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Capital Mobilization Plan for a Canadian Low-Carbon Economy

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Contents

PREFACE

This report follows the first of the 15 recommendations made by the Expert Panel of Sustainable Finance. This report is a *descriptive* report and not a *prescriptive* report. By descriptive we mean that we describe a likely abatement path and costs. The abatement path is assumed to be a linear and proportional decrease in emissions from 2020 to 2030. Costs over the next 10 years are assumed to be the same as the historical costs realized in actual carbon abatement projects — these are not model-based predictions. As such, the report represents a "middle of the road" analysis based on historic abatement compiled from publicly available academic and industry reports and journal articles. The literature is sparse, leading to a low number of abatement costs for some sectors and wide variation in cost estimates. We average across the reported costs to arrive at an estimate that represents the best available estimate given the current data.

Our report does not use the often-employed dynamic stochastic general equilibrium (DSGE) or "black box" macroeconomic model. We appreciate the sophistication behind these models, however, the abatement cost estimate generated are often not based on actual costs and the mechanisms generating the predictions are not transparent to the reader. Our methodology places emphasis on transparent data and calculations that can be readily used by anyone. If a reader disagrees with a cost assumption they can simply replace our average costs assumption with their own cost assumption and attain new estimates.

There are (at least) two prevailing assumptions about the future path of abatement costs:

1. The first tonne of abatement will be cheaper to abate than the last
2. Technological improvements will reduce abatement costs over time

We believe both are likely to be true. With respect to the first assumption, we do not expect there to be a meaningful difference in the cost to abate the first 1% of carbon emissions relative to the 30% of carbon emissions. With respect to the second assumption, it is hard to imagine that technologies will be implemented within the next 10 years that will meaningfully decrease carbon abatement. In a number of cases technologies do not yet exist at industrial scale and to assume that these technologies will be implemented and then improved on enough to reduce today's estimates is not based in serious analysis. Finally, we tested our historical abatement costs data for a trend and found none. This can either be related to insufficient data (likely), an absence of a trend, and perhaps two trends pushing and pulling abatement costs in two directions. Our assumption is that the average historical abatement costs are the best estimate of abatement costs over the next 10 years.

Our descriptive analysis does not seek to identify an optimal least-cost path. This is reflected in our assumption that provinces and sectors will reduce emissions proportional to what they currently emit. We intentionally avoid identifying the least-cost path in this phase of the report because it assumes policy changes whose implementation success is unclear or simply unknown. Prescriptive or optimal estimates generally suggest that abatement should happen where the lowest marginal costs of abatement occurs. A prescriptive analysis makes two assumptions, the first is that we can estimate marginal abatement costs and policy will be enacted to compensate firms and sectors that abate more than other firms and sectors. Assuming that a firm in one sector is willing to abate proportionally more than a firm in another sector because that firm has lower marginal abatement costs, runs contrary to how most modern economies operate. In most cases the firm that abates more will required to be compensated for shouldering more of the costs than other firms. This requires government compensation policies or cap-and-trade systems. To date there is no pan-Canadian cap-and-trade system. In 2018 Ontario cancelled their participation in a cap-and-trade system, and there is no evidence that another mechanism exists to take its place. We therefore assume that an optimal abatement path is unlikely to be the realized abatement path over the next 10 years. As new information becomes available we plan to periodically update our estimate of the costs.

EXECUTIVE SUMMARY

"... the most important thing [for climate change] is to move capital from where it is today to where it needs to be tomorrow. The [finance] system is very much part of the solution."

Mark Carney, United Nations Special Envoy on Climate Action

"... with 2030 barely a decade away, we need to consider the plans and investments required to achieve Canada's longer-term climate aspirations and keep pace with international competition. Industries and markets need this horizon and visibility...to make sustainable long-term investment decisions and accurately price risk and opportunity."

The Final Report of the Expert Panel on Sustainable Finance, 2019

WHY CANADA NEEDS A CAPITAL MOBILIZATION PLAN FOR A LOW-CARBON ECONOMY

The Final Report of Canada's Expert Panel on Sustainable Finance is clear that transitioning to a low-carbon economy is as much an economic as it is an environmental necessity, and that with this transition, ample economic opportunities exist. Sustainable finance will not solve climate change alone, but it can play a major role and the expertise acquired in the process can place Canada as a global leader. In fact, as the report states, we should consider the pursuits for a sustainable climate and a sustainable economy to be one and the same. The imperative to act on climate change in the context of a shifting global economy is critical to the future competitiveness of Canadian industries in international markets, the ability to attract global capital to Canada, as well as attract and retain top talent catering to the new generation's focus on sustainability, and finally our ability to foresee, plan for, and mitigate significant economic and environmental risks.

The Expert Panel on Sustainable Finance was created to investigate ways in which the financial sector can assist in low-carbon Canadian initiatives, the first and foundational pillar of their report is *the need to shift Canada's climate change conversation from burden to opportunity*[1]. This means: *establishing a concrete vision and capital plan for Canada's path to a competitive low-emissions, climate-smart economy; offering Canadian businesses, financial firms and individuals the ability to connect with that vision through investment and savings; and ensuring that government and industry join forces to pursue opportunity and manage risk* [1].

This is the starting place for the Institute for Sustainable Finance's Capital Mobilization Plan series. **Its purpose: to provide a detailed and data-driven blueprint for the transition to a low-carbon economy in Canada.** It should be noted that this report is "descriptive" and not "prescriptive". We aim to remain neutral and non-biased by making objective assumptions.

The idea that "what gets financed, gets built," is central to understanding the importance of the financial sector in achieving the greenhouse gas emission reduction targets we have committed to globally, seizing the market opportunity of a low-carbon transition in the process.

While Canada's goal of achieving a 30% reduction in greenhouse gas (GHG) emissions within the next decade and net-zero emissions by 2050 is clear, the way to get there is not. The Capital Mobilization Plan series aims to provide the roadmap of Canada's transition path through consecutive studies.

The most salient conclusion from this first report, is that Canada requires a substantial, but far from insurmountable, investment of $128 billion over the next 10 years to achieve our 2030 emission reduction targets.

A substantial percentage of this investment can be drawn from the private sector.

Indeed, there is significant evidence to suggest that private capital is already flowing, and poised to flow at a more significant pace, in this direction over the next decade—not only despite the unique economic challenges brought on by a global pandemic, but as a result of it.

How we transition from a high GHG emissions Canada to a low GHG emissions Canada, particularly in the context of sweeping economic change, is one of the fundamental questions that will determine our near-term and long-term future and prosperity. Canadian governments and firms are already working together to

1 The expert panel is made up of Tiff Macklem, Kim Thomassin, Barbara Zvan, and Andy Chisholm

determine our path through the most devastating recession since the Great Depression. The choices we make now will also determine our economy's resilience to climate change, the longer-term crisis of our lifetime, as well as prepare our economy for the global economic transformation in line with a low-carbon transition that is already well in progress. To make wise decisions, we need sound data and sober analysis. That is the primary contribution this work offers to Canada's efforts to shape our way forward.

DEFINING THE MARKET OPPORTUNITY: REPORT METHODOLOGY

The primary purpose of our Capital Mobilization Plan is to provide a clear-eyed, evidence-based understanding of the required investment associated with reducing GHG emissions to 30% below 2005 levels, which is the Canadian government's 2030 milestone. To further ground this analysis in the reality of the Canadian context, we examine the breakdown of these investments across sectors and jurisdictions. Finally, to lend meaningful perspective, we place these investments in context relative to other major economic indicators and benchmarks such as gross domestic product (GDP), major stimulus spending, and public and private balance sheets.

To conduct this study, we first surveyed the academic and practitioner literature to identify specific costs associated with abating GHG emissions.[2] Our focus was to pinpoint straightforward estimates of the actual costs associated with carbon abatement projects. We were vigilant in identifying and avoiding suspiciously low estimates arrived at through the omission of implementation barriers (e.g. split incentives, information failures, financing hurdles etc. [2]) and narrow cost definitions, for example those found in the oft-cited 2007 McKinsey cost curve study [3]. These cost estimates form the basis of our calculation of the capital required to reach the 2030 Paris Agreement target of annual emissions 30% below 2005 levels.[3]

To determine the amount of emissions that require abatement over a 10-year period, to achieve the 2030 target, we use Canada's projected "2019 Reference Case"[4] to calculate a total of **789 million tonnes**.

Recognizing that abatement costs vary by sector, we group them to calculate average costs per sector. We then weigh these sectoral costs, using the assumption each sector will reduce emissions in the same proportion as they did in 2017.

Let's look at Transportation as an example:

- The average sectoral cost of abatement for Transportation is **$283/t CO_2eq**[5] (or $283 per one tonne of reduced CO_2 or the equivalent of another greenhouse gas)
- The weight assigned to Transportation is **23.5%**, the proportion by which that sector contributed to total emissions in 2017
- When we calculate **23.5%** of the 789 million tonne emission reduction requirement, we see that Transportation's estimated share of reductions is **186 million tonnes** (expressed as Mt. CO_2eq)
- By multiplying the weighted average abatement cost of $283/t$CO_2$eq by the total required abatement of 186 million tonnes, we reach a total required investment of $52.7 billion for this sector

When we apply this approach across all Canadian sectors, and add up each sector's required contribution, we arrive at a total investment estimate of $128 billion (see Table 2 in body of report reproduced below), representing a weighted average abatement cost of $162.4 per tonne. The "Abatement Required" column is total or cumulative abatement and not annual.

As noted, the underlying assumption in this estimate is that all sectors will continue to reduce emissions in the same proportion as they have in the past. It also assumes that average abatement costs in each sector will stay relatively the same over the next decade. While reasonable, this is far from a guarantee. Variables, from technological breakthroughs to consumer behaviour and policy change, could drive those costs down or up, and sectors may then increase or decrease their emissions reductions accordingly. By examining the abatement costs presented in ranges, we arrive at an overall investment range of **$90 to $166 billion to meet the 2030 goal**.[6]

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2 See for instance: "The cost of reducing greenhouse gas emissions," by Gillingham and Stock in the Journal of Economic Perspectives, 2018, or the 2014 Report from the Inter-governmental Panel on Climate Change

3 Abatement costs are borne by firms when they are required to reduce undesirable negative by-products created during production. Abatement costs can also be calculated for the costs of implementing policy that will reduce CO_2 emissions

4 Sourced from Canadian government's "Progress towards Canada's greenhouse gas emissions reduction target"

5 We express abatement costs—the cost of lowering one tonne of CO_2 or the equivalent (eq) of another GHG—as ($/t$CO_2$eq).

6 While this report is specific to Canada, our methodology and the associated abatement costs estimate can be applied globally.

Total Weighted Average Abatement Cost Breakdown

Sector	Proportion (%)	Average Cost ($/t CO_2eq)	Abatement Required (Mt. CO_2eq)	Required Investment ($ millions)
Oil & Gas	27	126	209	26,329
Transportation	24	283	186	52,656
Buildings	11	123	88	10,847
Electricity	10	214	76	16,252
Heavy industry	9	126	75	9,391
Agriculture	9	88	74	6,455
Waste & others	5	139	41	5,650
Land use & Forestry (LULUCF)	5	14	39	545
Total			**789**	**128,125**

We take a similar approach to determining the amount of required investment for each Canadian jurisdiction. The "weighted average abatement cost" for each province and territory is achieved by adding the proportional costs of each sector that contributes to that jurisdiction's emissions. For example, Saskatchewan's top three emissions drivers are Oil & Gas, Agriculture, and Electricity. The province's weighted abatement cost of $150/ t$CO_2$eq factors in the proportional costs of those three main drivers (as well as those of other, smaller, contributing sectors).

