Northwest Territories, and Quebec
Energy efficiency regulations	National
Green Freight Assessment Program	National
Hydrofluorocarbon Controls	National
Light-Duty Zero Emissions Vehicle subsidy	National
Regulations Amending the Heavy-duty Vehicle and Engine GHG Emission	National
Regulations Amending the Passenger Automobile and Light Truck GHG Emission	National
Regulations Amending the Reduction of CO_2 Emissions from Coal-fired Generation of Electricity	National
Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity	National
Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds	National
Renewable Fuels Regulation	National
Zero Emissions Vehicle Tax Write-Off	National
Zero Emissions Vehicle Infrastructure Program	National
Capping oil sands emissions	Alberta
Carbon tax	British Columbia
Low carbon energy act	British Columbia
Light-Duty ZEV subsidies	British Columbia
Low Carbon Fuel Requirement Regulation	British Columbia
PST Exemption	British Columbia
Renewable natural gas regulation	British Columbia
Specialty Use Vehicle Inventive	British Columbia
Zero Emissions Vehicle Standard	British Columbia
Biofuels Mandate Amendment	Manitoba
Coal Phaseout	Manitoba
Efficient Trucking Program	Manitoba
Keeyask Hydro-electricity Project	Manitoba
Renewable Portfolio Standard	New Brunswick
Freight Transportation Fuel Efficiency Program	Newfoundland and Labrador
Muskrat Falls Hydro Project	Newfoundland and Labrador
Cap-and-Trade Program,	Nova Scotia
Cap on GHG emissions from electricity generation	Nova Scotia
Renewable Portfolio Standard	Nova Scotia
Maritime Link	Nova Scotia
Coal Phaseout	Ontario
Greener Diesel Regulation	Ontario
Greener Gasoline Regulation	Ontario
Nuclear Power Plant Refurbishment	Ontario
Biofuels Mandate	Quebec
Cap-and-trade system for GHG Emissions Allowances	Quebec
Electric Vehicle Incentives	Quebec
Renewable Natural Gas Regulation	Quebec
Zero Emissions Vehicle Standard	Quebec
Boundary dam Carbon Capture Project	Saskatchewan
Ethanol Fuel (General) Regulations	Saskatchewan
Renewable Diesel Act	Saskatchewan