CO_2 Mitigation Costs for Canada and the Alberta Oil Sands

By

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Abstract

The threat of climate change proposes difficult problems for regulators and decision-makers in terms of uncertainties, varying exposures to risks and different attitudes towards risk among nations. Impact and cost assessments aim to alleviate some of these difficulties by attempting to treat the costs of inaction, regulation and adaptation. For such assessments to be relevant, they must deal with regions individually to estimate costs associated with different regulations since across regions the impacts from climate change and climate change regulation are heterogeneous. Canada, and her oil sands industry, is the focus of this CO_2 mitigation cost and climate change impacts study. Two Canadian policies, in line with the stated goals of the two largest Canadian political parties, have been modeled using MIT's Emission Prediction and Policy Analysis tool to better understand the costs of the policies and the emission reductions that they will achieve. Welfare losses reaching 3.3% (in 2050) for the goals outlined in the Canadian government's "Climate Action Plan" and 8.3% (in 2050) for the goal to meet Kyoto and post-Kyoto targets put forward by the opposition are predicted by the model. Oil sands upgrading/refining experiences severe carbon leakage while Oil Sands production is more resilient and may present less regulatory risk for investment. Gasification to produce natural gas substitutes could potentially be undermined by strict CO_2 policy unless optimistic carbon capture technology emerges. The results are highly dependent on whether an international carbon trading regime exists and whether bio-fuels emerge as a large scale, affordable, alternative to fossil fuels. The results are also dependent, to a lesser extent, on international CO_2 policy

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Struggling for thought
Caught me moving, broke the fall
Never again to see like
The guilt and dream washed
Bubbling memory

Breathing now
Running now
To catch the wind – to taste the moment
Alone at last and together forever

To Irinochka and the girls. My absolute meaning.

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Introduction

The Intergovernmental Panel on Climate Change (IPCC), a group of scientists and policy makers who periodically meet and review climate change research, concluded that the evidence that anthropogenic greenhouse gases are responsible for warming is incontrovertible (Intergovernmental Panel On Climate Change 2007). Trying to quantify the potential impacts posed by global warming represent a significant challenge to the scientific community and are researched and debated today throughout the world. Possibly an even greater challenge is before international diplomacy and policy makers who will be responsible for the major economic and environmental fall out of any measures, or lack of measures, taken to address the issue.

A significant contribution to the difficulties of finding an optimal policy in response to the possible threat of anthropogenic climate change is the difficulty of predicting the impact of CO_2-reducing policies on the world's environment and economies. It is therefore necessary for individual nations to strive to quantify the benefits and costs associated with policy action, or inaction, with respect to greenhouse gas emissions. The primary purpose of this thesis is to help quantify the costs of climate change policy for one nation of the world, Canada, by focusing on the costs of CO_2 mitigation on Canada's economy and on one of her fastest growing industries – the Alberta Oil Sands. The primary goal is accomplished by means of the Emissions Prediction and Policy Analysis, or EPPA, model which will be introduced later. Before undertaking such an analysis I briefly investigate the environmental effect of a warmer climate for Canada by reviewing impacts literature relevant for Canada.

Background

The Canadian government has been considering climate change policy for some time as a party to international efforts to negotiate an agreement to limit greenhouse gases. In 1992, The United Nations Framework Convention on Climate Change (UNFCCC) set out the non-binding objective "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system" for its party countries (Intergovernmental Negotiating Committee for a Framework Convention on Climate Change 1992). Since the UNFCCC entered into force, the parties have met in annual Conferences of the Parties (COP) to assess the progress of the Convention and to establish legally binding commitments from developed countries to reduce their greenhouse gas emissions. COP-3, the third annual conference held in 1997 in Kyoto, Japan, set out a binding international agreement for reducing emissions in developed nations known as the Kyoto Protocol. The Kyoto Protocol binds Annex I countries[1] to reduce their greenhouse gas emissions to levels 6-8 percent below the protocol's 1990 reference year or buy international carbon credits to make up the difference. Most Annex I countries, with the notable exception of the United States and Australia, have since ratified of the treaty thereby committing their governments to enforcing Kyoto at a national level.

Canada ratified the Kyoto protocol on December 17, 2002 and in so doing committed to reducing its greenhouse gas emissions to 6 percent below its 1990 levels. However, Canadian Federal and Provincial governments have not passed any bills which set out a domestic trading scheme or greenhouse gas limits. Most of the response, so far, has been in the form of increasing efficiency and decreasing consumer energy consumption through such programs as the one ton challenge[2]. Those responses appear inadequate to meet Canada's Kyoto commitment. The primary objective of this thesis is to analyze proposed Canadian policies that would attempt to meet Kyoto and possible follow-on emission targets. I focus, particularly, on the oil sands industry. The growth of oil sands production has been a boon to the Canadian economy but also a major contributor to CO_2 emissions growth. Whether and under what conditions this industry remains viable with climate policy are the main questions addressed.

Before addressing theses questions in detail, I briefly review the environmental impacts of climate change. While a detailed environmental impacts study for Canada is beyond the scope of this thesis, any mitigation cost analysis should recognize that there are environmental costs and benefits associated with climate change.

Global Warming Impacts for Canada

Global warming will affect different countries in different ways. The focus of this section is to briefly investigate and summarize the warming effects on Canada over the past century.

Cropland, pastureland and forestry

Climate change will likely have its greatest impact on those industries whose operations are most dependent on the climate. Agriculture is such an industry. Many studies have explored, through models and experimentation, the potential effects of a CO_2-richer and warmer world on soil quality, an input for agriculture producers. Studies

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[1] Annex I countries include Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, European Union, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and The United States of America (SOURCE)

[2] The One Ton Challenge is an initiative to encourage consumers to reduce their CO2 emissions by a ton a year

range between negative impacts from increased insect populations and droughts to positive impacts due to increased water supplies, higher CO_2 concentrations and better soil conditions. The United States Department of Agriculture (Darwin et al. 1995) reports that "global changes in temperature and precipitation patterns during the next century are not likely to imperil food production for the world as a whole" and that "water supplies are likely to increase for the world". The report talks about impacts varying depending on the country and specifically cites Canada as an example where "the amount of land suitable for farming and forestry will increase". A 2002 report by the National Agriculture Assessment Group (Reilly, Graham, and Hrubovcak 2002) found more positive impacts on forestry and cropland yields as their models also accounted for the well documented beneficial effects of higher atmospheric CO_2 concentrations, an effect not accounted for in the 1995 US Department of Agriculture study. The assessment group found that the productivity for the US crops increased overall under increased temperature and CO_2 concentrations. A more recent MIT study (Reilly et al. 2006) yielded the same general result that CO_2 emissions positively impact cropland, pastureland and forestry yields.

While their exists important uncertainties in the impacts on cropland, pastureland and forestry yields from climate change, northern agriculture is usually expected to benefit from climate change. Northern climates are routinely identified as benefiting more from temperature and water supply increases. An MIT study (Deschenes and Greenstone 2007) using a hedonic[3] approach to evaluate economic impacts from climate change and climate variation found that climate change will lead to a 3.4% increase in annual agricultural sector profits with the 95% confidence band of -5.6% to 12.4% change in annual agricultural sector profits resulting from climate change and variation. While the confidence band is subject to uncertainty limitations, it does give a rough indication for the weighing of uncertainty in climate change and variation in impacts on agriculture. An integrated international CO_2 trading scheme could reduce the costs of meeting emission targets, especially for countries with strict policies relative to other carbon trading countries. As international CO_2 emission targets get more ambitious, Canada might benefit from the development of a large-scale Canadian bio-fuels industry to help countries meet those targets. However, such international policy could also cripple the oil sands by reducing global demand for carbon-rich fuels, such as bitumen. Canada's agricultural sector under climate change (using a GCM[4]) is 19-49 billion US dollars by the year 2100 (Mendelsohn et al. 2000).

A point emphasized by this final study and confirmed by the 2002 assessment group is that the consequences of climate change for agriculture hinge on changes in climate variability and extreme events. While increases in temperature and CO_2 concentrations benefit agricultural production, increases in drought, flood and storm frequency will have a negative effect on agriculture. The connection between extreme

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[3] hedonic approach is to be contrasted with the production function approach - the latter's limitation being that it does not account for the full range of compensatory responses to changes in weather made by profit-maximizing farmers

[4] General Circulation Model

weather events and climate change are not well understood and so impact analyses such as those cited above may provide an overly optimistic assessment of agricultural impacts.

Extreme weather events

Global warming has been linked to possible increases in extreme weather events such as hurricanes, droughts, blizzards, forest fires and tornadoes. The causal link, if any, between the frequency of extreme events and global warming only can be determined through statistical analyses of long-term data because the natural climate system can produce weather and climate events that often appear to be uncharacteristic of the recent climate (variability) and since precise causes of extreme weather events are generally poorly understood although under intense research.

Other extreme weather events, such as droughts and floods, are very region-dependent on the role that warming is having or will have on their frequency and intensity. As we are considering Canada specifically, I summarize the findings of a study published by the government of Alberta on the trending effects of global warming from the 1920s until now on Canadian extreme weather events (Khandekar 2002).

One main purpose of this thesis is to take a high-level potential problem, the threat of climate change, and investigate how it might impact a *specific* region – in this case Canada. For the threat of climate change to have traction, we must investigate how it will impact individual countries and communities. The major climate impacts of relevance to Canadians include (a) changes in summer time hot spells' and winter time cold spells' frequency and intensity, (b) changes in summer and winter heavy precipitation events, (c) changes in average winter temperatures and (d) changes in the frequency and intensity of droughts, floods, blizzards, ice storms, severe hail, severe wind, tornadoes and other storms. Table 1, which is based on the information in the Khandekar study, summarizes the trending of these events and conditions of concern over the past 80 years of about 1 degree mean warming in Canada. Unfortunately, it is the only study which I could find on extreme weather event trending for Canada.

Table 1 – Extreme weather impacts for Canada observed from 1920 until 2003

Impact	Trend
Average Temperature	1-3 degrees warming for the Western provinces in the summer. 1-2 degrees cooling for the Western provinces in the winter. Eastern Canadian provinces have seen little change in temperature trends during the winter and summer.
Average Precipitation	Moderate increase in annual precipitation. Moderate precipitation increases due largely to light or medium precipitation events.
Droughts	Droughts are a major concern for the Canadian prairies and have historically impacted the region with devastating consequences (especially during the 1920s and 1930s). The El-Nino-Southern Oscillation (ENSO) and the Pacific North American (PNA) atmospheric flows are the important driving mechanisms of droughts in the region. There is no present link between warming trends and drought occurrences on the Canadian prairies.
Floods	Major flooding is not an issue in Canada. No trend in localized flooding observed.
Heat waves	Heat waves have declined in the summer months.
Cold (and warm) spells	Mixed cold spell changes. The Western provinces have seen a decrease in the number of winter cold spells. Ontario and Quebec have seen no significant change in winter cold spells. The Atlantic provinces have seen an increase in winter cold spells. The majority of the country has had an increase in winter warm spells.
Blizzards	Several inconclusive studies caused the IPCC to conclude in 2001 that "the evidence on change in extra-tropical synoptic systems is inconclusive; there is no evidence of any uniform increase." The more recent Larson study (Lawson 2003) concluded no change in blizzard severity in Canada and a decrease in blizzard occurrences.
Ice Storms / Freezing Rain	Ice storms are primarily a concern for the Eastern provinces. No increasing trend in ice storm activity. The most intense ice storm in the last 40 years happened in 1998. Research concludes that the formation of two low-pressure weather systems in quick succession, aided by the extreme phases of the 97'/98' El Nino and a favorable NAO, were the main causes of the 98' ice storm.
Tornadoes / thunderstorms	Although no increasing or decreasing trends are detectable from the statistical analysis, the data is limited. The limitation is because advances in detection and frequent tornado and storm monitoring emerged only in recent decades. Theories postulate that tornado activity is more a function of regional mean surface maximums (which are trending to less extreme in Canada) than global mean temperatures.
Hail	The only significant data available is for Alberta and Saskatchewan where agriculture is impacted significantly from hail storms. No increasing or decreasing trend detected in hail activity for these regions. For continental USA, a declining trend in hail activity is observed over the past 50 years.
Wind	Wind damage from events other than thunderstorms and tornadoes are uncommon in Canada, except for rare east-coast hurricanes. No increasing or decreasing trend from this kind of wind damage observed.

Source: Summarized from (Khandekar 2002)

It is difficult to establish a causal link between the one degree of mean temperature rise in Canada over the past century and the occurrences of extreme weather events given the many variables that trigger such events and the poor understanding of (and poor ability to measure) many of those variables. Correlations between the occurrences and intensity of Canadian extreme weather events and the 0.6 degrees of mean global warming are generally non-existent or exhibit a negative association according to the Khandekar study.

Sea level

In 2007, the IPCC estimated using a range of model outputs based on various scenario inputs, that global sea level will rise anywhere from 18 to 54 cms from 1990 to 2100[5] (Intergovernmental Panel On Climate Change 2007). The large range represents the *modeled* uncertainties in both temperature change and gaps in ocean and hydrology understanding.

The main regions which could be impacted by significant sea level change include the great lakes region and the Atlantic Provinces. Sensitivity to sea level change for Canada's ocean coasts is shown in Figure 1. Sensitivity is influenced by geological characteristics of the shoreline and ocean processes in addition to whether sea level is rising or falling in the region.

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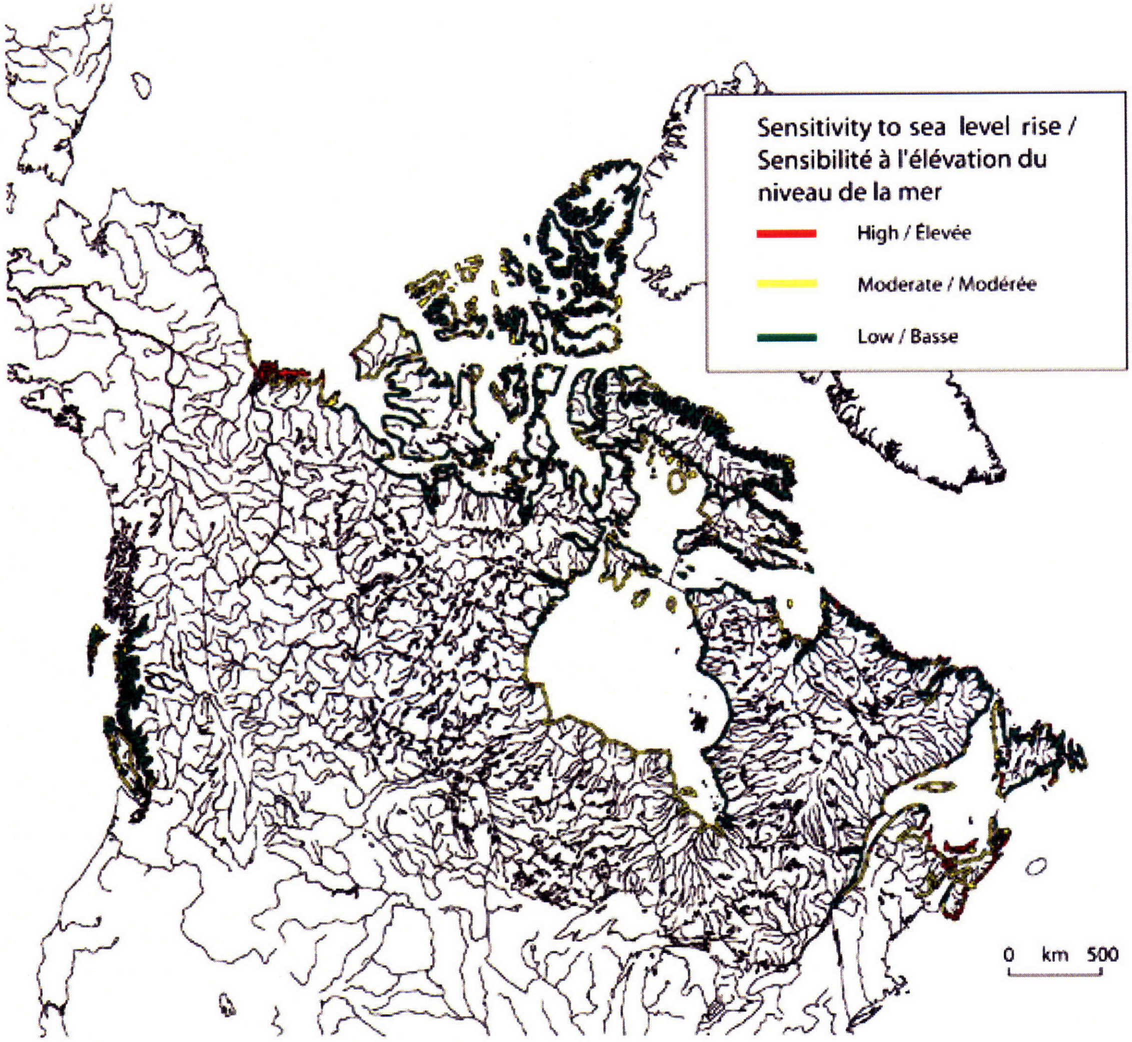
[5] In contrast to their 2001 estimate of 9cm to 88cm by 2100 (Intergovernmental Panel On Climate Change 2001).