We calculate a jurisdiction's required investment by multiplying its weighted cost by the amount of emissions it is required to reduce. The latter figure is simply a product of that jurisdiction's "share" of Canada's 789 million tonne reduction requirement, based on its current contribution to overall emissions. Again, using Saskatchewan as the example:

- Saskatchewan contributes 10.5% to Canada's overall emissions
- Therefore, its share of required reductions is equal to 82.7 Mt. CO_2 (or 10.5% of 789 Mt. CO_2)
- Given Saskatchewan's weighted abatement cost is $150/ t$CO_2$eq (a product of the proportional costs of its emissions drivers), its total required investment is roughly $12.4 billion over the next 10 years ($150 X 82.7 million)

COSTS BY SECTOR AND REGION: OUR FINDINGS

The stark differences in abatement costs across sectors and regions, and the contours of those differences, matter significantly if we want to take a pragmatic approach to financing Canada's low carbon transition.

In terms of sectors, on the low-cost end of the spectrum, we find Land Use, Land Use Change, and Forestry (LULUCF $14) and Agriculture ($88). Transportation ($283) marks the highest end of the scale, while Oil & Gas falls in the middle ($126), below the costs of Electricity ($214) and the average among the eight sectors ($139).

However average cost is only one part of the overall story when it comes to understanding the opportunities and requirements for low-carbon sectoral investments. Scale matters and so does the cost of capital[7], which speaks to the ease or difficulty of securing financing for abatement projects (see Table 6).

For example, Transportation, Canada's second highest GHG emitting sector, not only carries the highest overall cost of abatement, and greatest required capital investment ($52.6 billion), it also has a relatively high cost of capital at 6%, compared to other sectors and the overall average of 5.6%. The Oil & Gas sector has relatively low abatement costs, but it requires the second highest capital investment ($26.3 billion) because the scale of carbon emission reductions in that sector is higher than every other sector. Further, the cost of capital in Oil & Gas is among the highest of all sectors at around 7%. Electricity, on the other hand, has the second highest average cost, and third highest required investment ($16.3 billion), but a much lower cost of capital at about 4.4%.

7 The cost of capital describes the risk profile associated with a particular investment. In practical terms, sectors with high costs of capital related to abatement projects have a harder time securing private investment than those with lower costs of capital.

To arrive at a clear picture, we must also take into consideration the trends, technological developments, and economies of scale that are most likely to impact abatement costs over the next decade.

The rollout of biodiesel, electric vehicles (EVs), and EV charging networks are likely to lower the costs of abatement in Transportation. In the Electricity sector, economies of scale related to increased electrification as well as the development and deployment of technologies related to energy storage and district energy solutions are also likely to decrease costs. When it comes to Oil & Gas, we account for the cost-efficient and well-documented reductions that result from methane abatement technologies in that sector's average cost. Carbon capture and storage (CCS) raises this sector's overall average cost, however, when we factor in the potential of a price decline in CCS overtime, we see a potential cost savings in the sector of $5 billion over 10 years.

These unique sectoral profiles underlie the different investment opportunities and challenges for various provinces and territories. That is because, not only do jurisdictions differ in terms of carbon intensity, they also differ in terms of emissions drivers.

For example, while Nunavut's overall emission reduction requirement is the lowest in the country (0.6 Mt. CO_2), it has the highest weighted average abatement cost ($257/t$CO_2$eq). That's because Transportation, with its high abatement cost, makes up 92% of Nunavut's emissions. In other words, even though Nunavut's required contribution to carbon reductions is small, it won't necessarily be easy.

Indeed, the fact that Transportation is the largest contributor of GHG's in 10 out of Canada's 13 jurisdictions, frames the importance of focusing investment solutions in that sector.

On the flip side, while Alberta's weighted average cost of abatement is the lowest in the country ($146/t$CO_2$eq)—a direct result of Oil & Gas being its primary emissions driver—the province's overall required investment to reduce emissions ($43 billion) is the highest.

Again, this comes back to scale. Alberta's required emission reductions are the most significant in Canada (294 Mt. CO_2eq), much higher than its nearest contender, Ontario (179 Mt. CO_2eq). The high financing cost of Oil & Gas abatement projects is another important factor, which shapes Alberta's low-carbon investment reality.

Finally, if we look at each region's required investment to achieve Canada's overall 2030 goal relative to its GDP, we can further understand what it will take to make progress across the country. As a proportion of GDP, the greatest investment will be required in Saskatchewan, Alberta, and Nova Scotia, while Ontario, Quebec, and British Columbia require the lowest investments relative to their GDPs. Financing Canada's transition will require a sober understanding of these differences, the barriers they present, and the mechanisms by which those barriers can be redefined as investment opportunities.

Key Insights

While a number of insights emerge from our sectoral and jurisdictional analysis, here are the three most salient:

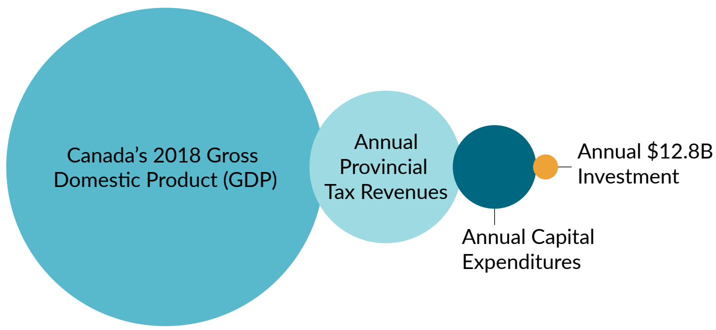
1. **The Building sector is Canada's lowest-hanging fruit.** When it comes to low-cost GHG reductions, the Building sector—Canada's third-highest source of emissions—offers the most substantial opportunity. In fact, it is the only sector where, in certain scenarios, reducing carbon emissions is less expensive than maintaining them. A small financial and/or behavioural nudge in this sector has the potential to unlock large environmental and economic benefits.
2. **Transportation is Canada's highest-stakes play.** Reducing emissions in this sector will require a significant investment and the need to address vast amounts of "locked-in capital," capital that is tied up in existing carbon-intensive infrastructure that is costly to abandon. At the same time, unlocking emissions reductions in this sector will have the most substantial impact on provincial and jurisdictional targets, and Canada's overall emissions profile. Public-private partnerships can be an effective way to mobilize capital in this sector. Financing and technology opportunities specific to GHG abatement strategies will be examined in greater detail in reports to come.

3. **Electricity and Oil & Gas are the big bets we need to get right.** These two sectors are both characterized by relatively high emission abatement requirements and relatively high levels of investment needed to achieve those reductions. What is also true about both sectors is they are poised for meaningful low-carbon technological disruption over the next decade. Saskatchewan, Alberta, and Nova Scotia—the provinces with the highest investment to GDP ratios—will be those best served by effective abatement investments in these sectors. Nova Scotia is the only province in the country where Electricity is the primary source of emissions. Oil & Gas is the primary driver of emissions in both Alberta and Saskatchewan (with Electricity being the second and third-highest driver, respectively). Collaborative efforts between these two sectors would be highly beneficial. Electricity will likely displace some Oil & Gas services in the future, so the Electricity sector should make use of some of the expertise and capital that is found in the Oil & Gas sector.

DOLLARS AND SENSE: PUTTING THE INVESTMENT OPPORTUNITY IN CONTEXT

Mobilizing the $90 to $166 billion required to achieve Canada's 2030 targets is not a small endeavour. However, when we put this investment in context, it is revealed as imminently reasonable and achievable.

Our estimated investment target of $12.8 billion annually represents just 0.62% of Canada's 2018 GDP, 2.7% of annual provincial tax revenues, and less than 10% of annual capital expenditures of firms listed on the TSX (see Table 8).



*Scaled for visualization

Three additional considerations matter, if we want to put this investment in real world context.

1. **Private capital can achieve at least 50% of the required investment.** Financing mechanisms, such as green and transition bonds and green investment trusts, can draw significant private capital to develop and scale up the technologies and innovations needed to reduce emissions in Canadian sectors. Blended finance in the form of public-private partnerships will help form the basis of new innovative partnerships and financing vehicles that harness the best of public and private financing worlds. The Canada Infrastructure Bank (CIB) is one effective way to encourage and stimulate these public-private partnerships as its mandate includes using federal support to attract private sector investment into green infrastructure projects.

   If large publicly traded Canadian firms devoted 5% of their annual capital expenditure to GHG abatement projects over the next decade, that would cover half of the investment required to achieve Canada's 2030 emissions target.

   This is not a pie-in-the-sky aspiration, but rather one grounded firmly in existing trends. For example, green bond issuance in the second quarter of 2020 totalled US$49.5 billion—the third highest quarterly total on record [4]. Last year, Canada broke the seal on sustainability-linked loans, which directly support private investment in abatement technologies and innovation [5].

2. **The costs of not investing are exceedingly high.** In its foremost study on the economic costs associated with inaction on climate change, the Economist Intelligence Unit (EIU) found that a five-degree warming scenario (a reasonable outcome of business-as-usual global carbon emissions)[8] would result, from a public-sector perspective, in present value losses worth US$18.4 trillion. At a six-degree warming scenario this number jumps to US$43 trillion—30% of the entire stock of the world's manageable assets [7].

   Discerning Canada's share of this loss is complicated, but if we approach it purely as a percentage of GDP, it could cost Canadians, on the high end, roughly double to not invest in lowering emissions in keeping with global targets. Economic losses will come in the form of direct and indirect impacts. Sectors like agriculture, forestry, tourism, and real estate are most at risk from floods, droughts, and other forms of climate change-induced extreme weather. A more substantial portion of losses will come in the form of weak growth and lower returns.

8 Recent reports from the U.N. World Meteorological Organization (WMO) state "On the current path of carbon dioxide emissions, we are heading towards a temperature increase of three to five degrees Celsius by the end of century" [6].

Even if the rest of the world acts to reduce emissions effectively, avoiding massive global losses, lack of a Canadian response to climate change still exposes our economy to major risks, namely the inability to attract global investment to key Canadian sectors and a significant competitive disadvantage for Canadian industries and business competing in a low-carbon global marketplace. In other words, the Canadian economy cannot free ride on the carbon-emission actions of other nations; climate-proofing our economy starts at home.

3. **Canada has a historic opportunity to align its goals for growth with its low-carbon transition.** Right now, as we face the most severe economic recession since the Great Depression, Canada is poised to make generation-defining decisions about how to invest in our economy's future. Spurred by the imperative for economic recovery in the short-term, and economic growth over the long-term, Canadian governments, financial institutions, and the private sector can work together to define tangible "clean growth" opportunities that will set us on the right path for 2030. With financing costs at a historic low, there is a unique opportunity to channel cheap capital into GHG abatement projects, which will pay economic and environmental dividends.

   The economic opportunities of a low-carbon transition have been well-documented. The New Climate Economy report found that "...bold action could yield a direct [global] economic gain of US$26 trillion," by 2030 [8]. This is the moment to chart how Canada will secure its share of that wealth, and the broader national prosperity that will come from achieving a healthy and sustainable climate.

1 INTRODUCTION

In order to meet Canada's goals of reducing annual CO_2 emissions 30% below 2005 (and net-zero by 2050) the participation of Canada's financial sector is imperative. Firms will need to invest in new technologies and ways of doing business. New and existing forms of financing will be required to ensure success. The investment in climate-friendly technologies and policies will not come from government alone, the private sector has an important role to play. For instance, a significant investment in productive assets will benefit Canadian firms in the long term. Calculating the amount of capital required to meet our reduction goals is an important first step to reducing emissions. The following implements the first of 15 recommendations of the Canadian Expert Panel on Sustainable Finance. We hope that this will operate as a loose blueprint on the path to transforming the Canadian economy.

