Reversing Carbon Leakage in the Aluminum Sector

An analysis of the benefits of reducing production costs in Canada's aluminum sector

SUBMITTED TO

Michael Binnion
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SUBMITTED BY

Mikela Hein
Jotham Peters
Navius Research Inc.
Box 48300 Bentall
Vancouver BC V7X 1A1

Contact@NaviusResearch.com

About Us

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

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- We use unique in-house models of the energy-economy system as principal analysis tools.
- We have a strong network of experts in related fields with whom we work to produce detailed and integrated climate and energy analyses.
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Executive Summary

The primary aluminum sector provides major economic benefits to Canada, but also contributes greatly to greenhouse gas (GHG) emissions. Such energy-intensive sectors present a challenge to countries like Canada who are participating in the Paris Agreement to prevent global temperature change from exceeding 2 ºC. Abatement initiatives, such as climate policies (i.e. carbon pricing and regulations) tend to be effective at reducing emissions but also tend to raise production costs. In terms of mitigating climate change, raising production costs in the aluminum sector may not be the optimal strategy. Although GHG emissions may decline domestically, if Canadian aluminum is out-competed by countries with cheaper production, these emissions could relocate internationally – a dynamic called carbon leakage.

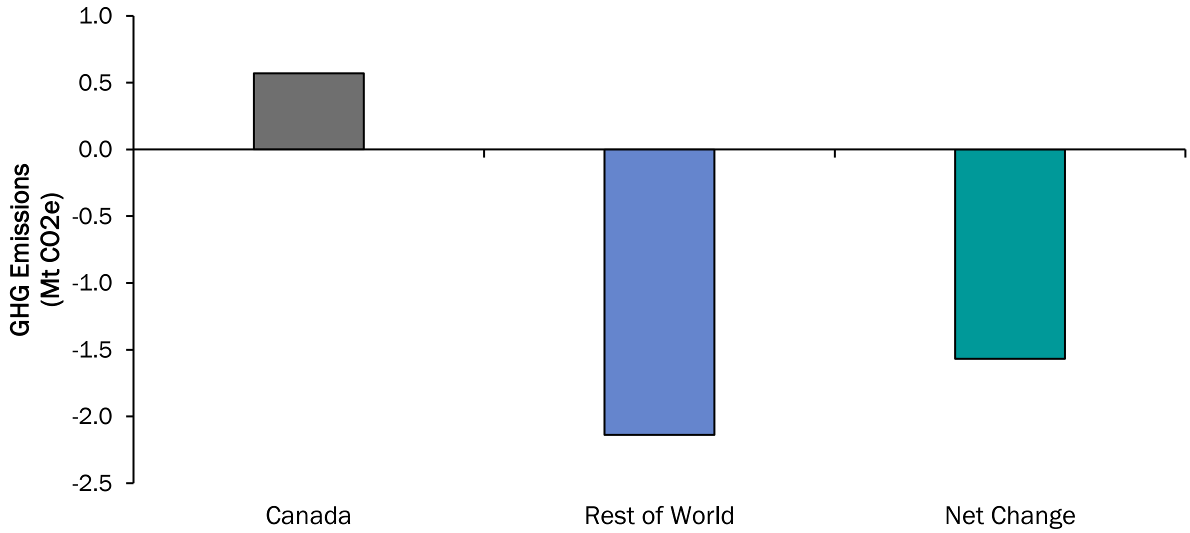
Carbon leakage is particularly unfavourable since Canadian primary aluminum production has among the lowest carbon footprints in the world[1]. A loss of competitiveness could lead to the relocation of production and subsequent greater global GHG emissions. This report uses an energy-economy model called gTech to analyze the impact of reversing carbon leakage from the Canadian aluminum sector. The reversal of carbon leakage is modeled by simulating a reduction in production costs via the removal of federal corporate income taxes in the aluminum sector.

Cutting federal corporate income taxes produces several economic benefits in Canada. The aluminum sector experiences 9% growth in employment, creating about an additional 1,400 jobs from 2020 to 2030. By 2030, the aluminum sector's GDP is $370 million (2010$) greater and national GDP is $27 million (2010$) greater relative to a business-as-usual forecast. These results suggest that Canada experiences a net economic benefit from reversing carbon leakage in the aluminum sector.

Conversely, in response to cutting federal corporate income taxes, domestic GHG emissions are 0.6 Mt CO2e greater by 2030 relative to a business-as-usual (BAU) forecast. Although emissions increase domestically, these are more than offset by greater GHG emission reductions internationally. GHG emissions in the rest of world decrease by 2.1 Mt, resulting in a net global decrease of 1.6 Mt (Figure 1). The cost of global abatement is estimated to be -$70/tonne CO2e (2010$). This number is negative because the Canadian aluminum sector is receiving a benefit (in terms of a tax reduction).

[1] Natural Resources Canada. (2018). Aluminum facts. Accessed from: https://www.nrcan.gc.ca/mining-materials/facts/aluminum/20510

Figure 1. Change in GHG emissions by 2030 in response to reversing carbon leakage in the aluminum sector



This report shows an example of where protecting the competitiveness of the Canadian aluminum industry results in a "win-win". Reversing carbon leakage in the aluminum sector helps to maintain economic activity in the country and reduces GHG emissions globally instead of just domestically. These results suggest the following:

1. **At a minimum, if Canada has a comparative advantage in a sector, activity in that sector should not decrease as a result of policy.** In fact, it would be advantageous to increase activity in these sectors, since it would act as a substitute to more carbon intensive producers and increase economic activity in Canada.
2. **In order to reduce global GHG emissions, national emissions may increase.** Increasing activity in a sector that has a global low carbon advantage will result in increased emissions domestically, but this can be more than offset by reductions elsewhere.

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1. Introduction

The primary production of aluminum is a major industry in Canada. In fact, Canada is the largest source of primary metal imports to the United States. However, the process of separating pure aluminum from its rawer state is energy and emissions intensive. This presents a challenge to Canada which is participating in the Paris Agreement to prevent global temperature change from exceeding 2 ºC. Additionally, the federal government has set a target to reduce GHG emissions 30% below 2005 levels by 2030.