Figure 1 - Sensitivity to sea level rise



Source: (Shaw et al. 1998)

The Atlantic Provinces and great lake region differ in the direction of projected sea-level change. Sea level is expected to continue to rise in the Atlantic Provinces and projected to recede in the great lakes region. The projected impacts of sea level change are summarized in the following table, summarizing a recent climate change impacts study by the government of Canada (Warren et al. 2004):

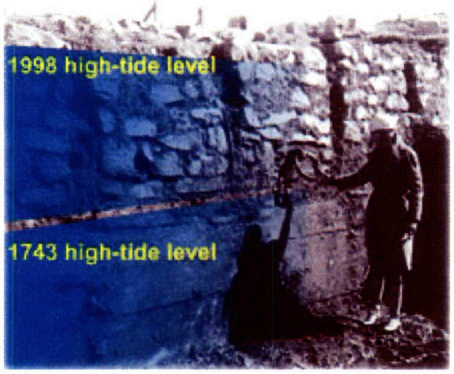
Table 2 - Impacts from changes in sea level

Increase in Sea Level (Atlantic provinces)	Decrease in Sea Level (Great Lakes region)
Bio-physical impacts • changes in coastal habitat • more storm surge flooding • saltwater intrusion into freshwater aquifers	**Bio-physical impacts** • changes in coastal habitat
Socio-economic impacts • coastal infrastructure damage • increased shipping season • increased property loss • increased tidal energy potential	**Socio-economic impacts** • increased property size • shortened shipping season • less flood damage

Source: Summarized from (Warren et al. 2004)

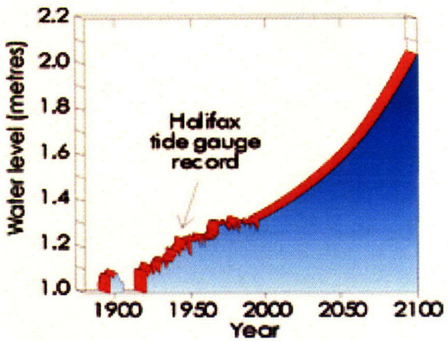
How has Canada dealt with sea level changes in the past? In Atlantic Canada (except Labrador) the sea level has been rising for thousands of years. The trend is illustrated in Figure 2 which shows the mooring rings at Fortress Louisbourg. The Halifax tide gauge record in Figure 3 gives us an idea of the sea level change rate in the region (about 3.6cm/decade) during the previous century together with some projections going forward. Canada has coped with sea level change in the past with fewer resources through a combination of coastal retreat and defense. The changes have presented new challenges and opportunities then and will do so in the future.

Figure 2 - Fort Louisbourg (1743) high tide sea level



Source: (Warren et al. 2004)

Figure 3 - Halifax tide gauge record



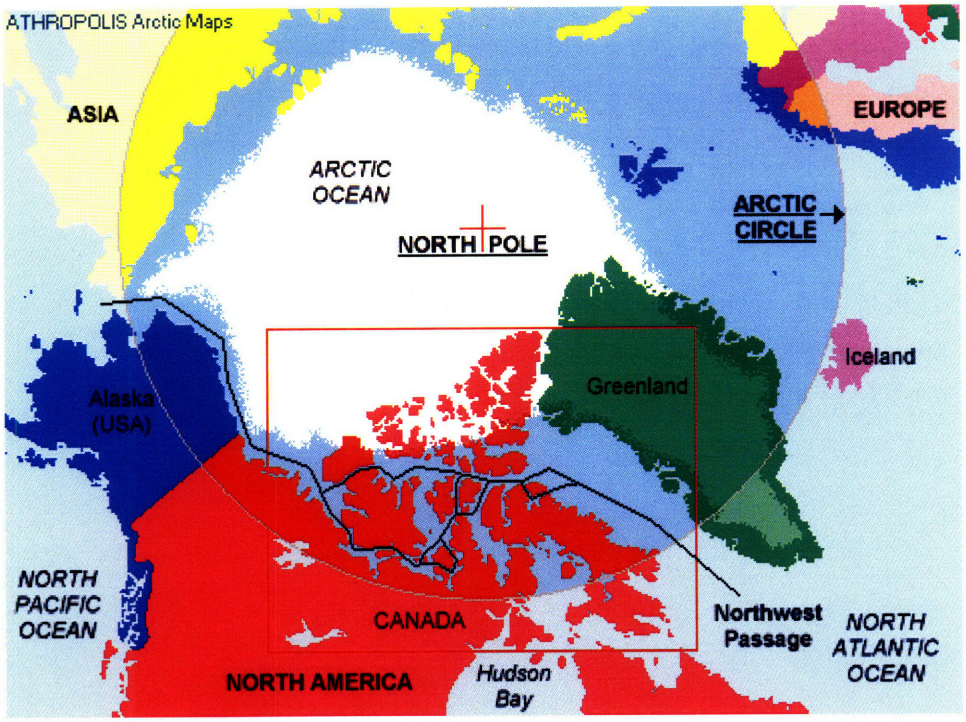
Source: (Warren et al. 2004)

Any rapid change in sea level will be costly to sensitive regions. The Atlantic region is the most exposed to possible damage from sea level change. Modern technology, the slow rate of sea level change, Canada's vast land mass, rocky shores and low coastal population density could mitigate the risks of sea level rise for Canada.

The Northwest Passage

Speculation exists about the possibility of global warming opening up the Northwest Passage to high volume shipping. The passage is presently seldom used by ships because of the often impassable sections of ice. Some thinning of the ice has been observed throughout the passage over the past few decades and interested parties are considering using of the passage for more frequent international shipping. Figure 4 displays the route in question.

Figure 4 - The Northwest Passage



The opening of the Northwest Passage would likely present opportunities and challenges for Canada. The passage, as a commercial shipping lane, could provide an economic boost for Northern towns and infrastructure. The use of the passage could also give Canada an opportunity to assert its sovereignty in the region and access to the passage could become a useful bargaining tool. Alternatively, if Canada is unable to assert her sovereignty over the region, she could lose her right to assert her own environmental standard over the passage. Environmental degradation related to increased activity in the passage could ensue. In addition, asserting sovereignty over the passage via warships and other vessels would require government expenditures. While the world would likely benefit from access to the Northwest Passage, it is not obvious that Canada would as well.

Forest Fires

Forest fires are an integral part of the survival of Canada's boreal forests and ecosystems – without them much of the ecosystem could not persist (Environment Canada 2006b). Forest fires can also cause significant property damage. The costs of forest fire damage in Canada are estimated to be around 7 million annually (Warren et al. 2004).

Predictions of how mean temperature and precipitation increases in Canada will impact forest fires are very uncertain (Warren et al. 2004). Studies of frequency and severity trending over the past century are conflicting with results showing slight decreasing, increasing and non-trending behavior. Projections of future severity and frequency by means of models are also conflicted, the box below showing the predictions of forest fire frequencies for various regions with different models.

Table 3 - Forest Fire projections

Region Prediction Eastern boreal forest
Fewer forest fires in future
(based on historical analysis)
Canada
Increase in forest fire danger
Great regional variability
(based on Forest Fire Weather Index)
Western Canada
Increase in strength and extent of fires
(based on RCM1 projections)
North America
General increase in forest fire activity
Little change or even a decrease in some regions
(based on GCM 2x CO_2 *projection)*
Alberta
Increase in fire frequency
(based on GCM 2x CO_2 *projection)*
Southwestern boreal forest, Quebec
Decrease in fire frequency
(based on GCM 2x CO_2 *projection)*
Ontario
Increase in forest fire frequency and severity
(based on Forest Fire Weather Index)
Canada
Increase in fire activity
Longer fire season
Increase in area of extreme fire danger
(based on GCM 2x CO_2 *projection)*

Source: Summarized from (Warren et al. 2004)

Paradoxically, it has been shown that warm weather does not necessarily lead to a bad forest fire season. 2001, the hottest year on record, had the lowest forest fire frequency and severity on record (Warren et al. 2004). Major variables affecting forest fire frequency and severity include vegetation type, wind, lightning frequency, antecedent moisture conditions and fire management mechanisms. Significant uncertainties remain in how climate change will impact forest fire frequency and severity.

Animals and Insects

Insects pose a more significant threat to forests than fires (Environment Canada 2006b). Like fires, insects can play an important role in controlling tree growth. While warmer weather may encourage migrations of new insects and accelerate the growth rates for some species (while reducing others), reduced snow cover during the winter may reduce insect survivability. Significant uncertainties remain in how climate change will impact insect populations.

The impacts of warming on wildlife populations, mentioned by the most recent IPCC impacts report (Parry et al. 2007), include changes in phenology, migration, reproduction dormancy and geographic range.

Water Resources

Canada has a lot of fresh water. While making up 0.5% of the world's population, Canada has 9% of the world's fresh water supplies (Warren et al. 2004). Weather extremes, such as hot spells and flooding, are the major drivers of stresses on water supplies. Given the difficulties in predicting the frequency and intensity of such events in a warmer and wetter Canada, it is difficult to predict the impact of global warming on Canada's water supplies on vulnerable locales.

Tourism

Tourism in Canada may increase from global warming. An international team of economists ran a study using the 'Hamburg Tourism Model' to predict how global mean temperature changes will affect tourism in various countries (Bigano, Hamilton, and Tol 2006). Canada was the biggest single net gainer of international tourism under global warming according to the study. The results are summarized in TB below as percent changes in tourism in 2100 from what the predicted levels at that time would be without warming.

Table 4 - Percent change in international tourism by century's end from warming

Biggest Increases	Biggest Declines
Canada +220%	Mauritania -60%
Russia +174%	Mali -59%
Mongolia +122%	Bahrain -58%
Kyrgyzstan +89%	Qatar -58%
Zimbabwe +88%	Kuwait -56%
Tajikistan +86%	United Arab Emirates -55%
Iceland +85%	Senegal -54%
Finland +82%	Niger -54%
Zambia +82%	Burkina Faso -53%
Norway +77%	Namibia -52%

Source: (Bigano, Hamilton, and Tol 2006)

The literature on tourism-analysis is limited and in particular, I can find no studies which investigate global warming-changes in tourism trends. The studies which use models, such as the study already mentioned, emphasize that some country's tourist industries will gain while others will lose from climate change. According to the Bigano study, Canada is considered one of the biggest gainers in tourism from global warming.

Conclusions: Global Warming Impacts for Canada

The purpose of this section is to summarize the challenges and opportunities presented to Canada should temperatures rise as projected by the 2007 IPCC report (Intergovernmental Panel On Climate Change 2007). Emphasis has been placed on using historical temperature data-climate statistical associations to predict how Canada's climate will change under IPCC global warming projections since there remains important gaps in climate-temperature theories and model predictions of local climate change impacts often present conflicting results or have unwieldy associated uncertainties.

Based on the literature reviewed, there will likely be numerous effects on Canada's environment from global warming. Canada's agricultural industry may benefit from warmer conditions and higher CO_2 concentrations however there could also be drought risks which might hurt the industry. Canada's tourist industry may benefit from the temperature rise as the tourist season would lengthen. Global warming may also contribute to the trend of the opening of the NW passage. The NW passage could be harnessed to Canada's benefit commercially but could provide challenges such as environmental pollution in the region from increased traffic and increased demands for governmental oversight in the region. Not many kinds of extreme weather events are trending much either way in terms of frequency or intensity. Sea level changes will likely be negative for Canada's Atlantic region requiring adaptation and changes in the deployment of coastal infrastructure. Finally, the work on the impacts on plant and animal life and Canada's internal water resources is too sparse to make any claims on those fronts. There are other potential environmental impacts than those mentioned here such as impacts of warming causing changes in tundra distribution and permafrost. Canada should expect significant environmental changes arising from global warming and should attempt to quantify the costs and benefits, and their uncertainties, as well as possible.

Canadian Mitigation Costs

Evaluating the mitigation costs for Canada is the central purpose of this thesis and is now considered. The analysis is performed using MIT's Emission Policy and Prediction Analysis (EPPA) tool. First, I introduce the EPPA model followed by an introduction to the Canadian and world policies which are used in the analysis. Finally, I present and analyze the results.

The EPPA Model

Two broad modeling approaches taken for predicting the interaction between energy, economic and environmental systems and technology (van der Zwaan, B.C.C. et al.). The bottom-up approach usually takes energy and other costs as exogenous and may be used, for example, to predict market penetration of technologies for a given energy output demand under constraints. The detail of the bottom-up approach is most effective at predicting interactions of similar technologies under certain conditions. The top-down approach sacrifices some detail with the aim of making energy demand and other important inputs endogenous (McFarland, Reilly, and Herzog 2002). For example, electricity production may be modeled as a production function whose inputs include capital, labor, natural gas, coal, etc and whose output is electricity. Electricity is then used as an input for a variety of other production functions. Elasticities of substitution allow for various levels of demand shifts between inputs, depending upon the ease of substitution. For example, if coal prices stay low while natural gas prices increase, the electricity sector will use more coal in its input stream and less natural gas which represents a relative increase in coal generating capacity. The advantages and disadvantages of the two broad approaches are summarized in Table 5.

Table 5 - Advantages and Disadvantages of predictive approaches

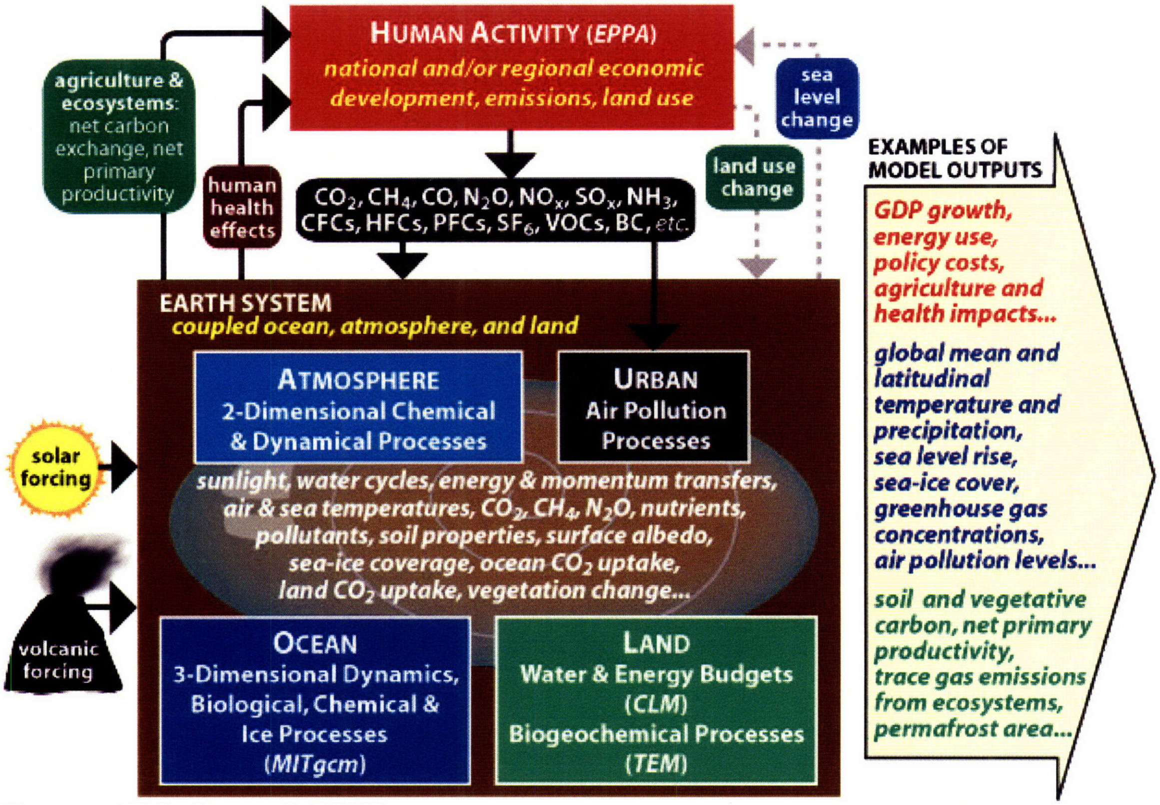
Approach type	Advantages	Disadvantages
Top-down	• Endogenous input prices • Captures the dynamics between sectors	• Use of many simplifying assumptions
Bottom-up	• Engineering cost and performance detail	• Exogenous input prices make it difficult to predict long term behavior between heterogeneous sectors

The analysis which follows makes use of MIT's EPPA model – a model which is fundamentally top down but with several key components, such as carbon capture technologies, added in the bottom-up approach.