We calculate costs (capital to be mobilized) associated with abatement, overall, broken down by sector, and across jurisdictions. Emissions are reported in CO_2eq. (CO_2 and equivalent GHG) across Canada's various economic sectors. We report abatement costs ($/$CO_2$eq.) grouped by economic sector and sector-specific weighted average costs of capital. Some sectors may have very low and specific one-off abatement costs associated with effective smaller-scale projects, however, in this report we focus on larger-scale carbon abatement opportunities that can be implemented sector- or industry-wide. Abatement costs are expressed in costs (CAD$) to abate one tonne of CO_2eq. These numbers enable us to estimate the amount of mobilized capital needed for Canada to reach its 2030 Paris Agreement target. Canada's 2030 target is to reduce GHG emissions to 30% below 2005 levels, or 511 megatonnes (Mt) of CO_2eq.

We have estimated the total required investment to reach emissions 30% below 2005 levels at $128 billion. We report costs for different abatement strategies and examine abatement costs across jurisdictions. We add context to the amount of required capital by expressing it relative to macroeconomic public finance variables such as GDP or stimulus spending, and relative to the private sector, such as average revenues or market capitalization. This analysis makes clear that the total amount is manageable and that co-operation between government (at all levels) and industry, supported by the Canadian financial system is best compared to government or industry addressing this issue alone. By acting fast Canada will be able to capitalize on the development of technologies to transition to a low-carbon future and the financial sector will develop the capacity to export their sustainable finance know-how to slower moving jurisdictions.

This type of research and specifically, a capital mobilization plan for Canada is needed not only because it will help spark additional conversations and research to follow but will assist Canada in reaching its Paris Agreement targets and effectively address climate change. This report also addresses the first of 15 recommendations provided by the Expert Panel on Sustainable Finance. The role of the Expert Panel on Sustainable Finance is to "work with the private sector and the federal government, in collaboration with securities commissions, to promote awareness among Canadian financial market participants of climate-related risks and to advance the recommendations of the TCFD [Task Force on Climate-related Financial Decisions]" [9]. This report along with subsequent complementary reports and the inclusion of results from numerous stakeholders, consultants, and academics will help the private and public sector understand their role and map out a pathway for integrating investment and climate goals.

Opportunities are present right now because the economy needs a strong stimulus package that can increase consumer confidence and help create jobs in new climate-friendly industries. The EU has risen to the occasion as they have recently approved a massive USD$2 trillion stimulus package of which USD$572 billion is earmarked for climate action [10]. With the 30-year Canadian bond sitting at just 1%, financing has never been cheaper than it is today, which makes for a favourable lending environment in which large scale spending can occur. Benefits associated with working towards a low-carbon future are also substantial. The New Climate Economy report found that "...bold action could yield a direct [global] economic gain of US$26 trillion through to 2030 compared with business-as-usual" [8]. Canada's GDP makes up about 1.34% of global GDP, if we assume gains are proportional to GDP, a quick calculation tells us that an economic gain of US$348, or roughly CAD$467 billion could flow to Canada [11]. These benefits together with our total cost estimate of $128 billion give this project a very high positive net present value (NPV) of CAD$339 billion.

Almost equivalent to benefits from action taken are the costs that could be incurred from inaction. The Economist Intelligence Unit (EIU) estimates value at risk (VaR), in present value, for both a private and public sector perspective, under a five-degree increase (a likely business-as-usual scenario), to be US$7.2 trillion to US$18.4 trillion, respectively. The percentage reduction in risk should warming be kept within two degrees relative to five degrees for the private and public sector is 63 and 71 percent, respectively. This means that acting on climate change and keeping warming within two degrees Celsius could help to reduce between US$4.54 trillion and US$13.064 trillion in present value losses, compared to a BAU scenario. Taking Canada's share at 1.34% of global GDP implies a cost savings between $81 to $234 billion in CAD. Given Canada's high GHG intensity, a more likely assumption is that these costs associated with climate change would be disproportionately larger than 1.34% of global costs for Canada.

2 CANADIAN GREENHOUSE GAS EMISSIONS

GHG emissions are reported in industry standard CO_2eq. The common units make reporting and tracking of these gases easier and comparable across firms, times, and jurisdictions. For simplicity, CO_2 simply denotes CO_2eq. for the rest of this report. The Government of Canada, the source of our data, reports its emissions for the following sectors: Oil & Gas, Transportation, Buildings, Electricity, Heavy Industry, Agriculture, and Waste & Others[9]. Total annual GHG emissions broken down by sector are reported in Figure 1.

Figure 1: Canada's GHG Emissions by Sector Over Time

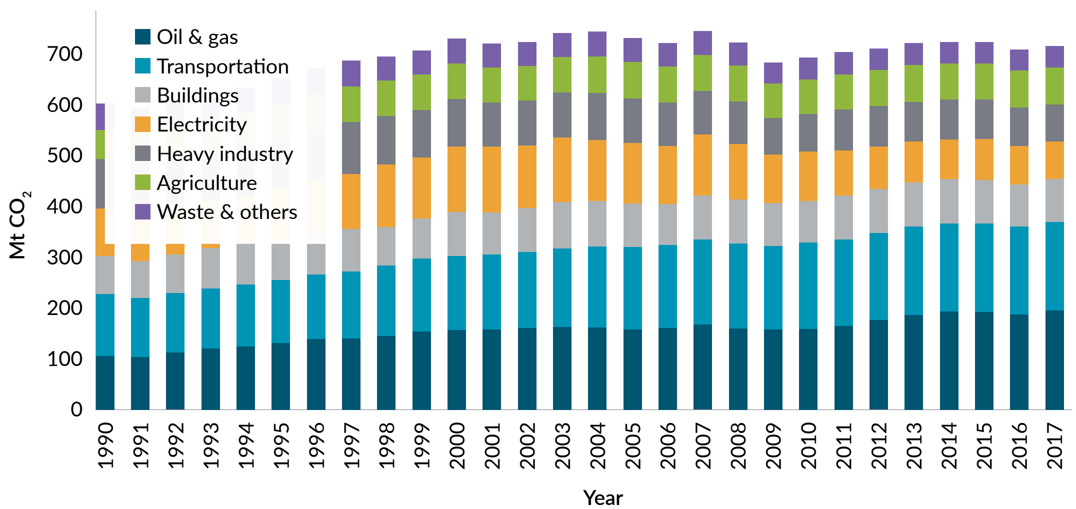
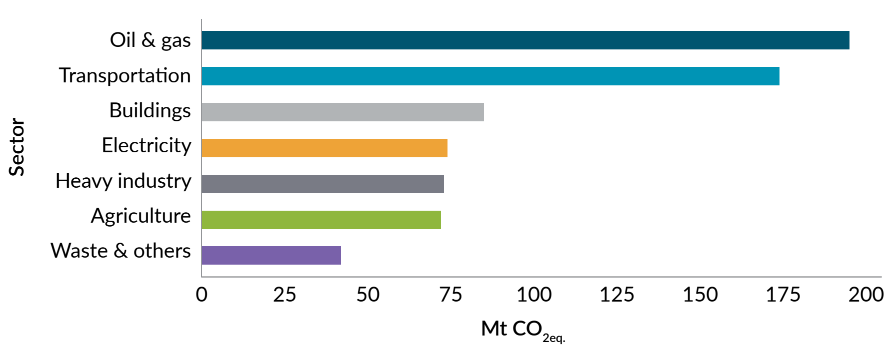


Figure 2 shows Canadian GHG emissions in 2017 (the most recent year for reported GHG emissions) by sector. Oil & Gas and Transportation combined make up more than half of GHG emissions in Canada.

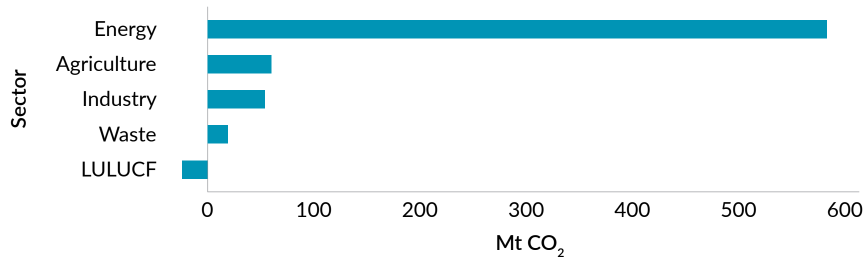
Figure 2: Canada's 2017 GHG Emissions by Sector



9 The Waste & Others sector consists of emissions from light manufacturing, construction, forest resources, waste and coal production

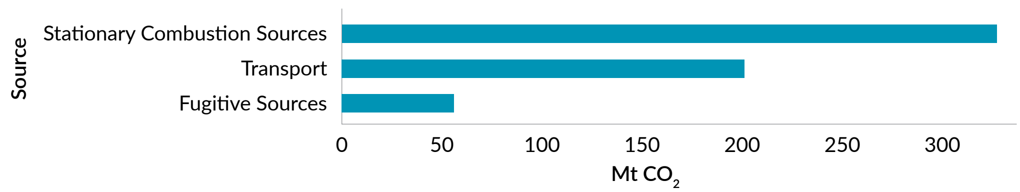
We also report GHG emissions within Canada for 2017 using the Intergovernmental Panel on Climate Change (IPCC) classification scheme for sectors, in Figure 3. Canada's national totals exclude emissions or removals from the LULUCF sector and are included when adhering to IPCC classifications. The emissions attributable to LULUCF are small and negligible and including or excluding these emissions do not meaningfully change our estimates of total costs. Total emissions in 2017 were 716 $MtCO_2$, the sum from Figure 2 or for energy, agriculture, industry, and waste (excluding LULUCF) in Figure 3.

Figure 3: Canada's 2017 GHG Emissions by IPCC Sector



As can be seen in Figure 3, energy use is the dominant sector in terms of CO_2 emissions. Breaking this down further, as in Figure 4, by source within the energy sector helps further illustrate emission sources.

Figure 4: Canada's 2017 GHG Emissions by Source within Energy



We have chosen to stick to the classification and scheme provided by the Government of Canada and not the IPCC as we prefer the Canada-specific context. Selecting one classification system over the other does not change our costs estimates in any meaningful manner. Formally CO_2 from transport and storage within the energy sector is reported at less than 0.05 Mt. CO_2 but was not included in the figure.

3 ABATEMENT COSTS

The previous section reports emissions across sectors in Canada. While important, it does not address the costs associated with abating, or not emitting, GHG. Clearly, GHG emissions cannot be abated without a cost. Thus far there are no estimates for the potential costs in Canada (or globally) and thus no clear idea about how much capital will be required, nor the potential sources for this capital. Our approach is both sober and neutral. We calculate abatement costs using publicly available academic papers, industry reports, and estimates. Where possible, we identify more than one cost estimate per sector and emission source. We then take an average of the estimates to arrive at a best estimate of the cost to abate.

To arrive at total and sector costs we use a simple approach. First, we take abatement costs and multiply the average by the total amount of GHG abatement required to attain the 2030 goal of emissions 30% below 2005. We also calculate a weighted average using the average abatement cost for each sector and the proportion of abatement required in each sector. We calculate the abatement proportion by sector by taking the relative emissions for each sector and assuming each sector will proportionally reduce emissions. High-emission sectors will abate proportionally more than low emission sectors. We have chosen this GHG reduction assumption as neutral and objective, and have avoided predicting if certain sectors will grow or shrink in the future (potential growth of the Electricity sector through electrification). Finally, we present a range for our total cost to provide additional information on our estimate of the best-case and worst-case cost scenarios.