Currently, the federal government along with the provinces and territories is implementing policies to meet its target and contribute to global climate change mitigation efforts. Climate policies may impact the aluminum sector by reducing emissions intensity and consequently raise the cost of production. In terms of mitigating climate change this might not be the optimal strategy. Although GHG emissions may be reduced domestically, if Canadian aluminum is out-competed by countries with cheaper production, these emissions could relocate internationally. This is particularly unfavourable since Canadian primary aluminum production has among the lowest carbon footprints in the world[2]. Canada has a comparative advantage in terms of its capability to produce relatively low-carbon aluminum, in part because the industry is regulated, but also because its smelters are positioned to receive inexpensive renewable electricity.

Climate change is a global problem since GHG emissions have the same impact regardless of what country emits them. This does not mean that Canada cannot contribute to climate change mitigation. Instead, this report considers options that do not reduce the competitiveness of the Canadian aluminum sector on an international level. Such a strategy is advantageous in two ways: (1) it could reduce GHG emissions globally instead of just domestically, and (2) it could strengthen the economic activity of the Canadian aluminum sector.

[2] Natural Resources Canada. (2018). Aluminum facts. Accessed from: https://www.nrcan.gc.ca/mining-materials/facts/aluminum/20510

2. Primer on Canada's aluminum sector

This Chapter introduces primary aluminum production in Canada. But first, it identifies sources of emissions from the production of primary aluminum (Section 2.1), and then explains some of the dynamics of production in Canada (Section 2.2) and internationally (Section 2.3).

2.1. Sources of emissions

Unlike most emission intensive industries, during the production of aluminum, combustion of fossil fuels comprises a very small proportion of total GHG emissions. In fact, in Canada it is estimated that combustion only accounts for 7% of all GHG emissions coming from the industry[3]. However, in order to produce primary aluminum, substantial GHG emissions are released into the atmosphere. Outlined below are the 4 sources responsible:

3. **Direct fossil fuel combustion emissions.** As mentioned above, the direct use of fossil fuels for energy is a small source of emissions in the industry. These emissions are produced on-site at aluminum smelters when fuels are combusted for a variety of activities, including anode production, transportation, etc.
4. **Indirect energy related emissions.** Most of the energy consumed during the production of primary aluminum is electricity. Electricity is used for electrolysis, the process that separates aluminum from its rawer compound with oxygen. The consumption of electricity produces zero emissions at its point of use. This does not mean there are no emissions associated. The production of electricity can be virtually free of emissions, if renewables are used, or it can be more emissions intensive, if fossil fuels (especially coal) are used. We refer to these emissions as "indirect" since they occur off-site.
5. **Process related CO_2 emissions.** Another major source of emissions is the release of CO_2 as a by-product of the primary aluminum production process. Carbon is used during aluminum smelting in order to help create an electrical current for electrolysis. This carbon is consumed during the smelting process and releases

[3] Aluminium Association of Canada. (2017). Position of the aluminium association of Canada as part of Canada's transition to a low-carbon economy. Accessed from: https://aluminium.ca/uploader/publications/aac_consultationssenatges_versionanglaise.pdf

CO_2. These CO_2 emissions are called process emissions since they are not related to the consumption of energy.

6. **Process related PFC emissions.** Another process emission related to the production of primary aluminum is perfluorocarbon (PFC). PFCs occur as an error in the smelting process when the electrical voltage exceeds a certain level. These gases have a substantially higher global warming potential than CO_2, and the main anthropogenic source of PFCs is aluminum smelting[4].

2.2. Canada's aluminum sector

Canada is one of the world's largest producers of primary aluminum, placing 3rd globally after China and Russia[5]. Canada's production is a fragment of China's, estimated at 3.2 million tonnes in 2017 compared to 33 million in China. However, Canada has a tremendous advantage in that its smelters operate with the lowest carbon footprint in the world[6]. This production is located in two provinces, with 9 smelters in Québec and 1 in British Columbia.

British Columbia's smelter is located in the north coast of the province in Kitimat. This smelter was constructed in the early 1950s, marking the largest private sector investment in Canada of its time. The facility is near the Douglas Channel, a deep, year-round, unobstructed port with access to Asia. In 2011, operators Rio Tinto announced that it would be investing in a modernization project at the Kitimat site. These upgrades were completed in 2015, costing $4.8 billion and employing 3,500 people at its peak[7]. This project was able to increase production capacity by 48% and reduce overall emissions by 50%, most of these emissions being PFCs[8].

Québec accounts for the majority of primary aluminum production in Canada with its 9 smelters supplying a capacity of 2.7 million tonnes per year, compared to just 0.4

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[4]Gibbs, M. J., Bakshi, V., Lawson, K., Pape, D., & Dolin, E. J. (1996). PFC emissions from primary aluminium production.

[5]Natural Resources Canada. (2018). Aluminum facts. Accessed from: https://www.nrcan.gc.ca/mining-materials/facts/aluminum/20510

[6]Ibid

[7]Kitimat Chamber of Commerce. (2016). Northwest BC Major Projects. Accessed from: http://www.kitimatchamber.ca/sites/default/files/KCOC_Major%20Projects_2016_Website1.pdf

[8]Aluminum Association of Canada. (2017). Canada's aluminium industry: A world perspective.

million tonnes per year in British Columbia[9]. Québec also has the only alumina refinery in the country, transforming rawer ore to the powder used in smelters. The aluminum sector has operated in Québec for over a 100 years and supports 30,000 jobs in the province[10].

Smelters in both provinces meet nearly all their electricity demand from renewable sources. The Kitimat site is unique because it has its own hydro-power dam from which to draw electricity. Even if the dam were to become insufficient to meet total demand, operations at the smelter could still be met by renewable sources supplied by BC Hydro. Québec's electricity demand is also met with hydro, although smelters purchase this from the local utility. Since electricity accounts for the largest proportion of a smelter's energy demands, access to renewable electricity is a large contributor to Canada's ability to produce primary aluminum at such relatively low emissions intensity.

Access to hydro electricity is not the only reason Canada is able to operates smelters at such low emissions intensity. Canadian facilities have shown a long record of reducing process emissions, including PFCs. Process CO2 is more difficult to reduce since it occurs at relatively fixed levels, since the consumption of carbon is part of the electrochemical process of smelting. However, as described in section 2.1, PFCs occur as an error in smelting, and there are technologies available to reduce these. As can be seen in Figure 2 the ratio between process CO2 and PFC emissions have been declining since 2000 in both British Columbia and Québec. The sharp decline seen in BC after 2015 represents the recent modernization project at the Kitimat site.