Standard EPPA

The MIT Emissions Prediction and Policy Analysis (EPPA) model is a recursive-dynamic multi-regional general equilibrium model of the world economy. EPPA may be used independently to study greenhouse gas emissions and environmental policy. It is also part of MIT's Integrated Global Systems Model (IGSM) as shown in Figure 5.

Figure 5 - Integrated Global Systems Model (IGSM)

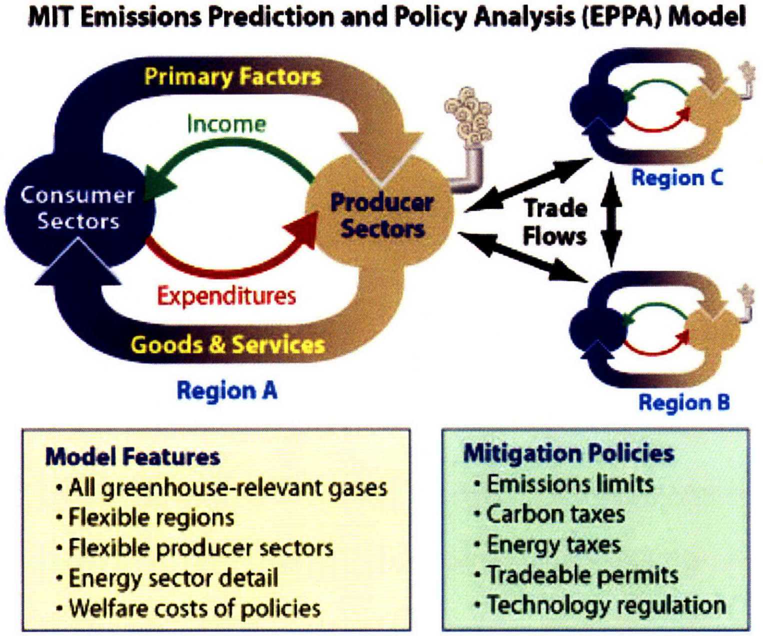


Source: (Sokolov et al. 2005)

The EPPA model, which can be thought of as an integrated part of the IGSM model as indicated in Figure 1, may be operated independently of IGSM for the purposes of a more focused and expedited economic and human emissions assessment tool.

EPPA is a computable general equilibrium (CGE) model. CGE models represent the flow of trade, goods and services as indicated in Figure 6 below. In addition to the high level information shown in Figure 6 are the inter-industry transactions and governmental flows both of which are important elements of CGE models.

Figure 6 - Trade, good and service flows in EPPA



Source: (Paltsev et al. 2005)

The EPPA and IGSM models are described in detail in (Paltsev et al. 2005) and (Sokolov et al. 2005) respectively.

EPPA Modifications

For the purposes of analysis presented here, I use a modified version of the standard EPPA model described above. The modified version is called EPPA-ROIL (Choumert, Paltsev, and Reilly 2006) and it builds on EPPA's capability by representing the oil industry more comprehensively. The changes in EPPA-ROIL can be most easily summarized by its three major modifications. Firstly, the ROIL sector in EPPA is disaggregated into multiple refined products. Secondly, the heavy fuel and refinery residue upgrading production functions are added. Thirdly, the major non-conventional oil fields are integrated. In addition to the modifications in EPPA-ROIL, I introduce a carbon capture and storage (CCS) option in the oil sands production and upgrading sectors.

With the first modification - the disaggregation of the ROIL commodity, EPPA-ROIL can effectively capture the trend of heavier crude supply coupled with higher demand for lighter fuels. Such modifications facilitate a more realistic analysis of the upstream and downstream oil and gas sectors in Canada. These sectors and their effect on the transportation sector together with the already well represented EPPA electricity sector are the most important industries affected by climate change policies in Canada.

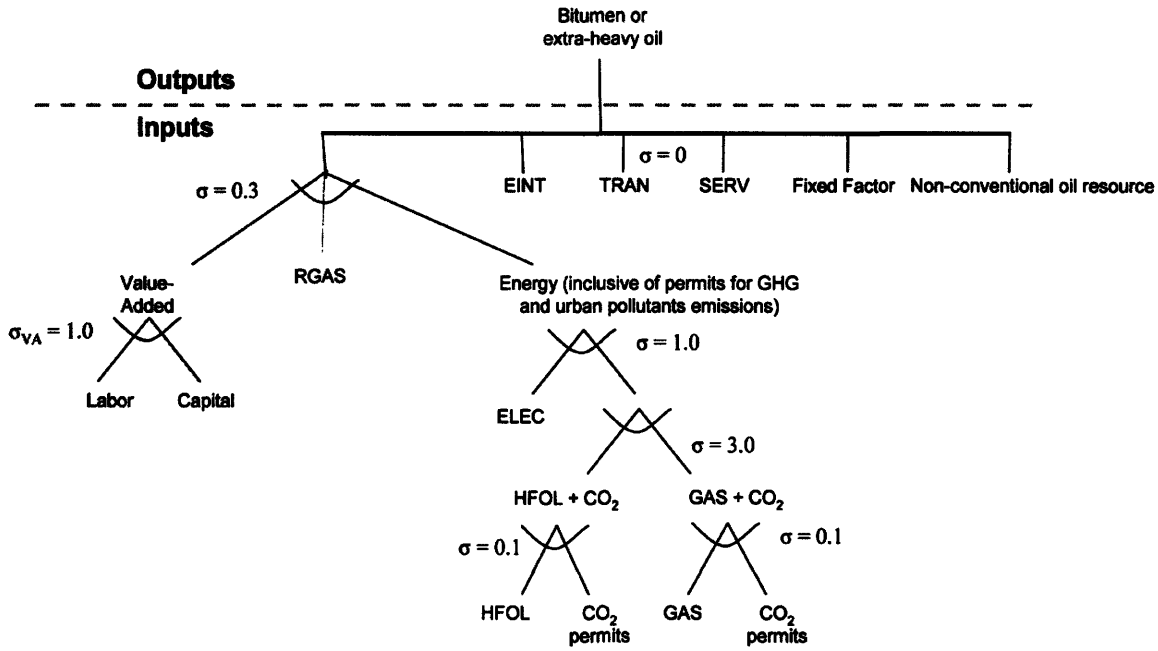
The second addition by EPPA-ROIL is the expansion of the fuel choice for gasification from coal alone to heavy oil and coke and the addition of residue upgrading technology. These additions represent conversion technologies more rigorously and provide a more transparent window into the timing and location of different kinds of refining capacity.

The third addition by EPPA-ROIL is the integration of oil sands reserves in Canada and the heavy oil reserves in Venezuela. Given the magnitude and heavy quality of these crudes, the overall oil supply picture changes significantly with their inclusion into the model. In the standard EPPA oil sands are part of 'conventional oil' sector - since we are focusing in on the oil sands, bitumen production and upgrading are vital sectors to have separated from conventional oil. As the addition of the bitumen sector to the model is fundamental to the analysis, I now discuss its implementation in more detail.

The Bitumen Sector

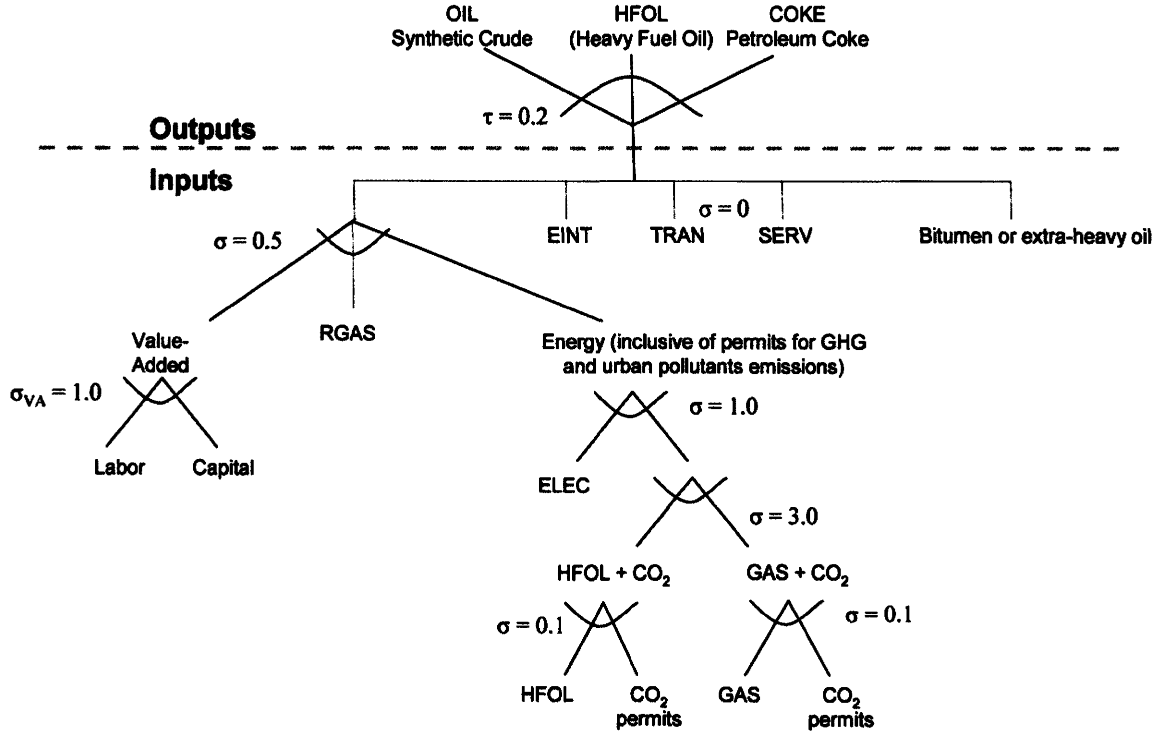
In order to add the bitumen sector to the EPPA model, we need to outline the sector's production functions and find the input and output share values for the production functions. For the EPPA implementation, two sectors were developed to represent the industry – bitumen production, whose output can substitute with heavy oil, and bitumen upgrading whose input is the bitumen production output and whose output can substitute with conventional oil. The production functions which represent the two sectors are shown in Figure 7 and Figure 8.

Figure 7 - Bitumen production function



Source: (Choumert, Paltsev, and Reilly 2006)

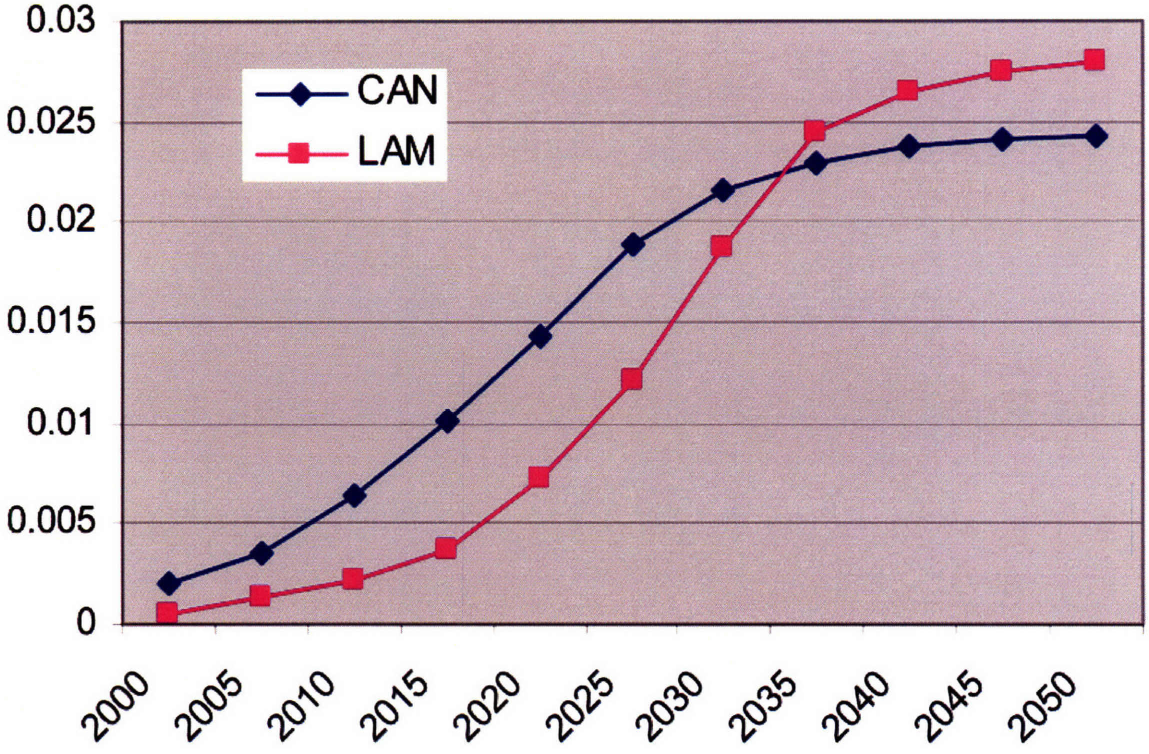
Figure 8 - Bitumen upgrading production function



Source: (Choumert, Paltsev, and Reilly 2006)

The fixed factor in Figure 7 is used to constrain the growth rate of bitumen production and represents the infrastructure and expertise constraints associated with the rapid growth of such capital intensive sectors. The fixed factor is originally set by estimating the future growth rate of the bitumen sector and fixing a curve to those estimates. Next, the fixed factor values which generate that desired growth rate are determined and used in the bitumen production function. The fixed factor values for Canada and Latin America (the other heavy oil producer affected by this fixed factor) are shown in blue and purple respectively in Figure 9.

Figure 9 - Fixed factor for Canadian and Latin American heavy oil production functions



Source: (Choumert, Paltsev, and Reilly 2006)

One drawback of this fixed factor implementation is evident when demand for bitumen declines for awhile but then resumes at some future time. The previous representation does not account for the reduced production and associated loss in infrastructure and expertise and can lead to unrealistically sharp surges in production when demand for bitumen returns. To alleviate this problem, and to make the fixed factor endogenous by relating it to bitumen output, a method[6], whereby the fixed factor is reduced under certain conditions, is added to the model. The equations that follow are calculated every five years in the model to update the fixed factor for Canada[7].

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[6] Note that for the following method there is a min fixed factor value of 2×10^{-3} and a maximum fixed factor value of 2.57×10^{-2}. Also note that "Output" refers to bitumen production output and "FF" refers to fixed factor.

[7] The same approach is used for Latin America.

If $(\text{Output})_t >= (\text{Output})_{t-1}$

$$FF_{t+1} = -6\times10^{-5}\times(Output)^2 + 2.5\times10^{-3}\times(Output) + 1.2\times10^{-3}$$

If $(\text{Output})_t < (\text{Output})_{t-1}$

$$FF_{t+1} = 0.9\times FF_t$$

In this representation, the fixed factor is both dependent on the output level of the bitumen sector and depreciates if output declines. Coefficients for the growth case are regressed from the curve in Figure 9 and the depreciation coefficient is set at one third of capital depreciation. Future work could investigate these coefficients further to estimate a more reliable relationship between sector output and growth.

Now that the production functions and fixed factor have been laid out, let us look at the cost structure for the oil sands in order to determine the production function shares. The cost structure for bitumen production and upgrading is laid out in Table 6 and Table 7. Since there are two methods used to produce bitumen, and they produce roughly equal barrels per year of product, the input shares are calculated by taking the average costs between them.

Table 6 - Cost Structure of Bitumen Production in Canada (USD/bbl)

Cost per barrel of bitumen produced	Mining/Extraction	SAGD
Natural gas (mcf/bbl)	0.27	1.26
Natural gas ($/bbl)*	1.11	5.16
Non-gas OPEX ($/bbl)	4.5	3.75
Capital maintenance ($/bbl)	0.375	0.49
Total CAPEX excluding maintenance ($Bn)	1.35	1.75
Lifetime (years)	42	37
Capacity (bbd)	100,000	100,000
CAPEX ($/bbl)**	3.89	5.20
Transportation ($/bbl)	1.15	1.75
Total cost ($/bbl)	**11.02**	**16.35**

* With natural gas at $4/MMBtu.