We express abatement costs in Canadian dollars per unit of CO_2. This is a transparent way to quantify the costs of reducing GHG emissions. For example, we use an abatement cost estimate for replacing coal-generated electricity with wind power. This particular abatement cost is relatively low for two reasons. First, the cost of onshore wind power is relatively low and second, the difference between coal-generated electricity emissions and wind emissions is very large. These two factors together make this mitigation strategy an attractive investment if one is looking to reduce overall GHG emissions.

Having a baseline case or technology is essential when estimating costs. This is because wind power doesn't explicitly reduce GHG emissions (unlike carbon capture), it indirectly reduces emissions by replacing electricity-generating technology with high emissions. For example, by replacing coal with wind, coal is the baseline. With a baseline established, the differences in costs associated with both options as well as the difference in emissions are calculated to finally obtain an abatement cost. See Appedix D for a more detailed look at how some of these costs are calculated. This idea of a baseline is directly linked to the idea of incremental costs. Costs are incremental because some will be incurred regardless of any thought for a low-carbon future - absent care for the environment, over time new electricity-generating units will still need to be built, serviced, or repaired. All abatement costs found in the Electricity sector should be viewed as incremental costs because they are calculated under the assumption they replace or are used in lieu of more carbon-intensive infrastructure. Replacing something contrasts with abatement costs associated with building something entirely new (e.g. carbon capture and storage) and should be viewed as absolute or non-incremental costs.

The methodologies used to calculate abatement costs vary greatly. Some of the studies are straightforward and transparent while others lack transparency. For instance, some studies lack details on the construction of their estimates, include or exclude behavioural forces, and exclude or include intertemporal dynamics and non-financial costs. We attempt to remain agnostic by including estimates from studies that use a wide variety of quantification techniques. By taking the average and median costs we hope to remove biases that may be specific to the methodology. Thus, our final cost estimate does not place a large weight on any particular cost construction methodology.

3.1 CALCULATION OF MOBILIZED CAPITAL AND TOTAL ABATEMENT REQUIRED

We estimate it will take $128 billion to reduce Canada's GHG emissions by 30% below 2005 levels. To arrive at our estimate, we use the Canadian Government's GHG emission projections for a "With Measures" scenario as the reference case. The "With Measures" or "2019 Reference Case" was taken from the Canadian Government's projections and is "based on federal, provincial, and territorial policies and measures that were in place as of September 2019. This projection assumes governments take no further climate action from September 2019 on" [13]. We took this as a fair base case as it incorporates action that has already been implemented and avoids dependence on future policies.

The 2030 emissions target is 511 Mt. of CO_2 per year. We assume that emissions will decrease linearly from the projected 694 Mt. per year in 2021 to 511 Mt. per year in 2030. This linear GHG reduction assumption was chosen as it keeps us in the middle of two extremes: reductions happening right away and just before the 2030 deadline. The Government of Canada projects emissions will decrease by 21 Mt. from 2021 to 2030 given current investment levels and policies. We work backwards from the 2030 required emissions of 511 Mt. to the projected 694 Mt. of emissions using each year's projected emissions to arrive at a total required abatement of 789 Mt. of CO_2. For instance, we estimate that in 2025 66 Mt. of CO_2 will need to be abated to meet the 2030 goal. Table 1 reports the details, where "Abatement Required" column is the "Projected" emissions column minus the calculated annual emissions target.

Table 1: Projected Emissions vs. Abatement Required for 2030 Goal

Year	Emissions (Mt. CO_2eq.) Projected[1]	Emissions (Mt. CO_2eq.) Abatement Required
2021	694	8
2022	684	18
2023	673	26
2024	670	43
2025	674	66
2026	676	87
2027	676	107
2028	676	126
2029	676	146
2030	673	162

1 2019 Reference Case sourced from Canada's 2019 Greenhouse Gas (GHG) Projections [12]

Our estimate uses a sectoral weighted average cost using average abatement costs by sector assuming each sector reduces emissions, proportional to 2017 emissions. This is reported in percent in "proportion" column in Table 2[10].Total required abatement is 789 Mt. and the weighted average abatement costs are \$162/tCO_2 generating a required investment of \$128 billion, or \$12.8 billion per year. Using a simple average generates an average abatement costs of \$169/tCO_2 and total costs of \$133 billion. The "Abatement Required" column is expressed as the total or cumulative abatement needed over the 10-year time frame from 2020 to 2030. Sectors are listed in descending order sorted by their CO_2 reduction contribution or "proportion" value. Due to rounding, numbers may not exactly add up to 100.

Using maximum and minimum cost estimates, we estimate a range of required investment between \$90 billion and \$166 billion depending on whether or not true costs are closer to the minimum or maximum estimates[11]. This large range reflects the uncertainty involved in future variables such as underlying technological advancement paths, clean energy implementation rates, and varying levels of government and private sector support. See Table 9 in the appendix for a summary of all the abatement cost estimates used in our calculation.

Table 2: Total Weighted Average Abatement Cost Breakdown

Sector	Proportion (%)	Average Cost (\$/t CO_2eq)	Abatement Required (Mt. CO_2eq)	Required Investment (\$ millions)
Oil & Gas	27	126	209	26,329
Transportation	24	283	186	52,656
Buildings	11	123	88	10,847
Electricity	10	214	76	16,252
Heavy industry	9	126	75	9,391
Agriculture	9	88	74	6,455
Waste & others	5	139	41	5,650
LULUCF	5	14	39	545
Total			**789**	**128,125**

One important assumption to make note of is the fact we assumed all these abatement costs to be annually recurring and not one-time expenses. This is a fair assumption given the relatively short term 10-year period of interest. These costs may fall over time and therefore have the potential to drastically lower the overall cost. Some examples are large-scale carbon capture that have been fully amortized with low variable operating costs. We largely avoid making predictions about future costs and whether costs will fall or increase as the empirical evidence is fairly limited.

3.2 CROSS-SECTOR COLLABORATION

Sectors vary in terms of the ease and cost with which they can reduce GHG emissions. Industries such as aviation/transportation are very hard (costly) to abate and electricity generation is easier (less expensive) to abate. The fact that abatement costs differ by sector combined with the fact sectors are highly interdependent leads to collaboration opportunities. In this environment two sectors that rely on each other for goods and services can coordinate their efforts and concentrate their capital to the most cost-effective strategy. For example, the technology and cloud computing industry require electricity to operate. Abatement strategies could include installing renewable electricity (solar or wind) to cool their data centres or retrofitting their offices. However, a relatively cheaper abatement option exists if they coordinate to invest in renewable with the electricity sector to replace coal-generated electricity for onshore wind or solar.

The idea of collaborating across sectors is generalized by the idea of buying and selling emissions credits. For instance, until recently Quebec, Ontario, and California participated in a cross-jurisdictional emissions trading program for large emitters. Even though Ontario has withdrawn from this agreement, Quebec and California are currently still involved. This allowed firms with inexpensive abatement opportunities to invest and finance the investment by selling emissions credits in the emissions market. Emissions credit trading formalizes the collaboration process across sectors and prevents firms from having to collaborate directly.

10 We assume that LULUCF acts as a carbon sink that removes 5% of overall CO_2.

11 Calculated as 128*(1-0.294) for low and 128*(1+0.294) for high. 0.294 is the median value of the series obtained from high-mid/mid for all abatement costs presented in a range.

3.3 NEGATIVE ABATEMENT COSTS

Abatement costs can be negative, in that a project can simultaneously reduce GHG emissions and save money. There is debate about this concept alone as it presents itself as a ”free lunch”, an idea economists treat with skepticism. Negative costs suggest that firms are leaving profitable unexploited investment opportunities on the table, implying an inefficient allocation of resources. Some negative abatement cost opportunities may exist, in particular for small investments required of unsophisticated individuals. These opportunities may remain unexploited because of misaligned incentives, lack of information, or significant upfront costs with an associated long payback period [2]. We avoid where possible negative abatement cost estimates as they are unlikely to be large and it is unclear that they exist. An example of negative abatement cost is included in the buildings sector because it is a non-price based, behavioural intervention that addresses a market imperfection.

3.4 DYNAMIC COSTS

Abatement costs are dynamic because of a classic “chicken and egg” problem, in which an expenditure today influences the options available to others in the future [14]. Kenneth Gillingham and James Stock outline this perfectly with their EV example “...purchases of electric vehicle today will, on the margin, stimulate demand for charging stations, which once installed will lower the effective cost for future potential purchasers of electric vehicles” [14].

Research and development (R&D), economies of scale, and learning by doing are also strong influential factors that can further reduce the future price of technologies such as solar and wind. Kavlak et al. estimate how each of these factors contributed to the price decline in photovoltaic modules between 1980 and 2012. They find public and private R&D and economies of scale contributed an estimated 59% and 22% respectively, of the cost reduction throughout the 1980 and 2012 time period [15]. Learning-by-doing, defined as incremental and resulting from a repeated, routine manufacturing process, contributed 7% of the cost decline during this period.

One central conclusion is that “economies of scale in particular have had a greater impact more recently, and likely offer an avenue for further cost reductions.”

Energy asset investment usually has a large irreversible component, which in general implies state dependence, meaning the dynamically optimal path may differ from a sequence of myopic optimizations each chosen at a point in time [14]. This argument is at the core of the “natural gas bridge fuel” debate, as further investment in the natural gas industry locks in large amounts of capital and delays future decarbonization.

3.5 TECHNOLOGICAL IMPROVEMENT

The previous analysis relies on static costs. Some studies assume abatement costs will fall in the future [3]. We could not identify a trend in the abatement costs over time and assume no trend. Put simply, we assume that the average abatement costs of the past will be the same as the average costs in the future. We think that this assumption is the most likely.

However, a scenario with declining technology costs or declining costs related to the scaling up of abatement technologies is not impossible. Certain sectors are more likely to experience lower abatement costs in the future than others. We perform a scenario analysis to show what would happen to our overall total cost estimate if some abatement costs decreased.

Technological advancements and economies of scale have the potential to lower costs. For example, subsidy programs, feed-in-tariffs, and the resulting R&D have assisted in drastically reducing the price of solar photovoltaics over time. However, one also needs to consider the cost changes of the non-green alternative. If the price of natural gas-generated electricity goes down the corresponding abatement cost for wind replacing natural gas would go up (wind alternative to natural gas would become *relatively* more expensive).

The electricity generation and transportation sectors are the two sectors most likely to exhibit cost of abatement decreases over the next 10 years. We also study the impact of costs reductions in CCS technology. For this scenario analysis we assume the average abatement cost for the Electricity and Transportation sectors to decrease by 3%, relative to the previous year, each year for 10 years. In this scenario our total required capital estimate drops from $128 billion to $114 billion. A steeper 5% annual decrease drops our total estimated required capital further to $107 billion. If we add the possibility of the estimated average abatement costs for carbon capture and storage to decrease by 3% each year, relative to the previous year, for ten years, then our total estimate drops to $102 billion.

We believe these costs are most likely to decline but the future is difficult to predict. In some cases, taking costs as static is perfectly reasonable. Take for example costs to seal up fugitive methane for natural gas distribution systems, the process is well-known and the costs of this process are likely to be similar in the future [14]. This is why we focus on reduced abatement costs for CCS in the Oil & Gas sector and not for methane-related abatement costs. Several abatement technologies and policies are experimental or new, meaning we do not have experiences with their efficacy or general applicability.