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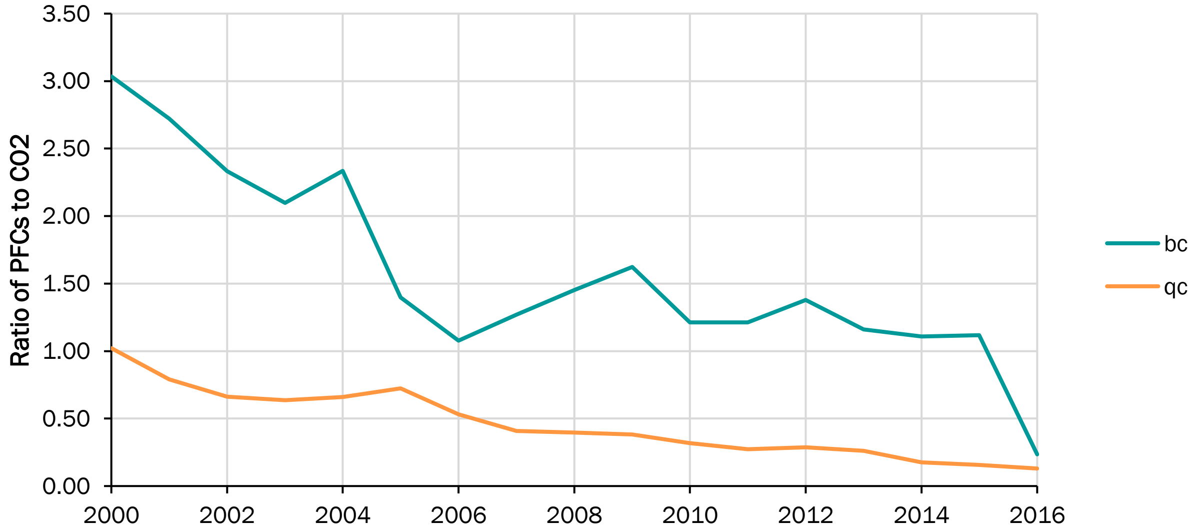
[9]Natural Resources Canada. (2018). Aluminum facts. Accessed from: https://www.nrcan.gc.ca/mining-materials/facts/aluminum/20510

[10]Investissement Québec. (2018). Québec Aluminium: A World-class Sector. Accessed from: http://www.investquebec.com/international/en/industries/aluminium.html

Figure 2. Ratio of process PFCs to CO_2



*This figure includes SF_6 emissions which make up a very small proportion of total process emissions

2.3. International aluminum production

The price of aluminum is set by a global market. This means that producers essentially receive the same price, putting countries with higher production costs at a disadvantage. The financial crisis of 2008 pushed prices down drastically, and more recently, prices have remained low due to speculation resulting from tremendous global capacity growth. These dynamics have challenged the competitiveness of many facilities, forcing some sites to shutdown[11].

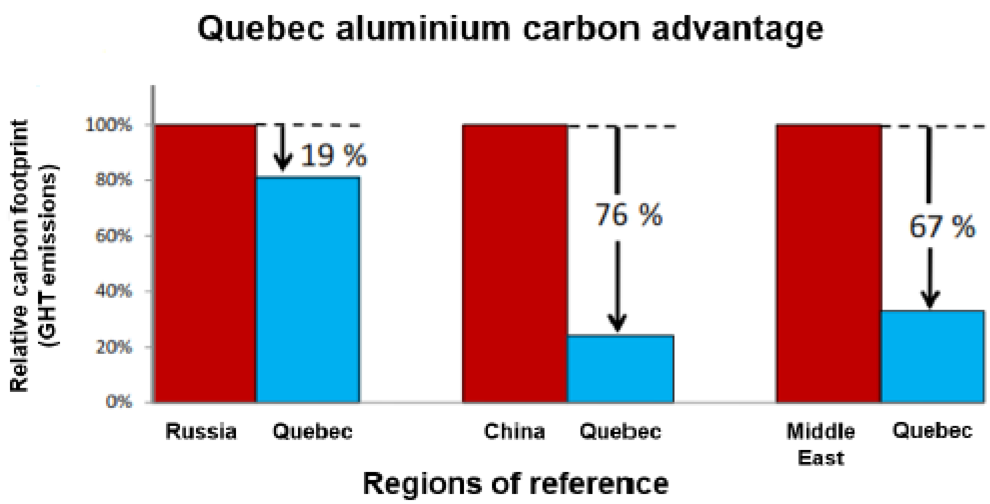
Production costs, capacity, and emissions-intensity vary widely between countries. Some of Canada's larger competitors are Russia, China, and the Middle East. As can be seen in Figure 3, all these regions operate at greater emissions intensity than Québec. It should be noted that with the recent modernization of the smelter in British Columbia, aluminum production in British Columbia is similar to Québec. So Figure 3 is a good proxy for aluminum production in Canada, not just Québec.

Russia produces about 3.8 million tonnes per year and has 11 smelters. Similar to Canada, Russian smelters meet their electricity demands with hydropower, making emissions intensity relatively low. However, Russia has not invested to the same extent

[11] Aluminium Association of Canada. (2017). Position of the aluminium association of Canada as part of Canada's transition to a low-carbon economy. Accessed from: https://aluminium.ca/uploader/publications/aac_consultationssenatges_versionanglaise.pdf

as Canada to reduce process emissions, and currently has few environmental policies on any of these emissions. In fact, Canada's production has been estimated to be about 19% less emissions intensive than Russia's (Figure 3).

Figure 3. Carbon advantage of Canadian aluminium



Source: Aluminium Association of Canada. (2017). Position of the aluminium association of Canada as part of Canada's transition to a low-carbon economy. Accessed from: https://aluminium.ca/uploader/publications/aac_consultationssenatges_versionanglaise.pdf

On the other hand, both China and the Middle East are significantly more emissions intensive than Canada. This is because most of the Middle East's electricity is generated using fossil fuels, and China's is predominantly generated with coal. This makes production very cheap and therefore competitive. It is estimated that Canada is about 76% less emissions intensive than China, and 67% less intensive than the Middle East (Figure 3). China makes up about 50% of total global production of aluminum with 33 million tonnes per year, and the Middle-East contributes a sizeable portion with 5.7 million tonnes per year[12].