** With a 10% capital charge rate.

Source: (Choumert, Paltsev, and Reilly 2006)

Table 7 - Cost Structure of Bitumen Upgrading in Canada (USD/bbl)

Costs per barrel produced	M/E + Upgrading	SAGD + Upgrading
Natural gas (mcf/bbl)	0.75	1.74
Natural gas ($/bbl)*	3.07	7.12
Non-gas OPEX ($/bbl)	7.5	6.75
Capital maintenance ($/bbl)	0.75	0.86
Total CAPEX excluding maintenance ($Bn)	5.48	5.88
Lifetime (years)	44	37
Capacity (bbd)	100,000	100,000
CAPEX ($/bbl)**	16.03	17.46
Transportation ($/bbl)	0.70	0.70
Total cost ($/bbl)	28.05	32.89

* With natural gas at $4/MMBtu.

** With a 10% capital charge rate.

Source: (Choumert, Paltsev, and Reilly 2006)

After calculating the base shares from Table 6 and Table 7, the input shares are modified to make sure that they are consistent with the CO_2 emission data in each process and account for transportation outside the production region. In the case of Canada, 60kg of CO_2 per bbl is used for production (an average of emissions from the two production processes) and 100kg of CO_2 per bbl is used for upgrading. HFOL and RGAS outputs are calibrated to make sure that the emissions and gas input shares are consistent. For bitumen upgrading, 90% efficiency is assumed for upgrading in the production region (representing the integration of production and upgrading processes) and 85% for upgrading outside the region. To account for transportation cost differences between countries, markups are included. Thus Canada and Latin America can export their heavy oil product to any of the countries in Table 8 but only at extra cost. For instance, if Canada sends produced bitumen to China to be upgraded there, the final costs are $24.19 per bbl of synthetic crude versus $21.80 in Canada – thus transportation costs amount to $2.39 per bbl.

Table 8 - Markups to account for transportation costs

USA	CAN	JPN	FSU	ASI	CHN	IND	LAM
1.25	1.08	1.30	1.30	1.30	1.30	1.35	1.05

Source: (Choumert, Paltsev, and Reilly 2006)

The final aspect necessary to implement the bitumen sectors is output values. To get the physical shares, data from the TOTAL Sincor project was used. For a 200 kbd[8] extra heavy oil stream of input, about 180kbd of synthetic crude output (or 30500 toe/day) and 5900t/d of coke output (or 4350 toe/day) result. The Sincor project uses a coker and so does not produce heavy oil. However, some upgraders also make use of

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[8] kbd: thousand barrels per day, toe: ton of oil equivilient and t/d: tons per day

hydro cracking (though the majority of planned upgraders use cokers). Accounting for the hydro cracking yields final output shares of 87% synthetic oil, 10% coke and 3% heavy oil from upgrading bitumen. To get the final value flows, these physical flows are multiplied by their refined product prices.

The addition of bitumen production and upgrading is an important feature of the modified EPPA model. The new sector lets us gain important insights into the effects of carbon caps on Canada's petroleum industry. For this carbon-intense industry to remain competitive, technologies, such as carbon capture and sequestration, may be important.

Bitumen CCS

The following section outlines the process that I used to add bitumen production and upgrading sectors with carbon capture and sequestration (CCS) – a technology that could prove fateful for the oil sands industry to continue operating in an environment of increasing carbon costs.

The addition of bitumen CCS was the result of research aiming at deploying non-power sector CCS technology to the EPPA model. According to the IPCC special report on CCS (The Intergovernmental Panel on Climate Change 2005) "CO_2 capture for industrial uses has not been widely studied" where "industrial" refers to energy intensive processes such as cement and steel production. Thus, using engineering data from power sector CCS may not be applicable to some non-power sector applications. However, some industrial applications, such as bitumen production and upgrading, use a significant amount of energy for the generation of steam in their processing. Furthermore, in the modifications to EPPA, fuels are disaggregated roughly into those which are combusted (natural gas and heavy oil) for energy and those used in chemical processing (lighter refinery gases and the bitumen resource). Therefore, when using CCS in the bitumen sector, we can apply it to those fuels which are combusted and form an exhaust stream as that process is similar to power sector applications.

The MIT Coal study (Ansolabehere et al. 2007) provides several cost assessments of various CCS technologies for the power sector. Pulverized coal (PC) plants represent a good source to understand the costs of flue gas capture as an 'add on' as opposed to other technologies, such as Integrated Gasification Combined Cycle (IGCC) with capture where the CO_2 can be extracted from more CO_2-concentrated streams depending on the arrangement. The data we have for PC plant CCS is per unit of electricity produced but we need an estimate of the cost per unit of CO_2 captured. To do this, the first step is to estimate the \$/ton of CO_2 sequestered cost of adding flue gas capture to your plant in terms of fuel, capital and labor.

The MIT study reports that a PC plant without CCS emits 830 g/kW-hr of CO_2 and a plant with CCS emits 109 g/kW-hr. Dividing the difference between (w/o CCS) and the (w/ CCS) costs with the difference in (w/o CCS) and the (w/ CCS) emissions leads to the total cost per ton of CO_2 sequestered.

$$\frac{\Delta \$ / kW - hr[withCCS - withoutCCS]}{\Delta tonCO2 / kW - hr[withoutCCS - withCCS]}$$

Table 9 – Pulverized Coal Capture Cost Data

	w/o CCS (cents/kW-hr)	w/ CCS (cents/kW-hr)	Difference (cents/kW-hr)	cents/kg	\$/ton CO_2
Capital	2.70	4.34	1.64	2.27	22.75
Labor	1.33	1.75	0.42	0.58	5.83
Fuel	0.75	1.60	0.85	1.18	11.79

Based on this assessment, the total cost of adding a flue gas CO_2 capture unit to a pulverized coal plant amount to \$40.36 per ton of CO_2 sequestered.

The next step is to determine the input value per ton of CO_2 for the sector to which the flue gas capture technology is to be applied. This is accomplished by dividing the \$ per boe[9] produced (of inputs) by the kg of CO_2 per boe (see Table 10). Table 11, which comes from the Choumert study, contains the relative value shares of the bitumen production and upgrading inputs.

Table 10 - Value of bitumen inputs per ton of CO_2 emitted, aggregated

	Bitumen Production	Bitumen Upgrading
Kg CO_2 / boe	55	85
\$ / boe produced	10	19
\$ / ton CO_2	181.82	223.53

Table 11 - Input Shares for bitumen production and upgrading

INPUT SHARE DATA			
Bitumen Production		Bitumen Upgrading	
NOIL	0.1	BITUM	0.439
GAS	0.216	GAS	0.127
RGAS	0.018	RGAS	0.008
HFOL	0.005	HFOL	0.029
ELEC	0.014	ELEC	0.007
K	0.286	K	0.287
L	0.209	L	0.048
EINT	0.035	EINT	0.033
SERV	0.015	SERV	0.004
TRAN	0.092	TRAN	0.018
SO2	0	SO2	0
FF	0.01		

Source: (Choumert, Paltsev, and Reilly 2006)

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[9] boe = barrels of oil equivalent. It is an energy measure and in the case of bitumen includes coke, heavy oil and synthetic crude.

With the \$ / ton of CO_2 defined for the bitumen production and upgrading sector, the next step is to disaggregate the capital, labor and fuel shares of the \$ / ton of CO_2 values. This amounts to answering the question – what portion of the \$181.82 / ton of CO_2 of bitumen production inputs comes from capital, labor and fuel. The values for fuel should be those energy inputs which are used for energy production (for bitumen this includes GAS and HFOL) rather than those which end up in the output stream (for bitumen this includes RGAS and NCOIL) since the capture technology is applied only to the flue gas. Multiplying the fraction of capital, labor and fuel (Table 11) by the total \$ value of inputs / ton of CO_2 (Table 10) yields the values below (see column 2 in Table 12).

Table 12 – Capital, labor and fuel inputs for production and carbon capture and sequestration (\$/ton CO_2).

Bitumen Production	Production	CCS	Total	Mark-up for CCS (Total/Production)
Capital	52.00	22.75	74.75	1.44
Labor	38.00	5.83	43.83	1.15
Fuel	40.18	11.79	51.97	1.29
Bitumen Upgrading				
Capital	64.15	22.75	86.90	1.35
Labor	10.73	5.83	16.55	1.54
Fuel	34.87	11.79	46.66	1.34

To clarify, row 2, column 2 in Table 12 can be read "for every ton of CO_2 in the bitumen production process, there is 52 dollars of capital input." In order to apply the capture technology outlined in Table 9, we must add to the costs of the CCS technology to each input – for example, the value of the capital input for bitumen production with CCS is now \$52.00 (base technology) + \$22.75 (CCS) = \$74.75 giving a capital markup of \$74.75 / \$52.00 or 1.44. The markup is applied to the base technology in order to model the costs of a CCS version of that technology.

By representing several broad categories of refined products, adding explicit technologies to the oil sectors, including the effect of a changing crude mix on the refining industry and adding bitumen CCS technology, the EPPA modifications provide a more accurate picture of the oil and transportation industries than standard EPPA and allow for a better analysis of climate and environmental policy impacts on these sectors. The top-down assessment of energy policy in Canada, a country with significant energy industries, is enhanced by the greater detail captured by these EPPA modifications. Using this model, policies may be tested and the effects analyzed to better understand the economic impacts of greenhouse gas regulation on Canada. Let us now turn to the details of the regulations under consideration.

Scenarios

The modified EPPA model provides insights into the market and welfare impacts arising from Canadian regulation. Assessing the economic costs of a policy does not account for the potential impacts associated with climate change. Typically environmental economics seeks to balance marginal costs and marginal benefits of a policy. That is complicated in the case of climate change because Canada's mitigation actions, by themselves, have little effect on the trajectory of climate change. I thus restrict myself to estimating welfare costs and environmental implications of mitigation policies. The 'core' policies used in the assessment are now set out.

Three scenarios will make up the core of the EPPA-ROIL analysis. Three Canadian policy scenarios, of different GHG control severity, are matched with the 'weak' international policy outlined below. Time horizon for the analysis goes from 2005 through to 2050.

Canadian Policy

Although Canada signed the Kyoto Protocol, a treaty which was to come into force in 2005, and ratified it in December 2002, no substantive legislative initiatives were taken until the federal government introduced bill C-30, known as the "Clean Air Act", on the 19th of October, 2006. The act set out the government's intention to develop and implement a number of regulations under CEPA (Canadian Environmental Protection Act) to address air pollutants and GHGs by means of the amendments in Bill C-30. According to the first readings, strict limits on GHGs would not be in place until 2020 or 2025 and emission regulations on large final emitters would not take effect until 2010.

The original draft of the bill was rejected by all opposition parties and hence not approved since the conservative government held only a minority government. The bill was then referred to the legislative committee before the second reading. The amended C-30 bill focused on stricter controls in line with the Kyoto Protocol (Kyoto wasn't mentioned in the first reading). The amended bill C-30 is now no longer pursued by the government which is, instead, moving to regulate greenhouse gas emissions under CEPA (Canadian Environmental Protection Act).

The current Conservative minority government is instead proposing a new plan which is outlined in the document 'EcoAction: Action on Climate Change and Air Pollution' (Environment Canada 2007). The plan calls for emission intensity reductions of 6% in 2008, 2009 and 2010 - summing to 18% by 2010. Subsequent years aim for further 2% annual reductions. Finally, two *goals* are set for 2020 at 20% absolute reductions from 2006 emissions and 2050 at 50% absolute reductions from 2006 emissions. While this plan will likely be implemented if the conservative government retains its position, an election in a Canadian minority government can happen at almost any moment. If the conservative party loses the next election, it is likely that the official opposition will put forward their own climate-change plan.

The other major Canadian political party is the Liberal party and they have proposed their own GHG reduction plan called 'Balancing our Carbon Budget' (Liberal Party of Canada 2007). The plan, unlike the conservative plan, aims to meet Kyoto commitments by aiming for a 6% reduction in absolute emissions from 2008-2012. The plan provides 'free' permits to each sector based on absolute reductions from 1990 levels (Table 13). Additional emissions beyond the 'free' permits will require the polluter to pay \$20-\$30[10] per ton of CO_2 to a 'Green Investment Account' which is used for investments in low-emission technologies. It is very difficult to predict how the plan will operate post 2013 – the only information we have is (a) the carbon tax will not go below \$30 / ton of CO_2 and (b) the 'carbon budget' *goals* change as indicated by Table 13 (under the 'Kyoto and Beyond' section).

Table 13 – Major Canadian Party Proposals and Discussions for GHG regulation

Year	Conservative 'Climate Action Plan'	'Kyoto and Beyond'
2010	18% reduction in emission *intensity* from 2006 levels	1990 emissions less 6%
2020	2006 emissions minus 20%	1990 emissions minus 20%
2035		1990 emissions minus 35%
2050	2006 emissions minus 50%	1990 emissions minus 60%

With the main parameters of the climate change plans before us, I now discuss how the plans will be treated for the purposes of this analysis. In implementing this analysis, it should be noted that there remains significant regulatory uncertainty for the years after 2010. Rather than guess at the carbon price or how many allowances each plan will provide after 2010, the analysis will simply use the *stated goals* of each plan[11]. For the 'Climate Action Plan' analysis, I apply emission *intensity* constraints equal to 18% in 2010, *absolute* constraints of 20% below 2006 levels for 2020 and 50% below 2006 levels for 2050[12]. For the 'Carbon Budget Plan' analysis, I apply the goal to meet Kyoto targets of 1990 emissions minus 6% by 2010, and then the plan's stated 'budget' goals of 1990 emissions minus 20% target by 2020, 1990 emissions minus 35% by 2035 and 1990 emissions minus 60%[13] for 2050. In order to translate the emission targets into a continuous policy for those years where the emission goals are undefined, I interpolate linearly[14] between years with clearer targets. From this point forward, I will refer to the

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[10] \$20 in 2008, \$25 from 2009-2010 and \$30 from 2011-2012

[11] This is likely a departure from what the plan would actually look like. Implicit in the 'Carbon Budget' plan is the idea that the budget will not be met – hence the carbon tax on emissions beyond the budget. However, political positions of three of four major Canadian parties (including the party who put out the 'Carbon Budget' plan) continue to call for meeting Kyoto targets. Whatever the disconnect may be between 'the carbon budget' plan and the assertions to meet Kyoto, this analysis will focus on costlier goal of meeting, and not exceeding, the carbon budget and Kyoto goals.

[12] An important caveat is the implementation uncertainty of these various constraints. The short-term emission intensity reductions are very likely to be implemented whereas the long-term absolute reductions are stated as "goals" which are predicted to come about from a combination of policy levers.

[13] 60% is at the lowest end of the stated goal for 2050

[14] A quota of 1000 MT in 2020 and 500 MT in 2010 would yield a quota of 750 MT in 2015

conservative goals as the 'Climate Action Plan' (CAP) and the Liberal goals as 'Kyoto and Beyond[15]' (KAB).

While I am attempting to analyze how these specific plans would impact the economy, the more important[16] result is the general understanding of how various degrees of climate change policy might impact the Canadian economy. With the two Canadian-policy plans defined, I now consider international policy.

International Policy

The Canadian regulations will be analyzed on the backdrop of two very different international GHG policy paths. The two paths include one 'strict' regime and one 'weak'[17] regime (the 'weak' policy is used in the core analysis, the 'strict' policy is used in the sensitivity analysis). The purpose of the two paths is to gain insight into how international climate policy might affect Canada's economy when Canada undertakes its own climate policy.

For the 'strict' case, the whole world, other than Canada, pursue Kyoto-like policies (starting in 2010 for USA, Europe, Australia, New Zealand and Japan and in 2020 for the remaining countries) where restrictions on carbon emissions grow steadily to approximately 50%, or half, of 1997 levels by 2050. For the 'weak' case, restrictions reach approximately double 1997 levels by 2050 and *only* the USA, Europe, Australia, New Zealand and Japan engage in the policy. For more details on the 'strict' and 'weak' policies, you may refer to the 450ppm and 750ppm scenarios (Paltsev et al. 2007) from which these two policies are derived. Except for the later application of the constraints in both international policies (2010 for USA, Japan, Europe, Australia and New Zealand and 2020 for the remaining regions) and the exclusive participation in CO_2 policy of USA, Japan, Europe, Australia and New Zealand in the 'weak' case, the 'strict' and 'weak' policies correspond to the 450ppm and 750ppm stabilization cases respectively for all[18] countries except Canada. Table 14 through Table 16 present the emission targets for each region in both the 'weak' and 'strict' case.