3.6 HIGHER ABATEMENT COST STRATEGIES

There is a temptation to invest in the lowest abatement cost projects. This path is fraught if these technologies are dead ends in the long term. An investment now, in a low-cost alternative may be counter-productive if it restricts investment in higher cost but higher long-term potential projects. For instance, investing in natural gas is a low-cost way to reduce abatement costs now. Natural gas projects require large and long-term investments in infrastructure, in order for the low costs to materialize the assets must remain in operation for long-periods of time to amortize and realize the cost benefits. This means they will continue to emit GHG in 20 years when other higher initial-cost technologies could be operational with considerably lower emissions.

Adrien Vogt-Schilb, Guy Meunier, and Stéphane Hallegatte highlights that it's

> *"...preferable to spend $25 to avoid the marginal ton of carbon in a sector where abatement capital is expensive, such as public transportation, or in a sector with large abatement potential, such as the power sector, than $15 for the marginal ton in a sector with lower cost or lower abatement potential. The reason, distinct from learning spillovers, is that reducing greenhouse gas emissions requires investment in long-lived abatement capital such as clean power plants or public transport infrastructure. The value of abatement investment comes from avoided emissions, but also from the value of abatement capital in the future"* [16].

3.7 COST OF NOT INVESTING

There are significant costs associated with not investing. In addition to the environmental costs and damages, there are costs associated with global capital flowing away from Canada, non-competitive products, shifts in consumer tastes, as well as costs associated with carbon tariffs and the costs of emissions.

Almost as large as the benefits from action taken are the costs that could be incurred from inaction. Costs from inaction, at least at lower levels of warming, will result from damages concentrated in sectors that are sensitive to weather conditions, such as agriculture, energy, forestry, and water. These sectors are interconnected with the rest of the economy so shifts in prices resulting from climate change will affect overall spending patterns and household incomes [7]. At higher levels of warming the impacts of climate change are projected to be economy wide thus posing systemic risk. Concretely, economy-wide damages can result from a higher frequency and intensity of events such as wildfires, droughts, floods, and hurricanes.

The Economist Intelligence Unit (EIU) quantifies the costs of inaction by estimating the value at risk (VaR) for the world's current stock of manageable assets resulting from damages of climate change. EIU estimates, in discounted, present value terms the costs from climate change under several different global warming scenarios. They also calculate the reduction in risk if warming was kept within two degrees Celsius to show the global "cost savings" of taking action. If we assume five degrees to be the BAU scenario then taking action to keep global warming within two degrees Celsius could result in cost savings between US$4.54 trillion and US$13.064 trillion globally. Taking Canada's share at 1.34% of global GDP implies the present value of cost savings of $61 billion to $175 billion in USD, or $81 to $234 billion in CAD at an exchange rate of $1.33774 CAD/USD. Given Canada's high GHG intensity a more likely assumption is that the costs associated with climate change would be disproportionately larger than 1.34% of global costs for Canada.

So far, we have largely talked about GHG mitigation, however, adaptation is also a key element to consider when discussing all climate change-related risks. According to the IPCC, impacts of climate change are effectively irreversible, meaning there will be costs for various adaptation measures used to adapt to physical climate risk. Some examples of adaptation measures include redesigning building codes to future climate conditions and extreme weather events; erecting flood defences and raising the levels of existing dikes; and developing drought-tolerant crops [17].

Canada could meet its 2030 target while the world does not. This could mean some of the benefits of abatement do not accrue to Canada. This calls for Canada, in addition to cleaning up our own backyard, to act as a global leader by researching, developing, and exporting effective technologies, capacities, and policies for the rest of the world.

4 COST BY SECTOR

Abatement strategies in certain sectors are much easier to quantify than in other sectors. For example, consider the difference between calculating the cost of implementing EVs in the transport sector vs. carbon capture and storage in the Oil & Gas sector. EVs have been implemented in several settings providing decision makers with voluminous data. Carbon capture and storage is at best an experimental technology with few large-scale implementations. Some costs also represent specific projects with idiosyncratic details and may not be broadly applicable. Further, the fact that it is very hard to find publicly available studies that quantify abatement costs or that only a few abatement cost estimates exist for a whole industry is telling. There also exists a degree of endogeneity in these sectoral costs; hard-to-abate sectors have very few abatement costs calculations because they are difficult to estimate, and few options exist. We proceed with an overview and discussion of abatement costs and methods to abate GHG emissions by sector.

4.1 OIL & GAS

In the Oil & Gas sector one technology that can be used is Carbon Capture and Storage (CCS). A report by the IPCC estimates costs between $50-150 USD per tonne of carbon captured (abated) [18]. Another estimate by Carbon Engineering's CEO states their technology will cost around $100- 150 CAD per tonne of CO_2 captured [19]. Carbon Engineering is a direct air capture company located in Squamish BC.

Another way to lower emissions in Canada's Oil & Gas sector is to reduce methane emissions, a potent GHG in terms of its global warming effects. The Government of Canada has released a report on a proposed federal methane regulation for the Oil & Gas sector. The report states it could reduce 20 Mt. of net GHG emissions in 2030, for a cost of $3.3 billion over an 18-year period [20]. They also state that these costs would be partially offset by $1.6 billion using recovered natural gas, which places the project at a net cost of $1.7 billion. We have compiled numerous abatement costs associated with addressing fugitive methane and they are by far the lowest cost option within the Oil & Gas sector. We find an average abatement cost for CCS within the Oil & Gas sector to be $156, which contrasts with just $20 for addressing fugitive methane.

The Oil & Gas sector is characterized by a slightly below average abatement cost of $126/tonne of CO_2 and the second highest overall total cost.

4.2 TRANSPORTATION

Transportation is the second highest GHG emitting sector. There are several different abatement estimates. Take for example the car allowance rebate system or "Cash for Clunkers". Christopher R. Knittel of MIT says it can cost up to $400 dollars per tonne of CO_2 abated, representing a relatively high abatement cost. He concludes that it may have acted as a good method for stimulus but had unattractive abatement potential per dollar spent.

Total capital required to abate from the Transportation sector is dependent on future policy. For instance, the role biodiesel will play in trucking and heavy equipment and the roll-out of EVs and EV charging networks. We do not predict future developments, rather we gather several estimates and average across all cost estimates. This reduces the influence of any individual estimate. Overall, this sector is characterized by high abatement costs due to vast amounts of locked-in capital and established networks built for carbon intensive vehicles.

4.3 ELECTRICITY

Electricity generation is an important factor for several reasons. It is hard to imagine a transition to a lower carbon economy without electricity and in particular without low-carbon electricity. Replacing internal combustion engine vehicles with EVs is useful insofar as the electricity used to charge the EVs is low CO_2. Charging cars with electricity generated at a coal-powered plant is counterproductive.

Estimating abatement costs for electricity generation is complicated as it includes several components. For instance, the levelized cost of electricity, an often-used measure, or energy (LCOE) for renewable energy sometimes leaves out important aspects of the total implied cost [21]. For a lengthier explanation about what LCOE is refer to Appendix C. For now we assume it is the cost per unit of energy sourced from a particular technology. For renewables, their lack of dispatchability is often omitted in their cost. Dispatchability means that for renewable energy it cannot be quickly dispatched, or turned on, to meet fluctuations in demand and are less reliable than nuclear or natural gas. The omission of costs or the loss of value from not being a dispatchable energy source will lead to a lower LCOE and abatement cost.

A lower LCOE occurs because the costs associated with making it a dispatchable source are not incurred, this lower LCOE then directly lowers the abatement cost. Some solutions to this are to use the levelized system cost of electricity, measuring the cost of the whole system rather than a single plant. Canadian Energy Research Institute (CERI) has addressed this when calculating abatement costs by having the green alternative be a system where wind and solar are used in coordination with a natural gas combined cycle (NGCC) system so that energy demand can always be matched with appropriate levels of supply. Abatement costs accompanied by a dispatchable energy source to displace a NGCC system are detailed in Appendix 9.

A low-cost energy sector estimate uses wind or a wind and NGCC coordinated system to displace coal or natural gas. These costs are low partially because onshore wind has become inexpensive and because the difference in CO_2 emitted from coal and wind is large.

Some experts predict electricity will capture a growing share of total energy consumed. This will occur through the electrification of other energy-consuming activities like transportation and heating and cooling of buildings. This growing dependence and demand for electricity has the potential to bring these costs down further as the benefits of economies of scale continue to bear fruit and greater R&D contributes to the steady price decline over time. Powering more of our activities and industries with clean electricity is recommendation 15 from the Expert Panel on Sustainable Finance.

4.4 BUILDINGS

Abatement costs for buildings or infrastructure are difficult to estimate because they often involve a non-financial cost or inconvenience associated with abating CO_2. For instance, you can lower the energy footprint of your home by investing in insulation, new windows, and a high-efficiency furnace but you have the inconvenience of living through a building project. The buildings sector exhibits numerous negative abatement cost estimates in various academic and industry sources. Negative abatement costs can arise when market imperfections or frictions cause decision-makers to ignore investments with pay-offs greater than the capital outlay. The same example as above can be used. Home/building owners can often retrofit and insulate at a cost well below the long-term value of the investment. The investment requires the borrowing of often large sums of money to finance the investment. This hurdle and perhaps a lack of information on the long-term financial benefits appears to be hindering investments that could generate significant negative abatement costs.

Retrofits of residential homes are presumably made by the homeowner themselves who may not have the most forward-looking, number-oriented mindset, which is in sharp contrast to a CFO of a company determining how to save money or lower a firm's carbon footprint. Homeowners are also more personally affected by the inconveniences associated with deep retrofits. Humans often resist actions that have clear long-term benefits if they are unpleasant in the short run. These barriers or hindrances are in addition to possibly unavailable or difficult to obtain upfront financing that would be necessary for some of the major retrofits expressed through negative abatement costs to be realized.

Split incentives are another reason for the non-realization of negative abatement costs that poses seemingly very attractive attributes, this occurs when the person responsible for paying the energy bill is not the same as the person considering the retrofit investment. Proper incentives that would lead to socially beneficial outcomes are not in place when such a scenario is present because the benefits associated with energy savings are not accrued by the person who made the investment decision in the first place.

In general, we have excluded negative abatement costs as being infeasible. We include one negative abatement cost in this sector's average as we deem it to be feasible based on the above arguments. The included estimate addresses a market imperfection and is a behaviourally-driven method to abate CO_2. This behavioural aspect and governmental nudges are important to consider because they can be quite cost effective. This behavioural measure is focused on programs that report on home energy use which create nudges for people to be more environmentally conscious. Normally negative abatement costs would be addressed by the market until their abatement potential is quickly exhausted. In this case the frictions associated are significantly large, so we believe significant abatement potential still exists.

4.5 HEAVY INDUSTRY

Heavy industry is the textbook example of a "hard to abate" sector. Most emissions in this sector are produced from what are called "process emissions" that occur during the production or mining of materials for cement, iron and steel, and chemicals. There are a few solutions to reducing the emissions intensity of these processes and they are largely limited to carbon capture or energy efficiency initiatives. Because the current technology is not fully developed and strategies to effectively reduce emissions in this sector have not been established the average abatement cost for this sector is likely artificially low.