[12] Ibid

3. Climate policy and carbon leakage

3.1. What is carbon leakage?

Carbon leakage occurs when GHG emissions that were previously emitted in one region relocate to another. This can occur in response to climate policy which makes it difficult or costly to produce emission in a particular region. Carbon leakage is concerning because efforts to mitigate climate change are either less effective than expected, make no difference, or worse, result in greater overall emissions.

Since Canada's primary aluminum production has the lowest carbon footprint in the world, a loss of competitiveness could lead to the relocation of production and subsequent greater global GHG emissions. For example, China's emissions intensity during aluminum production is estimated to be as much as seven times greater than Canada's[13]. So, one tonne reduction in emissions in Canada could be offset by an increase of 7 tonnes in China.

Ensuring the competitiveness of industry while reducing greenhouse gas emissions is an important objective of climate policy. Protecting the competitiveness of the Canadian aluminum industry is a "win-win". It helps to maintain economic activity in the country, and it ensures that industry remains in a region where it is subject to climate policy.

3.2. Climate policy challenges

Implementing climate policy has several challenges. First, climate policy can impose additional costs on firms and individuals. These costs can be obvious, as is the case with carbon pricing, or they can be more difficult to quantify. For example, a regulation may force an industry to invest in less emissions-intensive processes or fuels, and these changes have associated costs. Furthermore, the anticipation of policy may incentivise industry to make additional investments as a strategy to mitigate future expenses.

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[13] Aluminium Association of Canada. (2017). Position of the aluminium association of Canada as part of Canada's transition to a low-carbon economy. Accessed from: https://aluminium.ca/uploader/publications/aac_consultationssenatges_versionanglaise.pdf

Second, increased cost of production may decrease the international competitiveness of an industry. In the case of aluminum, added costs cannot be passed on to the consumer. This is because the price of aluminum is set globally. Although all aluminum producers receive the same price, they do not have the same costs. This means that if Canadian production becomes more expensive it could become less economically viable or be outcompeted by international producers. This could reduce Canadian economic activity and employment.

Third, if climate policy reduces the competitiveness of an industry, it may cause carbon leakage. As mentioned before, this is particularly concerning in the aluminum sector, since Canada is less emissions intensive compared to other global resources. Therefore, it is important to minimize carbon leakage when implementing climate policy.

Lastly, it is important to note that although climate policy may often increase costs to firms and individuals, it does not always result in carbon leakage. Canadian aluminum is especially susceptible because it is a trade heavy commodity. However, there are many instances where climate policy reduces emissions domestically, and these emissions do not relocate abroad. Sectors which face little trade exposure are relatively free of carbon leakage, examples include: transportation, construction, and electricity. It is an important distinction to make when considering what would be the best approach to mitigate GHG emissions.

3.3. Opportunities for reducing carbon leakage

Traditionally, climate policies focus on reducing regional emissions. Why not flip this concept on its head? Since Canada has comparatively low emissions in the aluminum sector, if production were to increase it would displace emissions elsewhere. Is it possible to reverse carbon leakage as a strategy to reduce global (not regional) GHG emissions?

There are several strategies available to increase Canadian aluminum production, even under a climate policy. For example, if the aluminum sector is included in a carbon pricing system, costs could be mitigated in the following ways: (1) the industry could receive free emission allowances that exceed their total requirements, (2) it could receive a rebate through the revenue generated by the carbon pricing system, or (3) only emissions that have viable abatement options would be included in the policy.

There are also strategies that do not involve traditional climate policies, but instead are designed to simply bolster production. These include the de-regulation of the aluminum sector, tax cuts, or government funding. There is also the possibility of creating trade agreements designed to pressure countries with no climate policies to reduce emissions. This would raise production costs abroad and decrease the tremendous cost advantage in countries such as China which mostly use coal to produce electricity.

For simplicity this report focuses on the effects of cutting federal corporate income taxes on the aluminum sector, as a strategy to increase Canadian primary aluminum production. Although there are several options available, this paper is not prescriptive about how this should be achieved. Instead it explores what the impacts of increased production in Canada would have on overall global emissions, and domestic economic activity.

4. Modeling as a method to calculate carbon leakage

This Chapter provides an overview of the methods and assumptions employed to forecast the impact of subsidizing Canada's aluminum sector. It introduces energy-economy modeling and how it can be used to quantify carbon leakage (Section 4.1), identifies the policy options modeled in this report for reversing carbon leakage (Section 4.2), reviews how carbon leakage is modeled (Section 4.3), and discusses the implication of uncertainty for energy-economy forecasting (Section 4.4)

4.1. Introduction to energy-economy modeling

One method to estimate the extent to which a policy could reduce carbon leakage is to use an economic model. This study employs Navius' gTech model, a model used to forecast the effect of policy on the economy, energy consumption, and air emissions. gTech is a computable general equilibrium (CGE) model of Canada, which simulates how the economy evolves under different economic conditions.

Unlike a conventional CGE model, gTech incorporates attributes of technologically-explicit energy-economy modeling within a macro-economic framework. The result is a model that simultaneously simulates technological adoption and impacts on the economy.

The gTech model is disaggregated by region and sector. Each sector is characterized by technologies that produce a commodity (e.g., steel, aluminum, cement) and the inputs required in production (i.e., labour, energy and materials). Commodities that are produced can then be sold to other producers (as intermediate inputs), to households (the final consumers of goods produced in the economy), or through bilateral trade to other regions and the rest of the world. Commodities can also be imported from other regions or the rest of the world.

Due to their framework, CGE models show how policies or different economic conditions alter the structure and growth of the economy. A policy leading to the contraction of one sector has a ripple effect throughout the economy as all sectors of the economy return to equilibrium. For example, a policy causing an increase in the cost of producing pulp and paper or refined petroleum products (assuming the prices for these goods remain constant) can lead to a loss of competitiveness and lower production levels. In turn, lower production would reduce the output from sectors that supply these sectors with goods and services, and capital and labour would be reallocated throughout the economy.

Included in the sectors modeled by gTech, are all the major energy supply and demand sectors in the economy as well as the main processes within those sectors (where demand for each process is satisfied by current and emerging technologies).The model offers near 100% coverage of GHG emissions, energy consumption and energy production in the economy; thus, it is well positioned to provide a realistic forecast of abatement opportunities in Canada. Furthermore, gTech has near perfect alignment with the NIR/PIR by IPCC categories as well as by economic sector. The disaggregation of the results facilitates comparisons to other inventories and forecasts.