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[15] As opposed to the 'Carbon Budget Plan' – I believe 'Kyoto and Beyond' is more in tune with the stated goals of the three opposition parties than the 'Carbon Budget Plan.' Also, details for the 'Carbon Budget Plan' are too few to predict the policy for the post-2012 period.

[16] More important due to the host of market, regulatory and technology assumptions necessary for such an analysis.

[17] 'strict' and 'weak' are met only to ease in distinguishing between the international policies used in the analysis. They should not be interpreted as normative.

[18] Note that for the 'weak' case the only countries involved in the 750ppm policy include the USA, Europe, Australia, New Zealand and Japan.

Table 14 – Carbon emission targets in mmt of C used in the 'weak' case

Year	USA	Japan	Australia-New Zealand	Western and Central Europe	Eastern Europe
2005	none	none	none	none	none
2010	1733.91	336.7	116.69	1087.66	243.25
2015	1754.29	362.32	127.09	1165.79	259.2
2020	1853.79	390.47	137.09	1229.18	272.17
2025	2005.28	421.09	144.72	1251.74	272.83
2030	2174.96	461.59	159.3	1307.12	260.91
2035	2363.42	506.32	173.67	1427.01	297.81
2040	2549.12	542.45	186.41	1520.03	324.68
2045	2696.29	567.93	196.05	1590.24	344.85
2050	2810.23	616.35	206.47	1671.37	366.22

Table 15 – Carbon emission targets in mmt of C used in the 'strict' case

Year	USA	Japan	Australia-New Zealand	Western and Central Europe	Eastern Europe
2005	none	none	none	none	none
2010	1514.05	311.1	102.98	849.88	136.93
2015	1519.98	335.18	105.57	775.26	133.11
2020	1582.76	355.72	96.19	645.18	115.29
2025	1509.79	361	74.41	592.91	89.07
2030	1347.06	383.75	65.78	589.19	91.36
2035	1143.89	378.67	51.5	564.53	86.67
2040	952.98	343.67	51.88	581.73	87.14
2045	790	266.79	43.74	536.39	78.93
2050	730.28	202.13	42.86	496.95	70.55

Table 16 – Carbon emission targets in mmt of C used in the 'strict' case

Year	Former Soviet Union	South East Asia	China	India	Indonesia	Africa	Middle Eastern States	Latin America	Rest of the world	Mexico
2005	none	none	none	none	none	none	none	none	none	none
2010	none	none	none	none	none	none	none	none	none	none
2015	none	none	none	none	none	none	none	none	none	none
2020	410.29	389.27	600.65	223.77	53.4	254.05	343.94	201.27	129.78	148.08
2025	402.84	379.11	599.61	211.95	57.05	178.94	355.31	130.37	129.39	57.97
2030	393.73	253.28	460.19	226.78	60.68	167.98	345.87	149.96	134.47	59.41
2035	373.33	195.81	350.42	197.84	60.77	177.11	297.33	152.64	150.95	54.83
2040	315.11	173.57	246.31	138.91	62.22	158.09	241.15	160.97	147.53	47.26
2045	280.69	153.74	239.65	138	55.91	130.18	187.05	155.95	124.08	44.88
2050	242.4	123.49	239.43	136.66	53.33	105.37	140.82	152.61	100.02	43.8

The goal of these two different policies is to better understand how dependent Canadian regulation costs are on international policies. These 'core' scenarios assume no emissions trading between regions (other than the implicit trading in aggregated regions, such as the Europe). Also, the countries have no ability in crediting reductions outside their regions (in the core analysis) via mechanisms like the Kyoto-sanctioned Clean Development Mechanism (CDM). With the regulations defined for both Canada and the rest of the world, let's turn to the 'core' technological and political assumptions used in the analysis.

Other 'core' assumptions

All policies use carbon quotas for each region to achieve carbon dioxide emission reductions. Allowances are distributed for free. While there are distribution issues such as who receives the allowances and, thereby, who bears the greatest costs of abatement, such issues are not addressed in this analysis[19]. Banking and borrowing[20] are not used nor is there any carbon trading between EPPA regions[21].

Sensitivity Issues

The analysis will begin with an examination of the economic impact of the Canadian policies (BAU, climate action plan, carbon budget plan) against the backdrop of the 'weak' international regime together with the above stated assumptions. Following the investigation of those results, I consider how shifts in certain 'core' assumptions affect the results. The changes include the exclusion of 2nd-generation bio-fuel technology, the creation of an international carbon-permit trading framework, the inclusion of a strict international policy described above and the inclusion[22] of CCS potential in the oil sands sector. Investigating the effects of these changes will allow for a more complete analysis and lend insights into understanding how various market, technological and regulatory changes can affect the core results.

Mitigation Costs for Canada

Emission Reductions

Canada will not likely meet its 2010 Kyoto targets. The 6% below 1990 levels target of 563 Mt CO_2 eq. has been dwarfed by ever increasing emissions - currently at around 758 Mt CO_2 eq. per year (Environment Canada 2006a). Canada emits about 2%

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[19] In 'Assessment of US Cap and Trade Proposals' report (Paltsev et al. 2007) the authors point out that in a model like EPPA all costs necessarily fall on the single representative agent as that agent owns all resources (ie. Labor, capital and other assets).

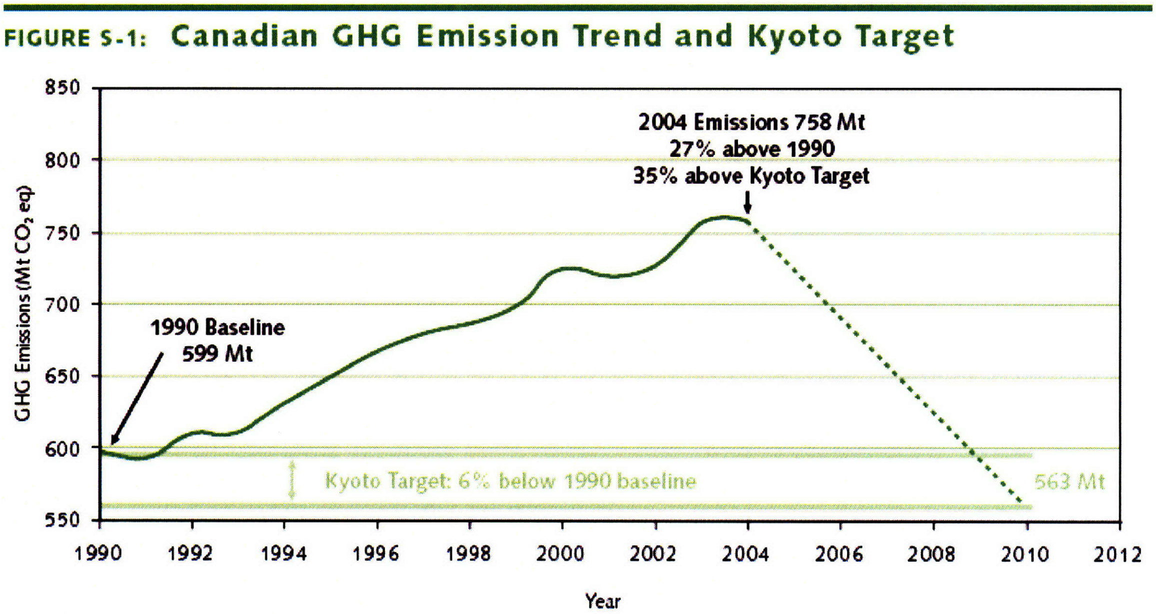
[20] Banking and borrowing refer to a mechanism whereby an emitter may buy or sell future allowances.

[21] Other than the trading implicit inside aggregated EPPA regions such as Europe.

[22] In the 'core' analysis, bitumen CCS is not active.

of the total world GHG emissions and is one of the world's highest per capita emitters largely due to its size, climate and energy-based economy. Alberta accounts for 40% of Canada's GHG emissions while Ontario accounts for about 30% (Environment Canada 2006a).

Figure 10 - Canadian Emissions 1990-2004



Source: (Environment Canada 2006a)

The first result from the model to consider is the world and Canadian emission profiles expected under a constant world policy (the 'weak' policy described above). It is clear, given Canada's population, that emission controls in Canada alone will do little to reduce world emissions. Figure 11 and Figure 12 indicate the impact on aggregate world emissions from the various Canadian policies and gives one an idea of the magnitude of emission reductions in Canada to be expected if the policy targets are met.

Figure 11 - World CO_2 Emissions, core cases

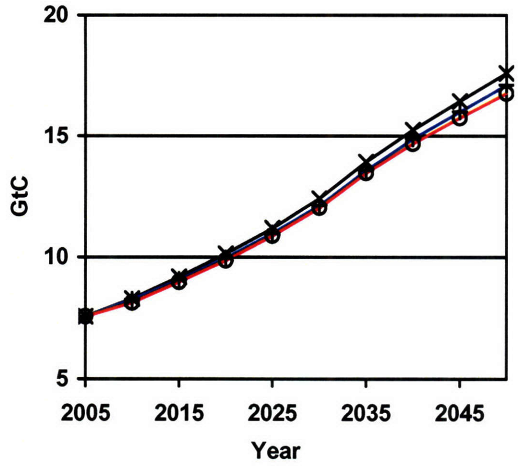
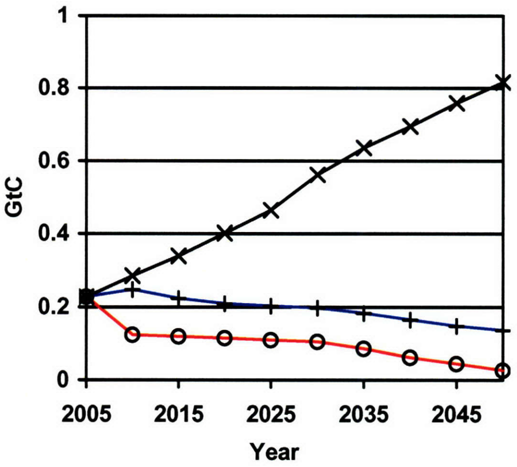


Figure 12 - Canadian CO_2 Emissions, core cases



Unilateral regulatory action by Canada on climate change will have no significant effect on reducing global CO_2 levels. If Canada wishes to see actual global emission reductions, international agreement with major emitters[23] must be sought - otherwise Canada's action is for reasons apart from actually impacting world GHG emissions. Domestic CO_2 controls should only be considered if it will help convince major emitters to follow suit. Whether Canadian GHG controls will affect policy in other countries, and to what extent, is beyond the scope of this work – work which is vital to understanding the full cost-benefit picture for Canada of taking early action on GHG mitigation.

Economic Impacts

The assumptions in this section are dependent on the economic and political assumptions outlined in previous sections. Other assumptions are certainly plausible as well but we must proceed from somewhere in trying to gain insight into the costs associated with the controls being discussed in the Canadian parliament. It is also true that the two CO_2 constraining Canadian policies will likely *not* match the implementation of the policy that they represent as new information is revealed regarding the government's, and opposition's, intentions and as more specific details emerge which bridge the difference between the stated goals and limited details outlined in the plans.

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[23] countries like China, India and USA

Carbon Price

Significant emission reductions sought in either the CAP or KAB policies will require carbon prices rising continually and reaching by 2050 \$150 per ton of CO_2 in CAP and \$700 per ton of CO_2 in KAB according to the model under the core assumptions. As will be evident in the sensitivity analysis, an international carbon trading regime would have a significant impact on carbon prices – especially when emission targets vary a lot between participating countries. The Carbon Budget plan and Climate Action plan both provide for some level of offsets by investing in green technologies in other countries – offsets that would likely increase in importance as carbon caps become stricter in Canada. The actual policy that will emerge will likely mix some international trading with domestic trading systems. However, as it is difficult to predict just how the trading mix will be implemented, I just model the 100% 'no trading' (Figure 13) and 100% 'trading' (Figure 30) cases to get an idea possible range of carbon price impact from varying the level of international trading.

Figure 13 – Canadian CO_2 Price, core cases

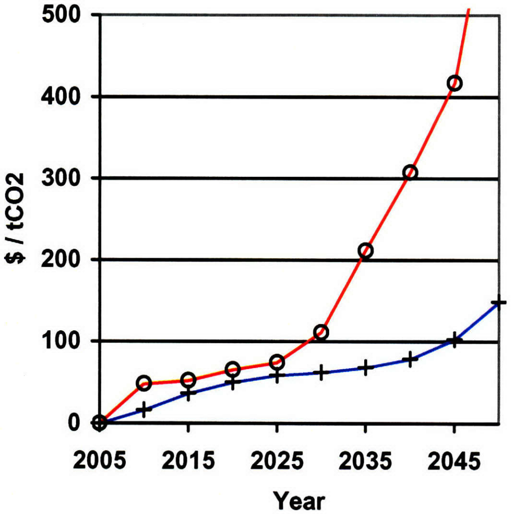
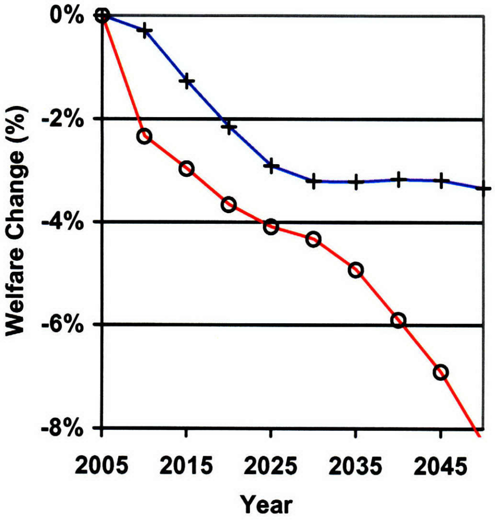


Figure 14 – Canadian Welfare Change, core cases



Welfare

Welfare is measured as a function of end user consumption in the region in question. Welfare change in Figure 14 is the percent change in welfare with respect to the business-as-usual (BAU) case; the case where Canada does not engage in carbon emission reductions while the rest of the world engages in the 'weak' policy described above. Without carbon trading and despite our inclusion of other cheap carbon-switching technologies such as 2nd generation bio-fuels, the impact on consumption in Canada will be significant under strict carbon constraints. According to the core scenario results, meeting CAP and KAB emission targets would reduce aggregate welfare in Canada by over 3% and 8% respectively from the case of no policy. Canada is likely more exposed to negative economic consequences from CO_2 restrictions than many nations because it has a carbon-rich energy-intensive economy. Work looking into and quantifying this difference could be useful for Canadian policy-makers.

Fuel Prices

As one would expect, carbon-constraining policies have an important impact on fuels and power markets. When considering energy prices it should be noted that the prices presented here are relative to the base year (2005) and include only the CO_2 that is emitted in supplying the energy product[24].

Two factors can explain the negligible impact of Canadian policy on oil prices. Firstly, Canada makes up a small percentage of world oil demand (about 2%) and supply (about 3.5%). Secondly, oil markets are largely integrated across the globe. Despite these factors, one can observe slight price increases induced by the CO_2 premium charged on the oil sands sector – a sector which plays an increasingly important role in global oil supply.

Coal, electricity and natural gas[25] markets do not have a single global price and are therefore more subject to regional supply and demand shifts. Looking at coal, one can observe that, overall, the price decreases depending on the severity of the carbon policy. Such is to be expected given the high carbon content of coal – consuming it is relatively more expensive when CO_2 prices are high. One other point of interest can be observed in the slight price recovery after 2015. The recovery results from the use of CCS technology for Integrated Gasification Combined Cycle (IGCC) power plants. Natural gas, a less carbon-intense source of electricity, is priced high in all cases. This can be explained in the policy cases easily enough by an increase in demand for less carbon-intense fuels. It is less obvious why prices for natural gas are highest in the early period for the BAU case. One explanation may be that oil sands production, a major

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[24] This means that for conventional oil, natural gas and coal the CO_2 price to be paid on the consumption of these products is not part of the price presented here. The CO_2 emitted in the production of these energy products is included in the price as they are part of the costs of supply.

[25] With the rise of LNG, a globally integrated natural gas market seems likely. Such a market would lower the effect of domestic supply and demand changes on prices.

consumer of natural gas, is highest when there is no CO_2 constraining policy – from 2015 to 2030, bitumen production in the BAU case is about 10-20% higher than in the CAP case and about 50-200% higher than in the KAB case. Further more, synthetic gas production from gasification, an extremely CO_2 on-intense process, enters only when there is no CO_2 constraining policy – the additional supply keeps gas prices lower in the later period of the BAU case. As for electricity, one can observe the expected early rise in prices depending on policy severity. As new technologies, such as IGCC and NGCC with CCS, enter the market[26] the price levels off. An important price driver starts around 2020 and continues thereafter – a relative reduction in demand for electricity consumption with respect to other CO_2 emitting goods, such as transportation fuels. The demand reduction reduces electricity prices and follows a similar pattern, of policy-dependent intensities, for both cases. The demand reduction might explain why in the stricter policy, KAB, electricity prices are lower than in CAP from 2020 to 2030.