Another hindrance in the decarbonization of this sector is that it is home to an abundance of long-lived assets. This is a problem because it locks in high-carbon assets for a longer than desirable period. Put differently, major financial decisions usually occur at the end of an asset's life because doing otherwise would imply the destruction or abandonment of a valuable resource, which then results in a higher overall cost for this course of action. This problem is similar to the stranded assets problem in the Canadian oil sands.

4.6 AGRICULTURE

A large portion of emissions from the Agriculture sector comes from enteric fermentation which is essentially when livestock break down carbohydrates and release it in the form of methane, a potent greenhouse gas. This is a biological fact, so to address this requires the changing of consumer behaviour to eat less meat. Plant based meat products may be one way to address this. These products have been on the rise as they become options at different major fast-food chains. Estimated abatement costs for this mitigation strategy are scant as these product offerings are relatively new and involve major behavioural considerations.

Some other forms of abatement measures in the Agriculture sector include increasing carbon sequestration in soils and reducing storage losses and wastes. The Agriculture sector in general has few abatement options that are currently seen as feasible and practical and they are mainly restricted to efficiency improvements, which is reflected in the abatement costs we have gathered in Table 9.

4.7 LAND USE, LAND USE CHANGE AND FORESTRY

Within the LULUCF sector there exist both GHG emission sources and sinks. Numbers reported on when adhering to the IPCC classification standard show that in 2017 the largest emission source was Harvested Wood Products at 130 Mt. CO_2 and the largest sink was Forest Land at a negative 150 Mt. CO_2. Other sources like Wetlands and Grasslands contribute relatively negligible amounts of CO_2 which leaves this sector as a net sink of GHG of 24 Mt. CO_2. Some specific methods to reduce or simply manage CO_2 using LULUCF include preventing or limiting deforestation, restoration of land, afforestation, improved soil management, and longer rotations of farmed forests. In general, LULUCF abatement costs are low but also have limited overall abatement potential.

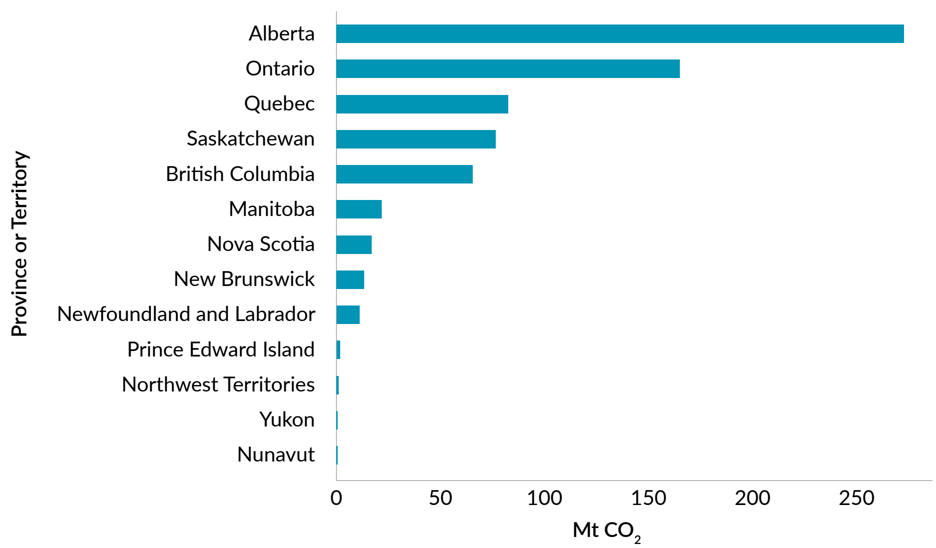
5 PROVINCIAL ANALYSIS

The costs of reaching our 2030 goals are not spread evenly across jurisdictions and provinces. We outline the details below.

5.1 PROVINCIAL GHG EMISSIONS

Figure 5 outlines 2018 GHG emissions by Canadian province or territory[12]. As shown in the graph, Alberta and Ontario are the largest emitters of GHG emissions within Canada. Alberta emits 37% of total emissions and Ontario emits 23%. Together they emit 60% of the Canadian total. Of the top five emitting provinces, Saskatchewan, British Columbia, and Alberta have increased their emissions from 2005 to 2018, whereas Ontario and Quebec have reduced their emissions.

Figure 5: 2018 GHG Emissions by Province



Emissions are not evenly distributed across provinces nor are the largest sources common across provinces. Transportation is the largest emissions source in Ontario and nine other provinces. Oil & Gas is the largest emissions source in Alberta and Saskatchewan. Only Nova Scotia has a top emissions source that is neither Transportation nor Oil & Gas with Electricity making up 41% of emissions. Figure 6 provides details on emissions source for the top 5 emitting provinces.

Figure 6: Sources of Emissions Within Top Five Most Emitting Provinces

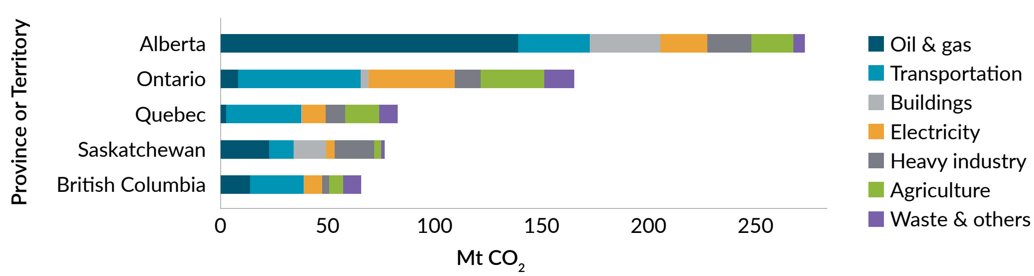


Table 3 outlines the sector in each province that emits that largest share of the provincial total. The table is sorted in descending order of the values found in the "Percent of Total" column. This column can act as a metric that reflects the diversity of sources of CO_2 for each province. Nunavut has the highest proportion of emissions from a single sector (Transportation). New Brunswick has the lowest, which is also Transportation. This relatively low number reflects a province whose emissions are more evenly distributed across sectors. New Brunswick's Electricity and Oil & Gas sector contribute comparable amounts, as of 2018 they were 24% and 23% respectively. Of all sectors, Transportation is most frequently the largest contributor of CO_2 emissions within each province or territory, marking it as a good sector in which to concentrate efforts.

12 Provincial emissions data was downloaded from Canada's Official Greenhouse Gas Inventory

5.2 PROVINCIAL ABATEMENT COSTS

Similar to the sector analysis, we calculate a weighted average abatement cost for each province. This cost is a product of sector average abatement costs and the proportion of emissions that come from each sector, in each province or territory. We also include the 5% contribution from the LULUCF in the provincial analysis. We then use this cost and multiply it by the "Abatement" Required column to find the total cost or required investment for each province. The set of "Required Abatement" values for each province is calculated by finding how much each province emits relative to the country as a whole and then multiplying this percent value by the total abatement required (789 Mt. CO_2). This is essentially a scenario where every province reduces emissions proportional to their emissions required to meet our 2030 target.

Table 3: Largest Sector Source of Emissions for Each Province

Province or Territory	Sector	Percent of Total
Nunavut	Transport	92
Yukon	Transport	79
Northwest Territories	Transport	59
Alberta	Oil & Gas	51
Prince Edward Island	Transport	44
Quebec	Transport	43
Nova Scotia	Electricity	41
British Columbia	Transport	38
Newfoundland & Labrador	Transport	37
Manitoba	Transport	36
Ontario	Transport	35
Saskatchewan	Oil & Gas	30
New Brunswick	Transport	28

These calculations and total required investment for each province or territory are listed below in Table 4. Nunavut has the highest weighted average abatement cost. This is because Transportation has the largest average abatement cost and it makes up 92% of Nunavut's overall emissions. Alberta has the lowest average weighted abatement cost due to the relatively low abatement cost for the Oil & Gas sector and its high proportion (51%) of emissions. Alberta also has the highest total required investment estimate even though it has the lowest weighted average abatement cost per tonne of CO_2. This is because Alberta's required abatement is significantly larger than every other province. Summing each province's total required investment yields a grand total required investment of $128 billion.

Table 4: Provincial Abatement Costs Using Abatement Cost Average

Sector	Proportion (%)	Average Cost ($/t CO_2eq)	Abatement Required (Mt. CO_2eq)	Required Investment ($ millions)
Alberta	37.4	146	294.9	43,042
Ontario	22.6	171	178.5	30,539
Quebec	11.3	180	89.3	16,116
Saskatchewan	10.5	150	82.7	12,400
British Columbia	9.0	176	70.9	12,494
Manitoba	3.0	162	23.6	3,814
Nova Scotia	2.3	202	18.4	3,720
New Brunswick	1.8	181	14.3	2,588
Newfoundland and Labrador	1.5	183	11.9	2,183
Prince Edward Island	0.2	176	1.8	319
Northwest Territories	0.2	207	1.2	258
Yukon	0.1	242	0.7	162
Nunavut	0.1	257	0.6	149
Total			**789**	**127,783**

We now put these provincial costs into context by dividing the annual required capital for each province (required investment column in Table 4 divided by 10) by provincial GDP[13]. We list GDP in absolute values (millions of $CAD) and its relative value (required investment divided by GDP) expressed as a percent value. Table 5 is ordered in descending order by GDP. All provincial data is sourced from Statistics Canada.

13 2018 GDP at market prices using chained 2012 dollars. Table: 36-10-0222-01 from Statistics Canada.

Table 5: Relative Required Abatement Capital

Province or Territory	GDP	
	M ($)	Relative (%)[1]
Ontario	778518	0.39
Quebec	394865	0.41
Alberta	346477	1.24
British Columbia	264063	0.47
Saskatchewan	86598	1.43
Manitoba	67432	0.57
Nova Scotia	40249	0.92
New Brunswick	33195	0.78
Newfoundland and Labrador	32406	0.67
Prince Edward Island	6314	0.51
Northwest Territories	4889	0.53
Nunavut	2986	0.50
Yukon	2699	0.60

1 relative to annual required capital

6 FINANCING THE TRANSITION

In the previous section we calculated abatement costs based on publicly available abatement costs and Government of Canada reported emissions. A second cost relates to the opportunity cost of capital required to finance the investments to reduce emissions.

6.1 WEIGHTED AVERAGE COST OF CAPITAL

We gather, from Bloomberg's terminal, the weighted average cost of capital (WACC) for each firm in Canada's benchmark index, the S&P/TSX Composite. Using these firm-specific WACCs we calculated a revenue weighted average WACC for various sectors or industry group/subgroup using Bloomberg's classification scheme. A revenue weighted average was used to avoid having small firms skew the estimates. This analysis can be viewed below in Table 6. Industry groups were selected such that they roughly coincide with the important sectors that are used in Government of Canada emissions reporting. Table 6 is ordered by WACC in descending order. For a more comprehensive list of WACCs along with a weighted average by market cap, in addition to revenue weighted, see Appendix 10.

The WACC for each sector represents the relative financing cost for each sector when investing in an abatement project. The WACC is often used as a hurdle rate for firms making investment decisions. Projects that offer net benefits below the hurdle rate are rejected whereas projects above the hurdle rate are undertaken. Firms and industries with high costs of capital may consequently under-invest in abatement projects relative to the ultimate goal of reducing emissions by 30%. For example, Transportation has the third highest WACC and the highest overall cost of abatement (see Table 2). This suggests that abating the required amount of carbon will be more difficult in the Transportation sector than in the low WACC Electricity generation sector.