The version of the model used for this study solves in 5-year increments from 2010 to 2030. One of the benefits of using a recursive model is it can simulate policies that change over time. For example, gTech can simulate carbon taxes that rise over time, or regulatory policies (e.g., requirements for carbon capture and storage) implemented in a certain year. Furthermore, the model simulates capital stock turnover over time. The data underlying the model is derived primarily from the Statistics Canada System of National Accounts.

4.2. Policy options for reversing carbon leakage

There are several options that can be modeled to reverse carbon leakage in the aluminum sector. These options can be divided into two categories:

- **Option 1: No policy on the aluminum sector.**
- **Option 2: Reduce costs to the aluminum sector.** There are many ways that costs can be reduced, including cutting taxes and direct government investments. Even climate policies can be used to reduce costs in the sector. For example, if a carbon pricing system covered the aluminum sector, the sector could receive its allowances for free, or receive revenue generated from the system.

It is important to note that this analysis is not prescriptive on the method to cut costs in the aluminum sector. For simplicity in this report we modeled the impact of cutting federal corporate income taxes on the primary aluminum sector.

The reduction in corporate income taxes for the aluminum sector is assumed to be "revenue neutral" from the perspective of the federal government. Any reduction in federal corporate income taxes for the aluminum sector are offset with increases in federal corporate income taxes on other sectors of the economy. We note that several other approaches for offsetting the loss of revenue from a federal corporate income tax reduction in the aluminum sector are possible. For example, government could increase other taxes or accept less government revenue. However, our approach was taken for several reason. First, it offers a more "conservative" view of the impact of this policy, since the rise in corporate income taxes for other sectors partially offset some of the economic gains from the aluminum sector. Second, gTech, and CGE models in general, do not fully account for the economic impacts from changes in government spending. For example, CGE models do not account for productivity gains from investments in public education. As such, the most defensible approach to modeling a reduction in corporate income taxes for the aluminum sector is to assume that this revenue is replaced with another source of revenue.

4.3. Modeling carbon leakage

To our knowledge there are few studies that seek to quantify the extent of carbon leakage in Canada. In the past, Navius Research has been involved in two such studies[14,15]. However, these studies may have understated carbon leakage. Both studies used a simplifying assumption that industrial sectors outside of Canada operate with the same emissions intensity as within Canada. This is unlikely since industries may operate with different energy sources, technologies, and regulations. This assumption was used because comprehensive data on the emissions intensity of industry by country is (to our knowledge) not available.

In this study, we've rectified this assumption for the aluminum sector by using a weighted average carbon intensity for global production, which is based on the three largest global aluminum producers outside of Canada (Russia, Middle-East, and China). We assume that (1) any reduction (or increase) in production in Canada would be offset by an increase (reduction) in production in these other regions, and (2) the change in aluminum production outside Canada would occur under the weighted average carbon intensity for global production.

[14] Canada's Ecofiscal Commission. (2016). Options and Trade-offs in Recycling Carbon Pricing Revenues.

[15] Sawyer, D., Peters, J., Stiebert, S. (2016). Impact Modelling and Analysis of Ontario's Proposed Cap and Trade Program.

4.4. Uncertainties in modeling

Despite using the best available forecasting methods and assumptions, the evolution of Canada's future energy economy is uncertain. In particular, forecasting activity and greenhouse emissions in the aluminum sector is subject to two main types of uncertainty.

First, all models are simplified representations of reality. While Navius' tools capture many dynamics within the economy and global trade, they do not account for everything. The inherent limitation of energy forecasting is that virtually all projections of the future will differ, to some extent, from what ultimately transpires.

Second, the assumptions used to parameterize the models are uncertain. These assumptions include, but are not limited to, commodity prices, improvements in labor productivity, and the level of growth in the aluminum manufacturing sector. There is also uncertainty as to how cutting costs would affect production. Additionally, there is much uncertainty to how the energy-economy will progress internationally (i.e. what will electricity generation in China look like by 2030?). If any of the assumptions used prove incorrect, the resulting forecast will be affected.

The uncertainties in modeling means that all models will err in their forecasts of the future. Despite this, we are quite confident that Canadian aluminum has a comparative advantage in greenhouse gas emissions for many years to come. Furthermore, the analysis of in this study employs highly sophisticated models that provide powerful insights into the effect of changing production costs in the aluminum sector.

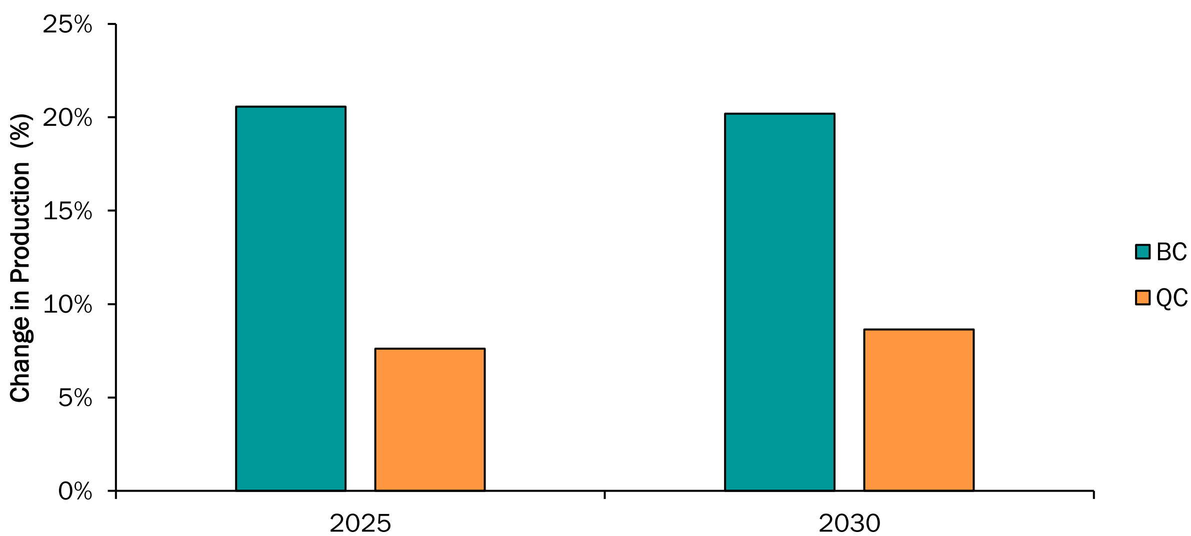
5. What is the effect of cutting federal corporate income taxes?