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[26] In EPPA, the power sector CCS technologies become commercially viable in 2015.

Figure 15 – World Petroleum Price, core cases

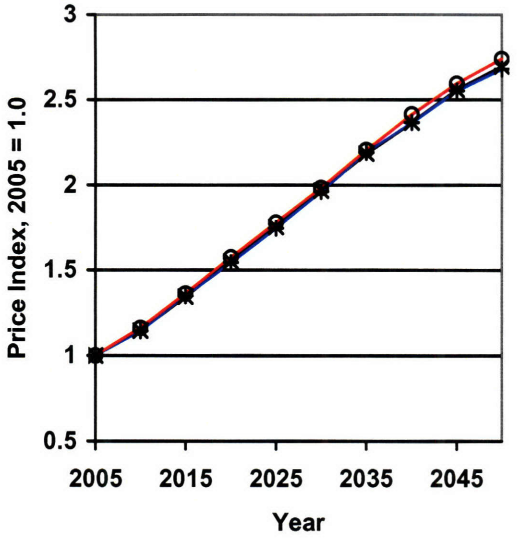


Figure 16 – North American Natural Gas Prices, core cases

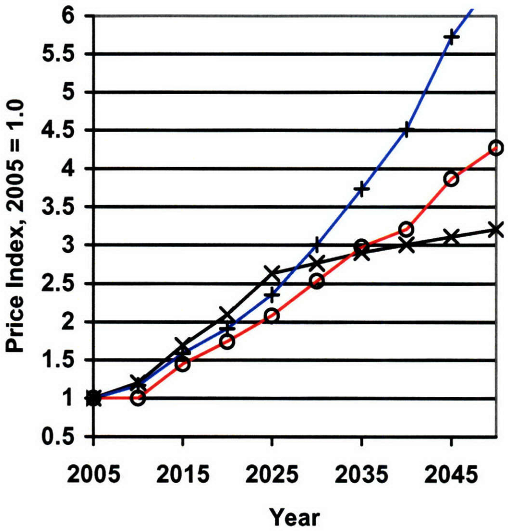


Figure 17 – North American Coal Prices, core cases

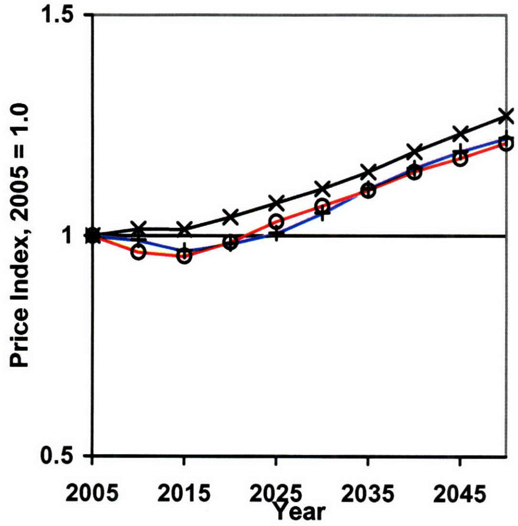
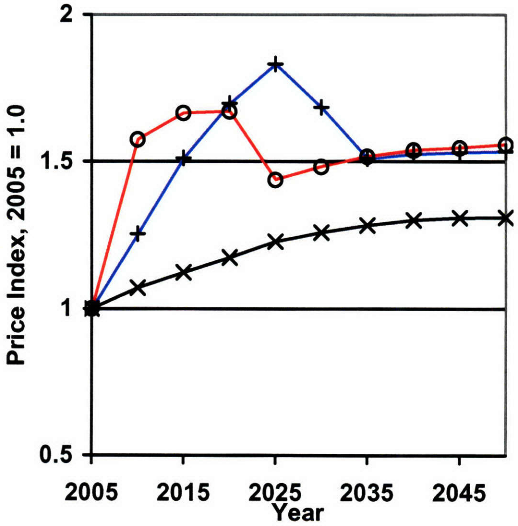


Figure 18 – North American Electricity Prices, core cases



Energy prices will likely change under CO_2 policy. Natural gas prices are largely dependent on whether the policy stifles bitumen production and upgrading. Natural gas prices, even without the cost of CO_2 when the gas is combusted included the price, is projected to increase as much as 8 times by 2050 in CAP and as little as 3 times in BAU. The power sector will likely undergo significant changes under policy. Nuclear power could be paramount in the power sector if CCS technology proves difficult to commercialize for whatever reason.

Primary Energy

According to the model results, Canada will reduce energy consumption if it wishes to achieve the targets set out in CAP and KAB. Figure 19 through Figure 24 provide some interesting insights into how Canadian energy production and consumption might be affected by emission restraining policies of varying severity.

Both policies exhibit the expected energy consumption reductions (Figure 22 and Figure 24). However, while energy production remains intact (Figure 21) in the CAP policy, it is reduced significantly (Figure 23) in the KAB policy. It begs the question – at what price of carbon dioxide would we expect to see significant cut-backs in Canadian energy production? Inspecting (Figure 13) suggests that at around \$50 - \$200 per ton of CO_2 we would see this accelerated production reduction depending on the timing of the price. Carbon-sensitive import and export restrictions could affect this number as well – ie. Export tariffs on carbon-rich fuels (such as diluted bitumen or synthetic crude oil) would reduce the carbon price point at which production is cut back.

If energy production remains strong under policy (especially in CAP) but energy consumption declines, the effect means that Canada, already in the BAU case a large net exporter of energy products, would export an even larger share of its energy products. Discussing the effects of such a trade imbalance is beyond the scope of this thesis other than to say that carbon policy may, according to the model's results, increase the ratio of energy exports to domestic energy consumption.

Another vital result is the importance of bio-fuels in maintaining energy production and, especially, energy consumption. As will be seen in the sensitivity analysis, if the transportation fuel sector does not have access to low-carbon conversion options, ambitious CO_2 targets will be either impossible or would seriously reduce the size of the economy relative to the BAU case. It should be noted also that optimistic projections of large scale bio-fuel penetration like that in our core case below would put enormous demands on land use. One estimate suggests that for the USA to supply its current transport fuel needs with bio-fuels, it would have to devote all its cropland, grassland and forestland to the effort (Paltsev et al. 2007). Large scale bio-fuel production would force food crops to compete for land - likely driving many food prices higher and potentially initiating concerns over food supplies. In addition, the impact on the environment through large scale land use would have important effects requiring consideration. Given the challenges with land use, food crops and technology viability, it is important to consider the case where optimistic commercial bio-fuel technology does not emerge – this is done in the sensitivity analysis below.

Figure 19 – Canadian Primary Energy Production, BAU

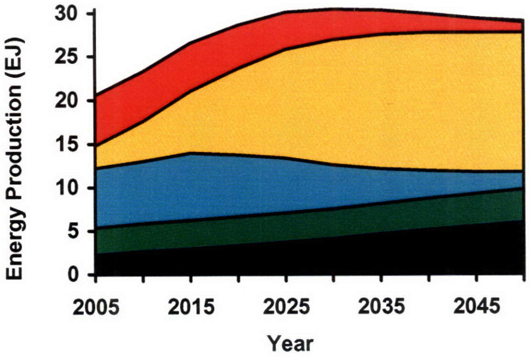


Figure 20 – Canadian Primary Energy Consumption, BAU

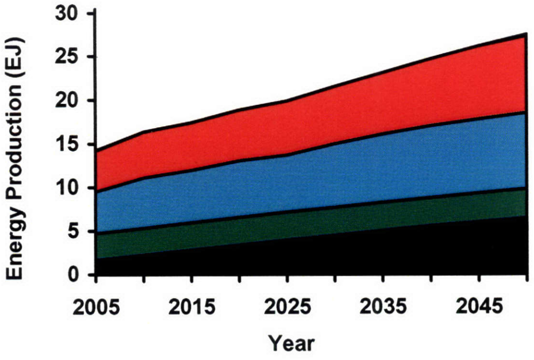


Figure 21 – Canadian Primary Energy Production, CAP

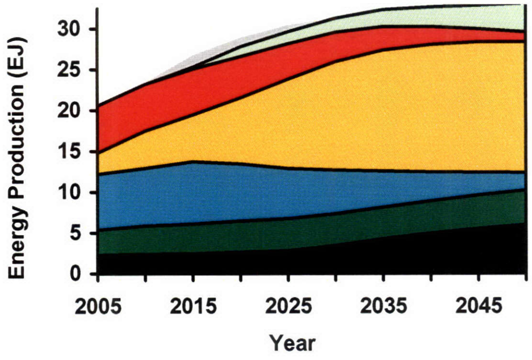


Figure 22 – Canadian Primary Energy Consumption, CAP

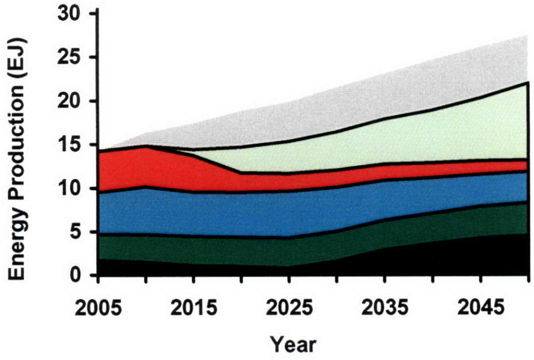


Figure 23 – Canadian Primary Energy Production, KAB

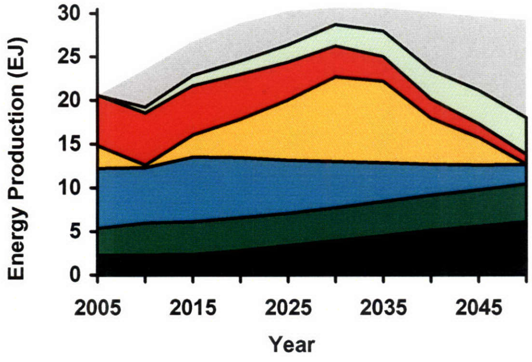
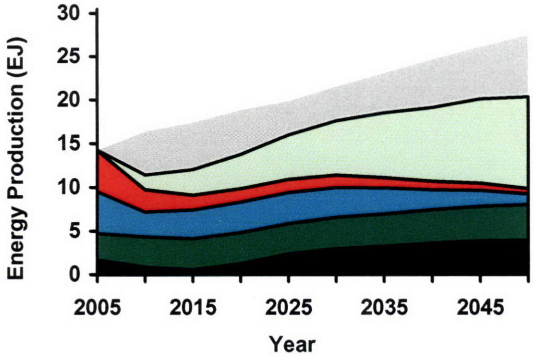


Figure 24 – Canadian Primary Energy Consumption, KAB



■ Coal
🟦 Natural Gas
🟥 Oil
░ Reduced Production / Use
🟩 Nuclear + Renewables
🟨 Bitumen
🟩 Bio-mass Liquids

Electricity

The three major uses of energy in Canada include transportation, space heating and electricity generation. I will consider Canada's transportation fuel sector in more depth in the case study on bitumen near the end of this work. The fuel of choice for space heating - natural gas - is not expected to change significantly across the policies under consideration. Thus, let us now consider electricity generation in Canada to gain insights on the kinds of technologies that might emerge under CAP and KAB.

I will exclude KAB from this discussion as it resembles CAP almost perfectly, albeit with about 10% less electricity output. The impact of CO_2 regulation will have a significant impact on the technologies of choice in the power sector. Conventional sources (mostly coal - but gas and oil plants as well) steadily decline in the policy cases to be replaced first by NGCC, then by NGCC with CCS and finally, when the price of natural gas continues to grow relative to coal, IGCC with CCS becomes the plant of choice. In this analysis, the rapid deployment of Nuclear is restrained for reasons related to perceived risks over proliferation and waste disposal. It should be noted that IGCC with capture is similar to Nuclear in that its fuel source is relatively cheap, it emits little carbon (though Nuclear is carbon-free) and it is capital intensive. If political constraints were lifted off of nuclear deployment, it might be expected to penetrate in a similar manner as IGCC with CCS in the policy cases.

Figure 25 – Canadian Electricity Generation, BAU

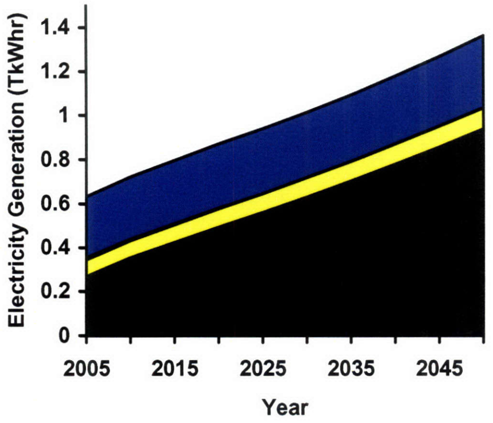
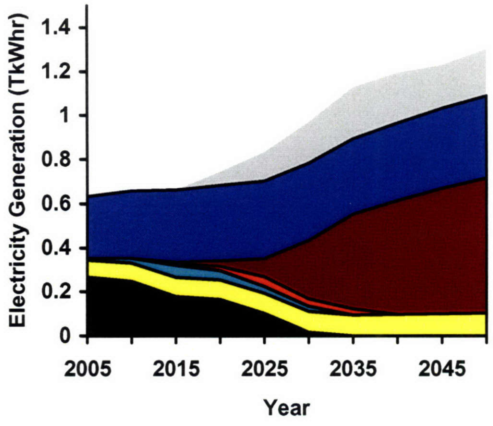


Figure 26 – Canadian Electricity Generation, CAP



Sensitivity Analysis

It is important to shift some of the core assumptions to gain insights into which technologies, policies and market forces may have the greatest effect on the economic impacts already discussed.

Transportation Fuel Technology

Point source emissions, characteristic of the power sector, make that sector amenable to technologies, such as IGCC + CCS, which can reduce emissions per unit of electricity delivered. Space heating makes use of natural gas which, while likely rising significantly in cost, remains a relatively low emission energy source. Low carbon transportation fuels, however, are more constrained due to the difficulties of storing natural gas (which still emits CO_2) and finding technologies which provide energy dense sources of energy.

While several potential technological solutions exist, the one that I am considering is bio-fuels – fuels which act as gasoline and diesel substitutes but come from crops rather than fossil fuels. It is by no means clear that bio-fuels will be commercially viable on a large scale or will cause less environmental and other problems than those arising from fossil fuel use. Therefore, to understand how the inclusion, or exclusion, of bio-fuel technology from the model will affect Canada's response to CO_2 regulation, let's look at how the welfare, carbon prices and energy market picture changes when 2nd generation bio-fuels are removed from the model.

Welfare losses from the exclusion of bio-fuel technology are large relative to the case of its inclusion. The main take away is that given the available low-emission technologies in the power sector (ie. Nuclear and CCS), strict emission controls will likely exert greatest pressure on the transportation fuels sector which may not have access to cheap substituting technologies. If bio-fuels do not perform well at scale, achieving strict emissions may be difficult (ie. greater than 30% [without bio-fuels] vs. 8% [with bio-fuels] welfare loss in the KAB case by 2050). For Canada, therefore, it might be prudent to engage in intense research in the area of bio-fuels and other transportation fuel conversion technologies before agreeing to strict emission controls.