Table 6: Average Industry WACC of Firms in the S&P/TSX Composite

Sector	Industry Group/Subgroup	Number of Firms	WACC (%)
Energy	Oil Comp-Integrated	4	7.56
Energy	Oil Comp-Explor&Prodtn	10	6.63
Industrial	Transportation	5	6.10
Basic Materials	Iron/Steel	2	6.06
Industrial	Engineering/R&D Services	2	5.82
Energy	Pipelines	7	5.69
Basic Materials	Forest Products&Paper	4	5.69
Basic Materials	Agricultural Chemicals	1	5.49
Financial	Banks	9	4.94
Consumer, Cyclical	Airlines	2	4.88
Utilities	Electric Generation	3	4.74
Financial	REITS	21	4.65
Utilities	Renewable Energy Generation	2	4.30

Produced using data from Bloomberg terminal

Table 6 has a mean WACC of 5.58% and median value of 5.69%. If we allocate some of the firms in the S&P/TSX Composite Index to the economic sectors we have calculated total abatement required costs for in Table 2 and use their costs relative to the total $128 billion as the weights for a weighted average WACC, we arrive at a weighted average WACC of 5.59%. This 5.59% contrasts with an overall revenue-weighted WACC across all firms in the S&P/TSX Composite Index of 5.40%.

6.2 DIFFERENTIAL COSTS

High cost of abatement and high cost of capital sectors will benefit most from support from the financial industry and the federal government. The federal government for instance can borrow funds (The yield on 10-year government of Canada bonds is 0.55% as of July 15th) for less than 10% of the average cost of capital for firms in the S&P/TSX Composite Index. If funds could be made available in the form of investments, asset-backed loans, or other public- and private-backed financing vehicles that benefit from the historically low interest rates, all Canadians could be better off. The average WACC of 5.6% is also at a historical low for firms, further highlighting the fact that the time has never been better.

7 FINANCING SOURCES AND OPPORTUNITIES

The amount of capital required to meet our 2030 goal is large. Too large for either the public or the private purse alone. Below we add some context on the amount of capital required. In the future we will go into more detail on specific funding vehicles, individual projects, and provide specific advice on concrete steps that may be taken.

7.1 PUBLIC FINANCING

This section will put the required capital into the context of the public balance sheet. Table 7 below lists the amount associated with various government spending and financing activity. Public spending or funds are broken up into either annual flows like GDP or tax revenues, or fixed amounts (stock). Where applicable we will compare the total investment required ($128 billion) to stock or fixed amounts and the annual costs/investments ($12.8 billion) to flows. Table 7 is sorted by descending order of the “Amount” value. Percent values are rounded to the nearest integer.

Table 7: Historic Public Spending Relative to Required Mobilized Capital

Measure	Amount ($ billions)	Capital required/ flows or stocks (%)[1]
Annual Flows		
Canada's 2018 GDP [2]	2,058	1
2018 general provincial government revenue	476	3
2018 general federal government revenue	333	4
2018 annual Canadian green bond issuance [3]	5.5	233
Stocks		
March 2020 federal debt (accumulated deficit)	704	18
Total provincial debt securities	924	14
Covid-19 stimulus spending as of March 28 [4]	202	63

1 $12.8 billion is used as capital required for annual flows and $128 billion for stocks (total)
2 GDP, and government revenue and debt sourced from Statistics Canada
3 Climate Bond Initiative (2019)
4 Bloomberg (2020)

The capital required to achieve of 2030 goals are large but not so large as to be infeasible. For instance, $12.8 billion (the average annual amount of required capital) is roughly 1% of 2018 Canadian GDP, 3% of annual federal tax revenues, or 4% of annual provincial tax revenues. In total terms it is roughly 18% of outstanding Government of Canada debt or roughly 63% of the currently projected Covid-19 stimulus spending. The required capital is still large but not so large as to be impossible to mobilize.

Public sector support is vital. The Covid-19 recovery coincides with a pivotal time in history where the impacts of climate change must be addressed and managed. A stimulus package can simultaneously work to create jobs and boost economic activity as well as address and build long-lasting low-carbon assets that will aid us in reaching our 2030 GHG reduction target. Stimulus spending on green projects come with strong economic rewards. A recent study finds that government spending on renewable energy creates five more jobs per million invested compared to spending on fossil fuels [22]. This highlights the potential for governments to invest in both the Covid-19 recovery and the transition to a low-carbon economy.

Public support is also strong for addressing climate change during the time of Covid-19. "A new Ipsos poll conducted in 14 countries finds that 71% of adults globally agree that, in the long term, climate change is as serious a crisis as Covid-19 is" [23]. Within Canada they found that 61% of respondents strongly agree/tend to agree with support for a green economic recovery from Covid-19[14].

7.2 PRIVATE FINANCING

Clearly federal, provincial, and municipal governments will not be able to finance the transition without the private sector. Most assets that emit GHG also generate economic value, as such these past and future revenues can be used to finance the transition to lower GHG. We compile commonly reported financial information for publicly listed firms on the S&P/TSX Composite Index to put the capital to be mobilized into the perspective of large public Canadian firms. It also allows for the assessment of the current capacity of the Canadian private sector to finance a transition.

Similarly to Table 7, we compute annual flows (income and cash flow statement) and capital stocks (balance sheet) for public Canadian firms. For ease of comparison we report annual costs ($12.8 billion) relative to private sector annual flows and total required capital ($128 billion) relative to accumulated private sector funds. We gather metrics such as revenue, capital expenditure (CapEx), free cash flow, market capitalization[15], and retained earnings. Balance sheet and income statement information is from 2019. We repeat the analysis for the largest Canadian financial institutions (Bank of Montreal, TD Canada Trust, Royal Bank of Canada, Scotiabank, and the Canadian Imperial Bank of Commerce) which we label "Canadian Financial System" in

14 The question posed was "To what extent do you agree or disagree with the following: In the economic recovery after Covid-19, it's important that government actions prioritize climate change"
15 market capitalization is total market value of all company's outstanding shares at period end date. Period end date is the most recent for which full fundamental data has been collected — Bloomberg definition

Table 8 and add interest income to further understand the impact the transition could have on our financial sector. We include total revenue, investment income, net income, market value of total assets, and short-term assets[16] for private sector trusteed pension funds for the Q4 2019 reporting period. Amounts and percent values are rounded to the nearest integer and can be seen below in Table 8. Data for S&P/TSX Composite Index and Canadian Financial System was collected from Bloomberg. Data for private pension funds was collected from Statistics Canada.

One thing we would like to emphasize is that the required capital will have to come from both the public and private sector. The private sector can and should play a major role in this transition. Specifically, blended finance (see below) will play a crucial role in this transition as it combines the costs and benefits of public capital (low cost of capital) with the costs and benefits of private capital (ability to select winners and losers).

The Rocky Mountain Institute's 2020 report Breaking the Code: Deciphering Climate Action Efforts in the Financial Sector concretely outlines the current discourse for the private sector's role [24]. They state:

> *"The debate over whether private financial institutions should play a proactive role in the low-carbon transition is coming to a close, and a proliferation of efforts to define what this role should be in practice has begun."*
>
> Rocky Mountain Institute

Table 8: Private Capital Relative to Required Mobilized Capital

Private Funds[1]	**Amount** ($ billions)	**Capital required/flows or stocks** (%)[2]
Annual Flows		
S&P/TSX Composite		
Revenue	1621	1
Free cash flow	167	8
CapEx	132	10
Canadian Financial System		
Revenue	241	5
Interest Income	136	9
Free cash flow	68	19
Private Trusteed Pension Funds		
Total Revenue	18	71
Stocks		
S&P/TSX Composite		
Market Capitalization	1893	7
Retained Earnings	494	26
Canadian Financial System		
Market Capitalization	376	34
Retained Earnings	200	64
Private Trusteed Pension Funds		
Total assets	625	21

1 S&P/TSX and "Canadian Financial System" data sourced from Bloomberg terminal. Pension Fund data sourced from Statistics Canada, Table: 11-10-0079-01 and 11- 10-0076-01.
2 $12.8 billion is used as capital required for annual flows and $128 billion for stocks (total).

In terms of S&P/TSX Composite revenues the amount of capital required annually is roughly 1%, similar to the comparison to 2018 GDP. Even in terms of the capital expenditure of large Canadian firms the amount of capital is only roughly 10%. This means that if these large firms shifted 10% of their capital expenditure to projects geared strictly towards reducing their carbon footprint, Canada could meet its 2030 goal. This simple average analysis abstracts away from the specifics and the heterogeneity across firms. We caution here because some firms may only have to invest 1% of their past capital expenditures, others may have to invest more than

16 short-term includes cash, deposits, Guaranteed Investment Certificates (GICs) and short-term securities. Some may mature in more than 12 months.

100%. Some firms could feasibly finance their transition without any support while others may be completely incapable of raising the required capital. The problem will be exacerbated in industries and jurisdictions with a concentration of high abatement costs.

Shifting a portion of capital expenditure or just more broadly shifting to be a less carbon-intensive firm does not come without benefits. Some benefits include greater access to resources through stronger government relations and support, cost reductions from lower energy consumption, attracting talent through greater social credibility, and enhanced investment returns through an emphasis on sustainable long-term planning [25]. In addition, firms that invest in a low-carbon transition will find it easier to raise debt and equity capital, thereby lowering their WACC and increasing profitability.

7.3 BLENDED FINANCING

Blended finance is one very important piece of the much larger puzzle of mobilizing enough capital to meet our various GHG reduction targets. Blended finance is essentially the act of the public and private sector working together to provide financing for socially beneficial projects. Blended finance helps lower the risk of especially risky yet very important areas to invest in that can bring down long term GHG emissions. Reduction of risk to levels that meet standard risk-return requirements allow for capital to then flow from traditional financial institutions. Specifically, one way blended finance could materialize in Canada is through tax exemption for transition bonds. The government is providing funding by forgoing tax revenues and the private sector puts to use its vast resources and expertise to decide which project is most promising. We plan to dive into this exciting area in greater detail in our subsequent CMP reports. The blended finance market is currently small. P3 Spectrum states there are 290 active public-private partnerships (PPP or P3) with a total market value of $139 billion [26]. Our estimated required $128 billion represents 92% of the total market value of active P3 projects in Canada. The Canada Infrastructure Bank (CIB) is one way to help stimulate private sector investment into green projects. The Bank will help public dollars go further by not only drawing additional private sector capital but also making use of expertise and extensive experience in infrastructure investing.

7.4 PUBLIC OR PRIVATE OR BOTH

In this report we stress that both public and private funds are required to finance the transition. Public funds can help support novel financing vehicles via the use of tax forgiveness (tax-free interest on green or transition bonds). They can support the purchase of new technologies with tax credits (similar to R&D tax credits for firms). They can also support behavioural changes that help reduce GHG emissions via specific policies (carbon taxes or cap-and-trade). The Task Force for Resilient Recovery (TFRR) report highlights a number of specific recommendations and suggests the public component of financing the transition to be roughly $50 billion over the next five years [27].

The $50 billion recommendation by the TFRR represents between 1/3 and 1/2 of the total required investment. The private sector has a significant role to play. Our report suggests that firms can finance much of the transition through their normal investment activities. For instance, if firms are required to finance just 50%, this represents 5% of the normal investments made by the largest public firms. If we include all public firms and private firms the number will fall to much less than 5%. In some cases, the abatement costs are incremental in that they represent an additional cost, on others they would simply require selecting a similar priced but lower emissions alternative. Put simply, a significant portion of the funds can be mobilized through the normal investment process of firms.

Blended finance will be helpful in mobilizing the required investment that is neither clearly public nor clearly private (firms and individuals). If we assume that $50 billion is contributed by government and another $50 billion from private sources, the remainder (between $2 billion and $33 billion depending on the scenario) can be mobilized via blended financing vehicles that combine public and private funds.