This Chapter quantifies the effects that cutting federal corporate income taxes in the Canadian aluminum sector is expected to have through 2030. It measures the impacts on aluminum production (Section 5.1), GHG emissions (Section 5.2), and economic growth (Section 5.3). These impacts are estimated by comparing a forecast that includes federal corporate income tax cuts against a business-as-usual forecast.

5.1. Aluminum production

Cutting federal corporate income taxes results in greater domestic aluminum production. Cutting federal corporate income taxes reduces the cost of production in Canada's aluminum sector. This increases production in British Columbia and Québec in 2030 by 20% and 9%, respectively (Figure 4). This amounts to a 10% increase in the total production of Canadian aluminum, or $790 million (2010$), relative to the business-as-usual scenario. This analysis assumes that global aluminum production does not change. Instead, the share of global aluminum production is redistributed. Therefore, if Canada's production increases by $790 million (2010$), an equal reduction in production is experienced in the rest of the world.

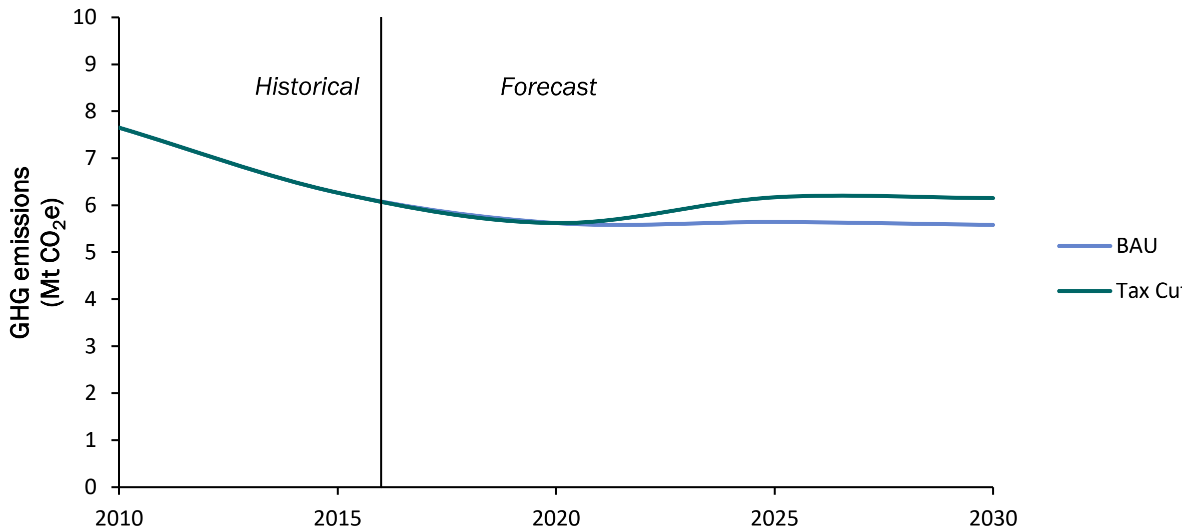
Figure 4. Change in Production as a result to cutting federal corporate income taxes (%)



5.2. Greenhouse gas emissions

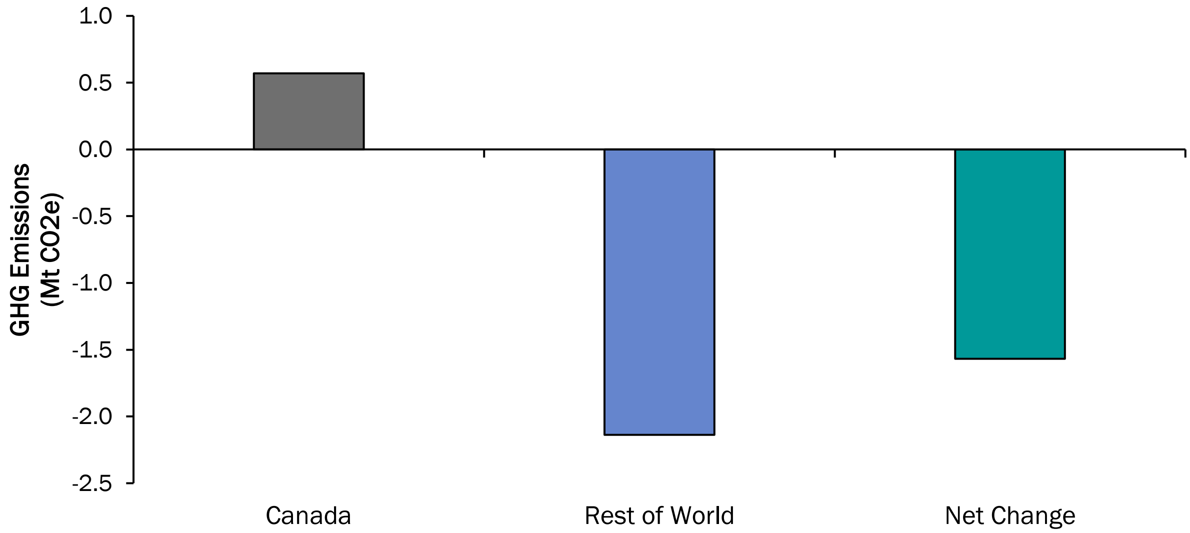
Cutting federal corporate incomes taxes causes GHG emissions to increase domestically. In response to cutting federal corporate income taxes GHG emissions increase by about 0.6 Mt CO_2e by 2030 relative to the business-as-usual (BAU) scenario (Figure 5). Although emissions increase domestically, these are more than offset by greater GHG emission reductions internationally.

Figure 5. Canadian GHG emissions in the Aluminum Sector



As can be seen in Figure 6, we estimate that GHG emissions in the “rest of world” decline significantly in response to increased production in Canada. GHG emissions in the rest of world decrease by 2.1 Mt, resulting in a net global decrease of 1.6 Mt. We estimate this decrease by weighing the carbon intensities of the 3 largest global aluminum producers outside of Canada (Russia, Middle-East, and China) and assume that the offset production would have occurred under this carbon intensity.