Figure 27 – Canadian Welfare Change, Limited Bio-fuels

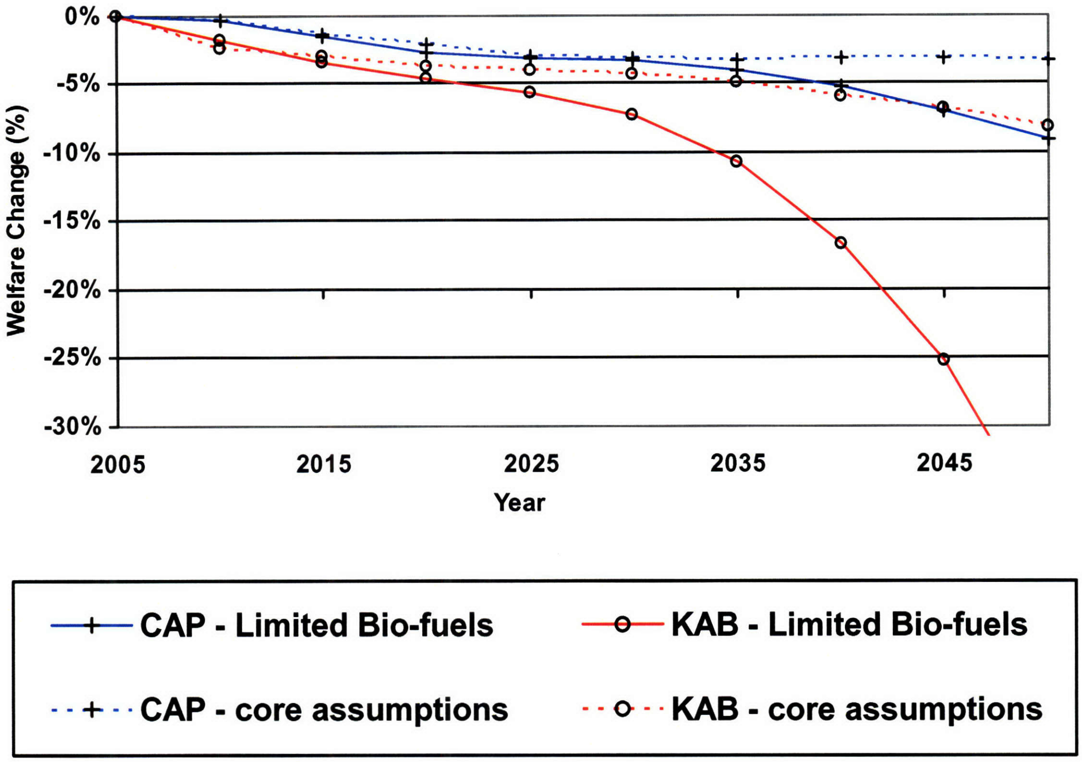
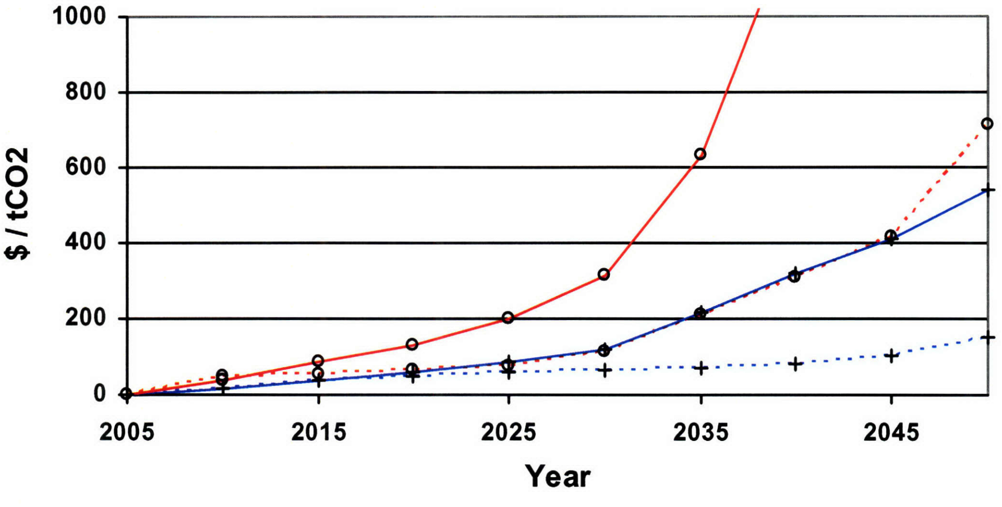


Figure 28 – Canadian CO_2 Price, Limited Bio-fuels



Issues over land use, technology viability and competition with food markets could reduce the prospects for bio-fuels in a carbon constrained world. According to the model, if large scale commercial bio-fuels are not able to emerge for whatever reason, the stress on the Canadian economy would be large relative to the case where bio-fuels are not constrained.

Welfare losses reach about 3% in CAP and 8% in KAB. These losses increase to about 8% in CAP and 30% in KAB if bio-fuel technology is limited in the model. The commercial viability of large scale bio-fuel technology could be important for Canada to reach the targets outlined in CAP and KAB. KAB and CAP-like emission goals reduce Canada's energy consumption by around 20% relative to the no-policy case.

International CO_2 Trading

Thus far, the analysis restricted CO_2 permit trading between countries. Given that there currently is no clear international trading regime in place, the assumption of no trading may be justified. However, with programs like the Kyoto Clean Development Mechanism[27] and proposed legislation[28] which make allowances for some limited international carbon trading, the potential of an integrated international trading regime is distinct – especially if the world takes strong measures to reduce GHGs. Strong measures could be achieved much more efficiently if less-efficient emissions were reduced before implementing changes in efficient plants. One caveat is the significant benefit arising from asymmetric policies. Since the only countries engaged in the trading and controls include the USA, Japan, Europe, Australia and New Zealand and given that the controls in those countries are much less stringent than in Canada, there exists ample opportunity to buy cheap credits from those countries which Canada does to reduces the negative impact on its own economy. International CO_2 trading could reduce the burden of emission controls – especially for countries adopting stricter policies relative to other carbon trading countries.

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[27] CDM is an arrangement under the Kyoto Protocol which allows developed countries to invest in low-carbon projects in developing countries to get some carbon permits in return.

[28] For example, CAP provides for access to the CDM to offset up to 10% of the emissions target.

Figure 29 – Canadian Welfare Change, CO_2 Trading

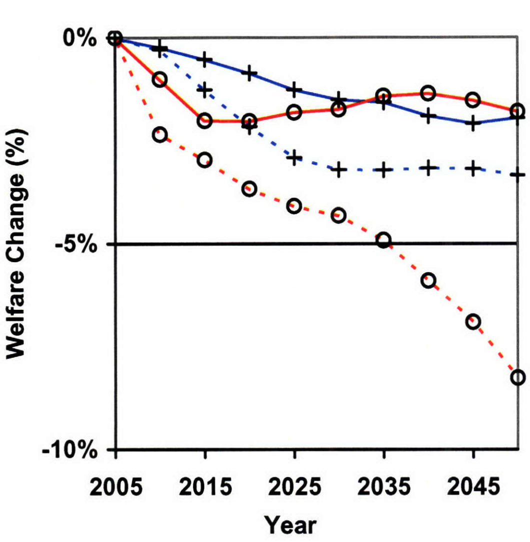
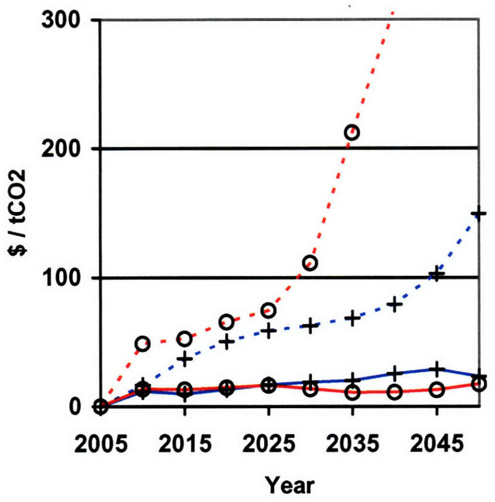


Figure 30 – Canadian CO_2 Price, CO_2 Trading



International CO_2 Regulations

Up to this point, the analysis has only considered the 'weak' international policy as outlined in the scenarios section above. How will the welfare and CO_2 price change should the international community engage in stricter CO_2 policy? The results are not impacted too much by a strict international policy but they are to some extent. The early period (2005-2025) exhibits slightly more welfare loses in contrast to welfare gains in the later period (2025-2050). The early period relative welfare loss is largely due to the near-closure of the oil sands industry as demand for heavy bitumen is reduced by high carbon prices. One driver of the late period benefit to Canada in the CAP case could be a kind of reverse carbon leakage where Canada is on the receiving end of the competitive advantage gains from asymmetric CO_2 policies. The gains also arise from Canada's relatively large land area being leveraged to produce bio-fuels for export. The strict foreign emission controls tends to reduce the price slightly of carbon driven potentially by greater bio-fuels supply. Taken together, stricter international controls would be necessary to achieve real CO_2 emission reductions and there is a net benefit that Canada's economy would receive relative to weak international controls in the long run.

Figure 31 – Canadian Welfare Change, Strict Foreign Policy

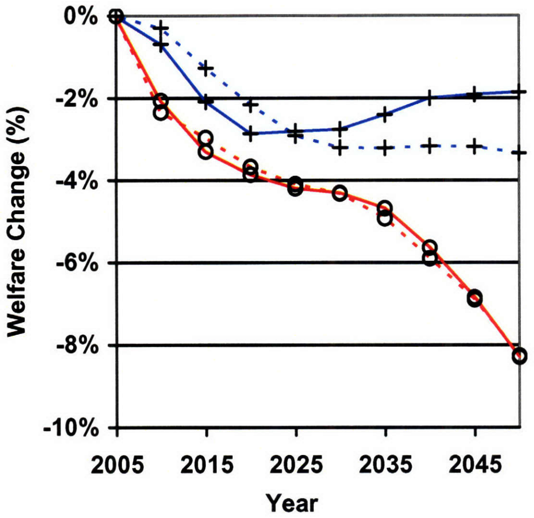
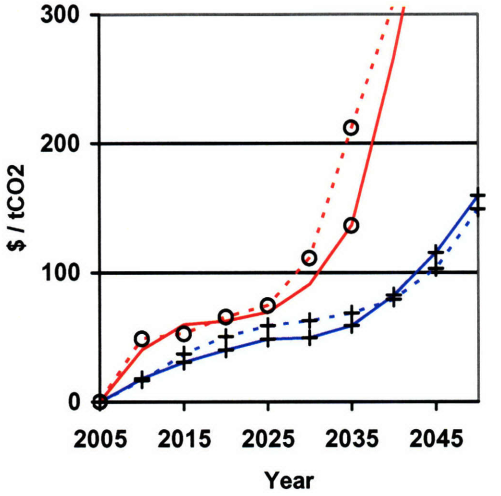


Figure 32 – Canadian CO_2 Price, Strict Foreign Policy



International and Domestic Politics and Trade

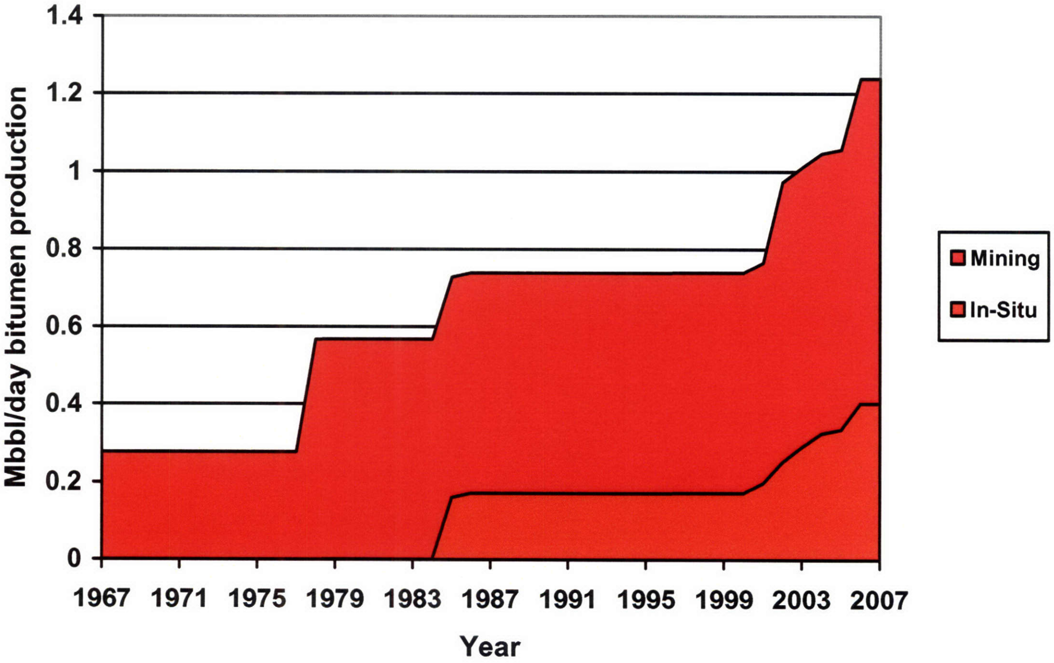
Other impacts with economic implications include the relationship between GHG policy, politics and international trade. Canada is a wealthy country and if she does not keep its international commitments, or make an effort to pursue a course in line with other developed countries with respect to GHGs, she could lose her influence in international negotiations and agreements unrelated to GHG controls. In the extreme case, she might expect high energy tariffs or even trade embargos if she tried to 'free ride' by not reducing GHG emissions. Canadian political parties which do not advocate for GHG controls will unlikely get into a position of power, at least in the current political climate. Finally, taking little to no action on GHGs could affect Canada's ability to influence poorer nations, such as China and India, where emission reductions are paramount if significant global CO_2 reductions are to be achieved. Gaining insights into these issues, and to what extend Canada's policies would affect them, is paramount for understanding the actual costs of reducing, or not reducing, CO_2 emissions in Canada.

Mitigation Costs for Oil Sands Industry

The Canadian oil sands industry began in 1967 with the Great Canadian Oil Sands Project, now known as Suncor Energy Inc. The oil sands are located near Fort McMurray, Alberta and they presently hold an estimated 315 billion barrels in ultimately recoverable reserves (National Energy Board 2006). The industry is a powerful economic engine for the country and especially for the provinces of Alberta and Ontario. The sands are also an important supply source with respect to concerns over energy security. The sands are now the source of over one half of total crude oil production in Canada at about 1.06 million barrels per day (of synthetic crude) and are experiencing intense growth. The National Energy Board predicts production levels to reach around 1.5-3.0 million barrels per day by 2015 (National Energy Board 2006).

There are two primary methods presently employed to extract bitumen. Traditionally, the industry employed surface mining and extraction techniques to produce the resource. Increasingly, SAGD (steam assisted gravity drainage), a process involving the injection of steam into the ground to reduce the viscosity of the resource, is used to produce bitumen. Presently, the majority of production comes from mining but there is a greater fraction of SAGD projects in development. It is likely that production by each method will represent about half of total bitumen production by 2015.

Figure 33 – Historical Canadian Bitumen Production since 1967



Once the bitumen is produced, the bitumen is either blended with lighter hydrocarbon liquids for transportation to heavy oil refineries or upgraded to synthetic crude which is an almost perfect substitute for light crude oil. While the production of bitumen is restricted to the oil sands region, upgrading and/or the refining of bitumen can be accomplished far from the oil sands region due the ability to transport and store diluted bitumen.

The numbers for kilograms of CO_2 emissions vary significantly by project and are based on many local factors such as the quality of the bitumen and what fuel is used to generate steam (burning residues vs. natural gas). Emissions from mining alone are approximately 40 kg CO_2e per bbl of bitumen (Alberta Chamber of Resources 2004). Emissions from SAGD range around 60 kg CO_2e per bbl of bitumen or 80kg if residues replace natural gas as the fuel. Upgrading bitumen emits around 80kg CO_2e per bbl of synthetic crude oil (SCO). These emissions numbers include both the direct emissions from combustion and gasification together with those from other operations such as mining equipment, tailings ponds and higher power consumption. These emission numbers, and other data, were used to create the oil sands sector and add it to the EPPA model. The addition of the oil sands sector into the EPPA model is discussed in the EPPA modifications section above and is presented in more detail on pages 31 to 41 in the technical note "Improving the Refining Sector in EPPA" (Choumert, Paltsev, and Reilly 2006).

Oil Sands Challenges

There is a significant amount of work which outlines the challenges facing the oil sands. An excellent source outlining these and other challenges is the National Energy Board's 'Canada's Oil Sands: Opportunities and Challenges to 2015 – an update' (National Energy Board 2006). The major struggles facing the sands include water supply constraints, natural gas constraints and lack of infrastructure. Infrastructure constraints (meaning shortages in trades people, roads, airports, etc) in the Athabasca region increase the cost and time to deploy a given project. In addition, strains on local services require deployment of infrastructure not usually associated with the oil sands constructing projects such as the building of schools and hospitals. Natural gas supplies in Canada are in decline while projected demand from the oil sands is increasing. Novell technologies, such as that deployed in the OPTI / Nexen Long Lake Project, reduce or eliminate the need for natural gas by using bitumen residues as the fuel for gasification – producing synthetic gas for steam and other energy processes. An important question which will need answering as the Long Lake project operates is to what extent such technologies affect the costs per barrel of synthetic crude oil produced. The technology's success could reduce the natural gas constraint and pave the way to decades of large scale oil sands production. The final major challenge for the sands is access to water for its operations.