The public sector can also reduce their financial burden of reaching our 2030 goal by creating clear and reliable policy direction. Gulen et al. (2016) show that policy uncertainty leads to lower levels of firm investment, particularly for firms that invest in long-term durable assets, like the Oil & Gas industry, and firms dependent on government spending [28]. A predictable policy environment is favourable as it creates an environment in which firms can make sensible long-term investments in durable assets and technologies without fear of those assets losing value due to future policy changes. This makes longer-term planning and financing of these assets easier and less expensive, leading to more private investment in carbon-abating projects.

It is important to note that these investments are associated with benefits. Not just to the public but also to individual firms that invest in new productive assets with low GHG emissions (that may be priced in the future). The New Climate Economy report found that "...bold action could yield a direct [global] economic gain of US$26 trillion through to 2030 compared with business-as-usual" [8]. Some benefits outlined in the report include an estimated 65 million new low-carbon jobs in 2030 and a generated US$2.8 trillion in government revenues per year in 2030 resulting from subsidy reform and carbon pricing. Canada's GDP makes up about 1.34% of global GDP, a quick calculation tells us that an economic gain of US$348, or roughly CAD$467 billion could flow to Canada [11]. These benefits together with our total cost estimate of $128 billion give this project a very high positive NPV of CAD$339 billion. These benefits will accrue to the public, firms, and individuals and as such should be financed proportionally.

The EIU estimates further highlight the costs of inaction. They show that the costs from climate change under a two-degree scenario versus a five degree are large. The action scenario generates a cost saving between $81 to $234 billion in CAD. Given Canada's high GHG intensity it is likely that costs are disproportionately higher in Canada than in the rest of the world.

8 SUMMARY

We have estimated the total required capital to fund the transition to a lower carbon economy at roughly $128 billion with a range between $90 to $166 billion. The public sector, private sector, and the financial system all have a large role to play. While too large for any group to finance alone the problem appears manageable and feasible via cooperation. A sense of urgency must be present when thinking about addressing climate change and a transition to a low-carbon economy, especially for longer term targets. As time runs out options will diminish and the fruits that can result from R&D may seem too distant to pursue in the first place. Technology costs will also largely have to be taken as static costs. Delayed action on climate change also implies eventual faster moving, more severe policy measures to combat GHG emissions, given Canada still aims to achieve its 2030 and 2050 goal. These fast moving and restrictive policy measures will impose a high degree of regulatory risk. This regulatory "shock" will deliver relatively more severe monetary costs like stranded assets or write-downs of carbon intensive firms.

The mapping out of Canadian GHG emissions by jurisdiction and economic sector along with GHG abatement costs we have outlined in this report should serve as a guide to achieving our climate reduction goals. Context is important to consider so that total estimates of required capital are not dismissed as insurmountable. In addition to public sector support, the private sector can and should play a substantial role in the mobilization of required capital.

This report uses the data in publicly available reports from reputable sources. As such, the accuracy of our final estimates is partially dependent on the accuracy of the publicly available reports. Where feasible, we average estimates across multiple reports to reduce the impact of one individual estimate. This reduces the noise of our estimates and likely does a better job of representing average abatement costs.

The estimates in this report are also not set in stone. By this we mean that we will continue to update them by feeding in new data on GHG emissions and abatement costs. Individual abatement costs will be studied in greater detail in subsequent reports for large abatement opportunities found in pivotal sectors for the low-carbon transition. This will materialize in shorter more specific reports with extensive industry consultation to gain a greater understanding of true, current, Canadian-specific abatement costs.

A APPENDIX

A ABATEMENT COSTS

Table 9: Abatement Costs Grouped by Economic Sector

Sector/Strategy	Reference	Cost (CAD/tCO_2)		
		low	high	mid
OIL & GAS				
CCS	IPCC (2014)	68	204	136
	CBC (2019)	100.0	150.0	125.0
CCS for Coal	CERI (2018)	72.0	72.0	72.0
CCS for Natural Gas		174.0	174.0	174.0
	Navius Research (2019)	149	149	149
CCS with hydrogen production at refineries and upgraders	Navius Research (2019)	102	102	102
CCS with heat generation in the oilsands		335	335	335
Methane Regulations	Gov. of Canada	11.7	11.7	11.7
	Lade, Rudik (2017)	28	28	28
TRANSPORTATION[1]				
Corn Starch	Gillingham & Stock (2018)	424	424	424
Ethanol				
Biodiesel (U.S.)		199	331	265
		243	405	324
		341	569	455
Renewable Fuel Standard	Sarica, Tyner (2013)	1.5	21	11
	Holland, Hughes, Knittel, Parker (2011)	99	99	99
Renewable Fuel Subsidies	Holland, Hughes, Knittel, Parker (2011)	141	141	141
Gasoline Tax	Knittel, Sandler (2013)	25	64	44
CAFE Standards	Kok, Annema, van Wee (2011)	146	211	179
	Sarica, Tyner (2013)	306	306	306
	Jacobsen (2013)	418	418	418
Low Carbon Fuel Standard	Holland, Hughes, Knittel, Parker (2011)	141	141	141
Cash for Clunkers	Knittel (2009)	368	567	468
Dedicated Battery Electric Vehicle Subsidy	Archsmith, Kendall, Rapson (2015)	473	867	670
Electric Vehicles	Sens Canada (2017)	300.0	300.0	300.0
BUILDINGS				
Behavioral Energy Efficiency	Allcott, Mullainathan (2010)	-224.4	-224.4	-224.4
Weatherization Assistance Program	Fowlie, Greenstone, Wolfram (2018)	471	471	471
ELECTRICITY				
New sourced tech. using coal as baseline:				
Onshore wind	Gillingham & Stock (2018) revised from Clean Air Task Force (2013)	34	34	34

Sector/Strategy	Reference	Cost (CAD/tCO2)		
		low	high	mid
Natural Gas Combined Cycle		37	37	37
Utility-scale Solar Photovolatic		39	39	39
New Natural Gas with CCS		59	59	59
Advanced Nuclear		80	80	80
Coal Retrofit with CCS		116	116	116
New Coal with CCS		129	129	129
Offshore Wind		143	143	143
Solar Thermal		181	181	181
Coordinated systems using natural gas as baseline:				
Wind & NGCC	CERI (2018)[2]	60	141	101
Wind & CAES		142	142	142
Fixed Solar PV & NGCC		559	1697	1127
Tracking Solar PV & NGCC		356	837	596
HEAVY INDUSTRY				
Enhanced Recycling, Cogeneration, and Process Intensification	IPCC (2014)	27	204	116
CCS	IPCC (2014)	68	204	136
	CBC (2019)	100	150	125
AGRICULTURE				
Agriculture Emissions Policies	De Cara, Jayet (2011)	68	89	78
Livestock Management Policies	Beach, DeAngelo, Rose, Li, Salas, DelGrosso (2008)	97	97	97
WASTE AND OTHERS				
Taking an average of other sectors' costs				
LULUCF				
Reforestation	Jayachandran, de Laat, Lambin, and Stanton (2016)	0.8	0.8	0.8
	Jack (2011)	13	13	13
	Olsen et al. (2009)	18	18	18
Reduced intensive agriculture conversion		40	40	40
Cropland afforestation		22	22	22
Forest Management		16	16	16
Pastureland afforestation		16	16	16
Reduced timber harvesting		6	6	6
Reduced deforestation from pastureland conversion		3	3	3
Reduced deforestation from slash and burn agriculture conversion		3	3	3

1 cost is average cost across all provinces
2 some costs are converted to Canadian dollars using the transformed aggregated abatement costs found in Gillingham & Stock (2018)

B WACCS

Table 10: WACC by Industry Group from S&P/TSX Composite Index

Industry Group	Number of firms	WACC (%) weighted by:	
		Revenue	Market cap
Mining	39	6.13	6.38
REITS	21	4.65	4.93
Oil & Gas	16	7.04	7.84
Electric	13	4.45	4.47
Banks	9	4.94	4.98
Food	8	3.44	3.58
Software	8	6.23	6.40
Retail	7	5.59	5.67
Insurance	7	6.67	6.86
Diversified Finan Serv	7	6.50	6.65
Commercial Services	7	6.54	6.01
Pipelines	7	5.69	5.56
Pharmaceuticals	7	3.35	6.24
Media	5	5.09	5.67
Transportation	5	6.10	6.14
Engineering & Construction	4	5.52	5.66
Forest Products & Paper	4	5.69	6.16
Packaging & Containers	4	5.41	5.69
Telecommunications	3	4.41	4.42
Real Estate	3	2.91	4.37
Distribution/Wholesale	2	6.38	6.38
Building Materials	2	6.79	6.41
Auto Parts & Equipment	2	7.46	7.42
Iron/Steel	2	6.06	7.13
Apparel	2	9.57	10.58
Private Equity	2	3.68	4.14
Airlines	2	4.88	4.87
Entertainment	2	4.31	4.31
Energy-Alternate Sources	2	7.83	8.08
Chemicals	2	5.33	5.44
Internet	1	9.30	9.30
Healthcare-Services	1	4.74	4.74
Auto Manufacturers	1	3.44	3.44
Oil&Gas Services	1	7.96	7.96
Beverages	1	4.60	4.60
Toys/Games/Hobbies	1	8.23	8.23
Environmental Control	1	5.05	5.05
Machinery-Diversified	1	5.41	5.41
Metal Fabricate/Hardware	1	3.82	3.82
Computers	1	6.88	6.88
Hand/Machine Tools	1	5.43	5.43
Leisure Time	1	8.03	8.03

Industry Group	Number of firms	WACC (%) weighted by:	
		Revenue	Market cap
Household Products/Wares	1	5.55	5.55
Electronics	1	5.87	5.87
Aerospace/Defense	1	7.45	7.45
Storage/Warehousing	1	4.77	4.77

Produced using data from Bloomberg terminal

C LEVELIZED COST OF ELECTRICITY

To understand how some abatement costs are calculated we must first explain and define the concept of levelized cost of electricity (LCOE). It is a commonly referenced metric to compare energy generating units across different technologies. It is also used to assess the financial attractiveness of an energy investment. The Corporate Finance Institute (CFI) defines LCOE as:

$$LCOE = \frac{\text{NPV of Total Costs Over Lifetime}}{\text{NPV of Electricity Energy Produced Over Lifetime}}$$

$$= \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where the following variables are defined as:

I_t = cost of investment expenditures at time t
M_t = maintenance and operations expenditures at time t
F_t = fuel expenditures (if applicable) at time t
E_t = electricity energy produced at time t
r = discount rate of project
n = expected lifetime of system or power station

D CALCULATING ABATEMENT COSTS

Having a baseline scenario when calculating abatement costs is paramount. This is because, as previously stated, you want to capture just the additional cost attributed to going with the green alternative not the cost that would be incurred regardless of any action to lower GHG emissions (a BAU scenario). The equation below shows the calculation behind the $72/$tCO_2$ abatement cost presented by CERI for coal with CCS. Superscripts A and B refer to the green alternative and the baseline scenario respectively. CERI lists LCOE in cents/KWh and net CO_2 as $kgCO_2$/MWh, so the numbers seen in the equation below have been converted so that the final product is in $/$tCO_2$ terms.

$$\frac{\$}{tCO_2} = \frac{LCOE^A - LCOE^B}{NetCO_2^B - NetCO_2^A}$$

$$= \frac{147 - 98}{.788 - .105}$$

$$= 71.74$$

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