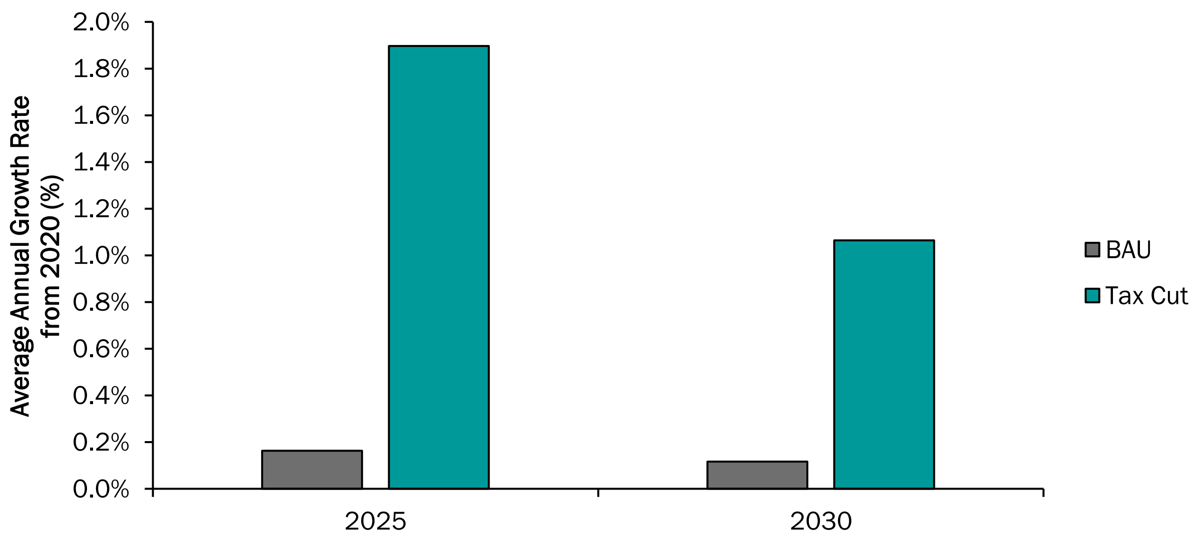
Figure 6. Change in GHG emissions by 2030 in response to reversing carbon leakage in the aluminum sector



5.3. Economic impacts in Canada

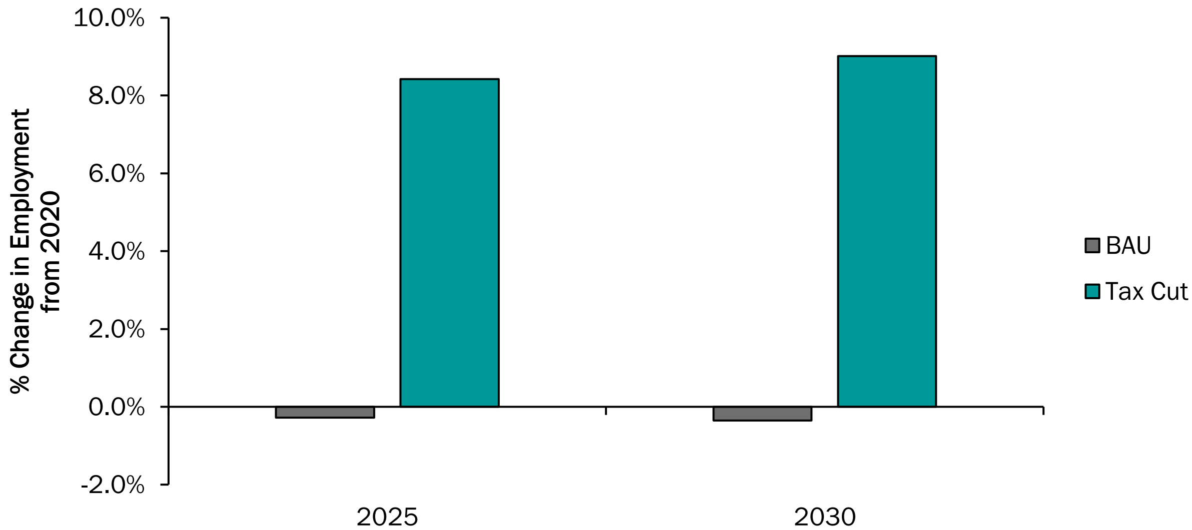
The impact of cutting federal corporate income taxes on the economic growth of the aluminum sector increases sectoral GDP 10% by 2030 relative to the business-as-usual (BAU) forecast. Average annual growth rate from 2020 onto 2030 is 1.1% relative to about 0.1% under the BAU forecast (Figure 7). This results in an increase of sectoral GDP of $370 million (2010$) relative to the BAU scenario.

Figure 7. Average annual growth rate from 2020 (%)



This increased economic growth results in greater employment in the Canadian aluminum sector. The sector experiences 9% growth in employment, creating about an additional 1,400 jobs from 2020 to 2030. As can be seen in Figure 8, under the business-as-usual (BAU) scenario, employment drops 0.4%, losing about 60 jobs from 2020 to 2030.

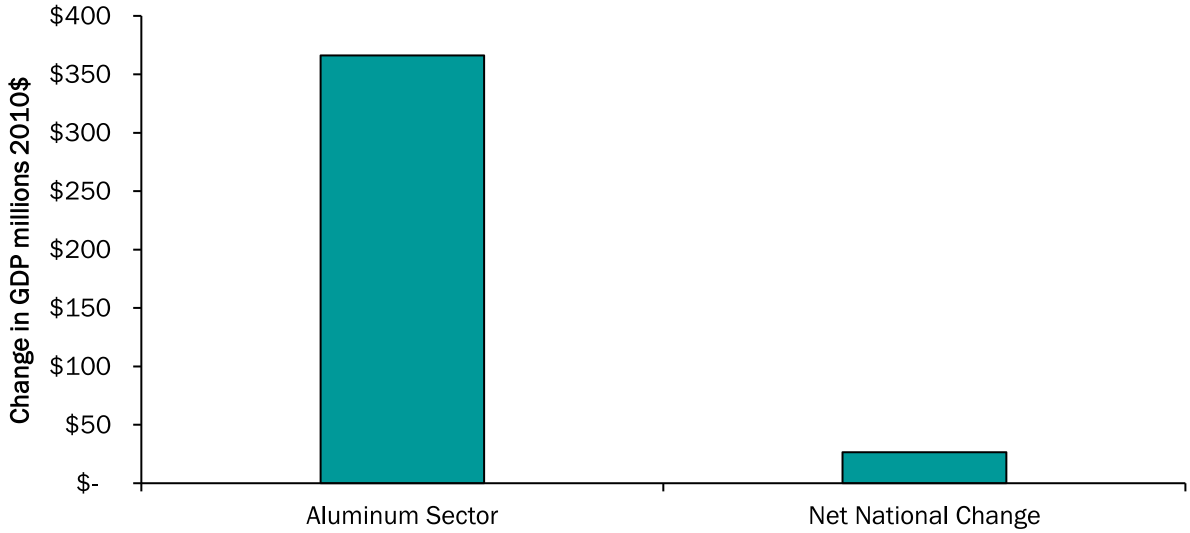
Figure 8. Change in employment from 2020 (%)



Additionally, Canada's overall GDP increases as a result of the federal corporate income tax break on the aluminum sector. By 2030, national GDP is $27 million (2010$) higher than the BAU forecast. These results suggest that Canada experiences a net economic benefit from reversing carbon leakage in the aluminum sector.

As can be seen in Figure 9, the increase in national GDP is smaller than the increase experienced by the aluminum sector. Although the GDP in the aluminum sector increased by $370 million (2010$), the net national change is only $27 million (2010$) This occurs because we modeled a rise in federal corporate income taxes for other sectors in order to maintain "revenue neutrality" from the perspective of the federal government. Therefore, economic gains from the aluminum sector are partially offset by reduced economic activity in other sectors.

Figure 9. Change in GDP as a result of cutting federal corporate income taxes in the aluminum sector (millions 2010$)



It should be noted that there are several other approaches for offsetting the loss of revenue from a federal corporate income tax reduction in the aluminum sector. For example, government could increase other taxes or accept less government revenue. These other approaches would lead to different economic impacts and likely have a more positive effect on national GDP. See Section 4.2 for an explanation of why we chose to raise federal corporate income taxes instead.

5.4. Cost of "global" abatement

The Canadian aluminum sector has hit a limit in terms of the options available to reduce GHG emissions. In recent years the sector has invested in modernization projects, electrification, efficiency, and reduction in process emissions. Barring an advance in current technologies, it is virtually impossible for the sector to further reduce emissions[16]. In fact, it is estimated that any further reduction could only be achieved through a reduction in production. This implies that it would be costly for Canada to abate GHG emissions within the domestic aluminum sector.

Traditionally, much of the focus of climate policies has been the cost of domestic abatement. For example, a policy such as a tax or regulation imposes a cost of

[16] Aluminium Association of Canada. (2017). Position of the aluminium association of Canada as part of Canada's transition to a low-carbon economy. Accessed from: https://aluminium.ca/uploader/publications/aac_consultationssenatges_versionanglaise.pdf

abatement per tonne of GHG emissions within a regulated region. This study provides insight into an alternative metric: the cost of "global" abatement. This metric includes emission reductions outside of the region imposing the policy, and therefore includes the effects of carbon leakage. Our results suggest that by 2030 reversing carbon leakage in Canada's aluminum sector has a cost of global abatement of -$70/tonne CO_2e (2010$). This number is negative because the Canadian aluminum sector is receiving a benefit (in terms of a tax reduction), leading to a reduction in net global emissions. The amount of federal corporate income taxes cut from the aluminum sector can be found in Table 1 below.

Table 1. Federal corporate income taxes cut from the aluminum sector (millions 2010$)

Region	2025	2030
British Columbia	$14	$14
Quebec	$96	$98

6. Challenging the UNFCC accounting methodology

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty established between countries to cooperatively reduce GHG emissions. Canada ratified this treaty along with 197 other parties, including all United Nation member states. These member nations committed to publish a periodic National Inventory Report (NIR) to help measure emission reductions. In Canada, progress is currently measured against a national target to reduce emissions 30% below 2005 levels by 2030. In some cases, metrics quantifying national emissions are useful, but they may also be misleading if they disregard the broader global context.

Domestic targets are easy to understand. Someone can intuitively assess whether progress has been made based on whether emissions have gone up or down. In the case of sectors that are not highly traded (i.e. transportation, construction, electricity) national metrics are very useful since there is almost no risk of carbon leakage. In these cases, if emissions have decreased domestically there has likely been a contribution to global GHG emission reductions. On the other hand, sectors which are trade exposed (i.e. aluminum, cement, steel) are vulnerable to carbon leakage. This means that if domestic GHG emission have gone down, global GHG emission have not necessarily decreased.

The results of this analysis provide an example of where increasing emissions in one country can be more than offset by reductions elsewhere. This analysis suggests that measuring Canada's contribution solely to the UNFCCC accounting methodology may be misleading. This does not mean that individual nations should not participate in climate policy to reduce domestic emissions. However, it is valuable to consider growth projects in countries such as Canada that have a low-carbon advantage in a particular sector. Growth projects can be one more tool in a collection of climate mitigation initiatives, similar to more traditional policies such as carbon pricing and regulations. However, contributions from such projects may increase domestic GHG emissions, taking us further away from a national target. This implies that in many cases climate policy impacts are best appreciated in a global context, and that efforts to reduce carbon leakage should be appreciated in a GHG emission accounting method.

Lastly, although this paper focuses on the aluminum sector, Canada is likely positioned to reverse carbon leakage in many other industries. Canada operates many electricity intensive industries in regions which have access to renewable energy.

These regions also function under climate policy. It is unclear how great this carbon advantage may be, and to what extent carbon leakage could be reversed in other sectors. However, it may be beneficial to explore other options were increasing domestic activity could help reduce global emissions.

7. Conclusion

The results of this analysis provide an example of where increasing emissions in one country can be more than offset by reductions elsewhere. These results suggest the following:

7. **At a minimum, if Canada has a comparative advantage in a sector, activity in that sector should not decrease as a result of policy.** In fact, it would be advantageous to increase activity in these sectors, since it would act as a substitute to more carbon intensive producers and increase economic activity in Canada.
8. **In order to reduce global GHG emissions, national emissions may increase.** Increasing activity in a sector that has a global low carbon advantage will result in increased emissions domestically, but this can be more than offset by reductions elsewhere.

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