Climate Change Risks for the Oil Sands Industry: Water Resource Constraints

Bitumen extraction, via mining or SAGD, requires large volumes of water. For each barrel of oil produced, 2-4.5 barrels of water are withdrawn (National Energy Board 2006). Bitumen extraction projects currently have approval to divert 370 million cubic meters per year from the Athabasca river – action that can affect the flow levels of the river during low-precipitation periods (usually during the winter months).

In response to the risks to the ecosystem, Alberta Environment issued 'An Interim Framework: Instream Flow Needs and Water Management System for Specific Reaches of the Lower Athabasca River' (Alberta Environment Fisheries and Oceans Canada 2007). The document sets a framework for project operator actions under various water flow-conditions to be taken. For example, under certain conditions, project owners are asked to reduce their diversion rates to under 10% of available flow. New licenses include conditions with mandatory incremental reductions in water use. New project applicants are being pushed to decrease water use by means of storage, processes which use less water and water recycling.

The Sage Centre and World Wildlife Fund-Canada released a study in November 2006 which stated "The combined impacts of water withdrawals from oil-sands projects and climate change will have serious consequences beyond the area of the projects themselves" (The Canadian Press 2006). At this point it is difficult to say with any confidence how climate change will impact the vital water resources in the Athabasca region. One can say that the oil sands projects are very sensitive to the region's water supplies and disruptions in water supply could prove damaging to the local ecosystem and economy.

Potential technological solutions may reduce the exposure to the risks from water resource shortages, whether or not such shortages are accentuated by human-induced climate change. Recycling, storage and better processes can all reduce dependency on what was traditionally a free resource. For example, a proposal by CONRAD (the Canadian Oil Sands Network for Research and Development) proposes a 37 million dollar off-stream reservoir project which could reduce weak water flows by accumulating water during high-flow periods and discharging during the winter low-flow periods (Golder Associates 2004). By servicing multiple large projects, the reservoir could achieve economies of scale and reduce the costs of water storage five-fold when compared to traditional on-site storage. Technology is an important factor to consider when assessing the vulnerability of oil sands development to changes in water supply.

Technology might negate the risks associated with potential climate change impacts on oil sands development. However, should the favorable economic climate remain, the scale of oil sands development may continue to accelerate and/or outpace technological innovation. Under these circumstances, the oil sands industry might be adversely affected by the uncertainty of how human-induced climate change will affect the water resources which they depend on.

Oil Sands Industry Mitigation Costs

The three main areas of oil sands industry impacts from CO_2 regulation include bitumen production, bitumen upgrading and gas supplies. The analysis will try to uncover first what BAU, CAP and KAB scenarios suggest might happen in these areas and then, with slightly less detail (by focusing only on CAP), a similar sensitivity analysis to that performed above is undertaken. The intention of the sensitivity analysis is to shift core assumptions to gain insights into which variables are most salient in determining the oil sands industry's future.

Bitumen Production

Bitumen production for the three core scenarios is already displayed in Figure 19, Figure 21 and Figure 23. The main point is the similar production levels observed in the BAU and CAP cases and the strikingly large reduction of production in the KAB case. CO_2 prices reach a point which deters bitumen production despite oil's rising price. Interestingly, the early reduction in bitumen production, in the KAB case, occurs at a CO_2 price below the CO_2 price in later years when production increases. This effect is driven by several effects including a) rising oil prices making bitumen production more profitable in later years and b) the availability of less CO_2 intense technologies in later years allows significant CO_2 reductions in some areas of the economy freeing up permits for oil sands production. The reduction of Canadian bitumen production reduces the supply of oil in the world and hence the price of oil is increased, as evident by Figure 15. A significant shut down of oil sands production would certainly have a deleterious effect on the Alberta and Canadian economy given the jobs the industry provides to the country and the royalties earned on the resource rents.

Bitumen Upgrading Capacity

Given the mobility of bitumen upgrading, it is exposed to a wider range of options in response to CO_2 controls than bitumen production - namely the ability to relocate to regions with fewer CO_2 controls. In fact, the bitumen upgrading sector is highly exposed to carbon leakage[29] – a phenomenon where CO_2 emissions reduced in one country are

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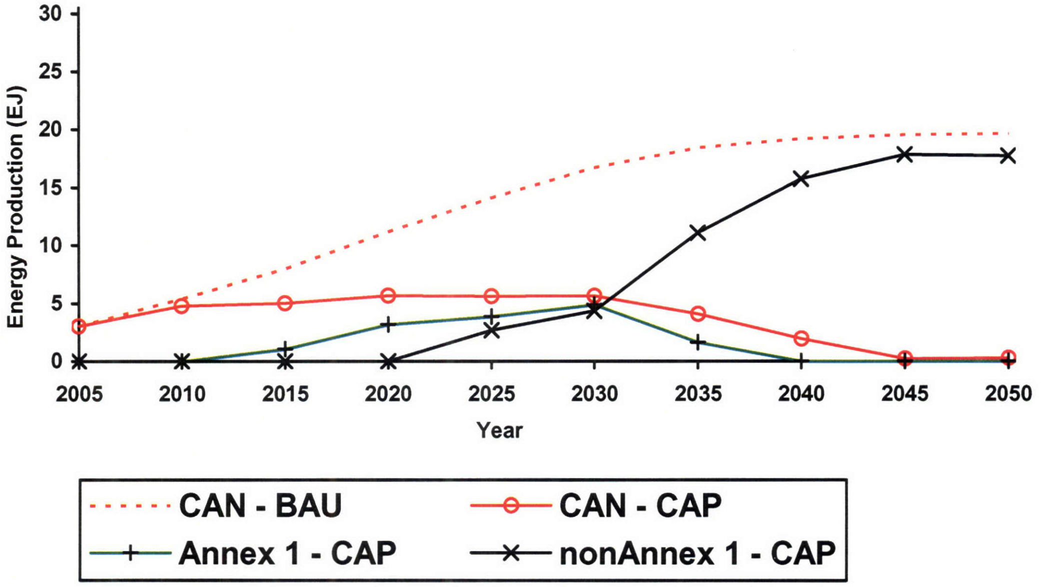
[29] In 'Refinery Implications of Carbon Constraints' (Choumert et al. 2007) the authors point out the two main drivers of carbon leakage as 1) shifts in the competitive advantage of firms in countries with asymmetric policies and 2) the tendency for demand of carbon-rich fuels to decrease in constrained regions due to the increased cost of using them. Such a demand decrease lowers the world price which then increases the attractiveness of the carbon-rich fuels to unconstrained regions which then consume more than they otherwise would.

're-emitted' in another country driven by asymmetric carbon constraining policies. In Figure 34 the carbon leakage phenomenon is evident. As the CAP policy increases in severity over time, bitumen upgrading capacity moves from Canada (solid red) to first the weakly constrained countries (primarily the USA) and then to the unconstrained regions (primarily in Asia). Overall demand for bitumen upgrading capacity isn't reduced significantly - instead it shifts presence to regions where production is cheapest. On average, 87% of carbon emission reductions in the Canadian bitumen upgrading sector is 'leaked' to countries with weaker CO_2 policies. Given the strong economic growth in Asia, it is quite possible to imagine large amounts of diluted bitumen being shipped across the Rockies to Pacific ports to be sent to markets in Asia whereupon the bitumen would be upgraded and consumed in those growing economies.

Figure 34 – Bitumen Upgrading Capacity – core case



Bitumen upgrading capacity is highly exposed to carbon leakage whereby capacity relocates (up to 87% in the core case) from Canada to unconstrained regions if Canada adopts strict, or even moderate, carbon policies. Canada loses both the economic advantages of upgrading the product in Canada and its efforts to reduce emissions are stifled as the emissions are just sent out of the country (in the bitumen resource) only to be emitted elsewhere (when the bitumen is refined and consumed). Import and Export taxes on CO_2-rich fuels could mitigate leakage but with their own set of problems associated with driving energy prices higher and possibly introducing economic efficiency losses.

Natural Gas

Given the value of natural gas as a premium fuel, it can be seen as unfortunate the amount of natural gas consumed by the oil sands to produce bitumen and synthetic oil – just other kinds of fuels. Using gasification with low value bitumen residues as a feedstock can provide an alternative whereby natural gas use is avoided. The gasification process is also good for concentrating CO_2 emissions but also boasts among the highest CO_2 emissions possible especially when compared to natural gas. Thus, without CCS, gasification is a technology that will be hard pressed to emerge under significant CO_2 controls as evident by Figure 36. Figure 36 also explains why the CAP case sees the highest gas prices as bitumen production remains high and doesn't make use of any synthetic gas in its operations due to the high cost of emissions. Demand for low-emission natural gas remains high and recourse to novel gas substitutes does not emerge. The struggle between the needs for new gas substitutes and CO_2 regulation might emerge as a key political debate in Canada.

Figure 35 – Canadian Natural / Synthetic Gas Production, core case, BAU

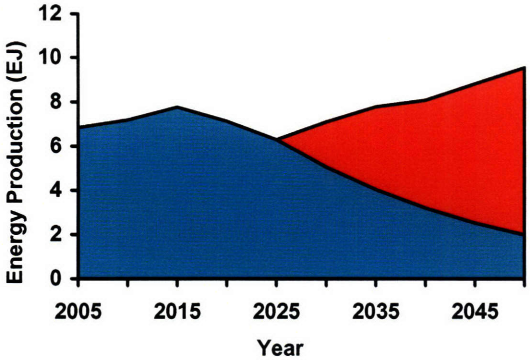
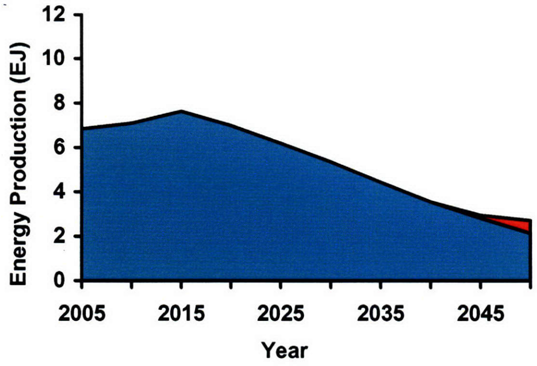


Figure 36 – Canadian Natural / Synthetic Gas Production, core case, CAP



The stresses in the BAU and CAP scenario are made clearer when one considers gas production (synthetic + natural) in Canada vs. gas use in Canada. Canada currently is a large exporter of gas, as is evident by the first bar in all three figures below. Canada is an important supplier for the USA whose natural gas supplies are also in decline. Neither country has a significant infrastructure for receiving LNG imports – something that could change in the near future given supply changes. In the BAU and CAP case below one can see that Canada is essentially breaking even and even importing significantly in the CAP case as it is unable to produce synthetic gas on a large scale from CO_2 constraints. Traditional natural gas trade revenues could be compromised in such circumstances not to mention the issue of natural gas security – a concept presently foreign to Canada.

Figure 37 – Canadian Natural / Synthetic Gas Use, core case, BAU

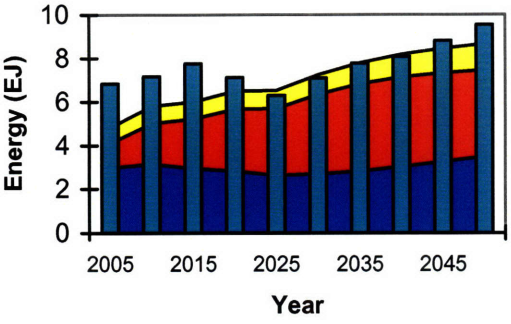
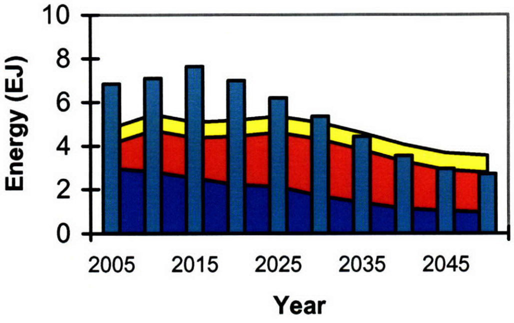
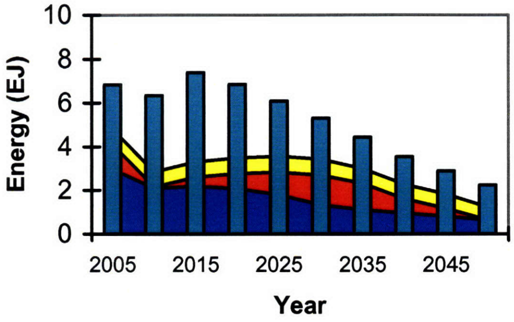


Figure 38 – Canadian Natural / Synthetic Gas Use, core case, CAP



🟦 Electricity + Industry
🟨 Households
🟥 Oil Sands
🟦 Synthetic / Natural Gas Production

Figure 39 – Canadian Natural / Synthetic Gas Use, core case, KAB



Synthetic gas from the gasification of bitumen residues could be a key natural gas substitute given the declining supply of natural gas in Canada and increasing demand for gas by the oil sands. However, given the significant emissions associated with gasification, synthetic gas may only alleviate supply in weaker policies. The timing of when synthetic gas production becomes economical in the model depends largely on the price of natural gas and the price of carbon – for example, at around $40 / ton of CO_2 synthetic gas becomes competitive if supply prices of natural gas are between 3 and 4 times 2005 levels. As CO_2 prices and natural gas prices are constantly changing, it is difficult to predict exactly which price combination will favor synthetic gas production. However, we may conclude that high natural gas prices and low CO_2 prices favor synthetic gas production. The sustainability of oil sands development could be dependent on the emergence of synthetic gas. In the CAP case, Canada becomes an importer of natural gas to support the oil sands development and in KAB it still exports natural gas as demand for gas from oil sands is reduced since the oil sands itself shrinks from the stricter CO_2 policy. Like bitumen production and upgrading, it is possible that CCS technology research could provide sustainability for the oil sands industry by allowing low-carbon emission synthetic gas production.

Sensitivity Analysis

Now let's consider what happens to the results from bitumen production and upgrading when one shifts some of the underlying core analysis assumptions.

Bitumen Production and Upgrading

Figure 40 – Canadian Bitumen Production, CAP

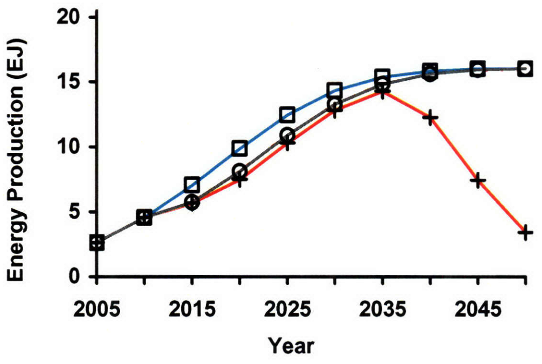
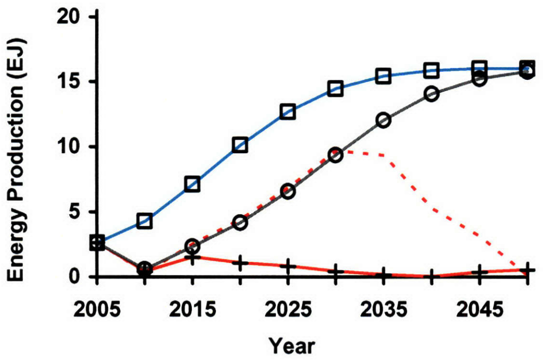


Figure 41 – Canadian Bitumen Production, KAB



Changes in transport fuel conversion technology could have a significant impact on oil sands production and upgrading. Interestingly, limited bio-fuels commercialization actually reduces the production and Canadian upgrading of bitumen (see Figure 40 and Figure 41). At first glance, one might think that bio-fuels, a competitor in the transportation fuel market, would hurt bitumen production. In fact, the presence of bio-fuels greatly reduces the stress on carbon prices as there is a decent substitute for fossil fuels. The lower carbon price allows bitumen supply to remain competitive as long as there are regions which demand the CO_2 intensive product. Upgrading capacity changes are similar to that in the core cases where capacity goes from Canada to the USA and then to Asia. The main difference is that bitumen production, and hence upgrading, starts to decrease significantly post 2035.

With international trading, bitumen production and upgrading would barely be impacted by Canada's policy. However, given that the countries involved in the trading include USA, Japan, Europe, Australia and New Zealand, and given their *light* constraints, it is simple to understand why such trading would impact Canada in this way. Canada would simply buy permits from these countries which could easily afford to sell them to Canada as the marginal cost for their reductions are much lower than that in strictly constrained Canada. Endless perturbations in assumptions are possible and one that might be of interest would be to subject the other countries to Canadian-like reductions to see a potentially less pronounced, and more realistic, impact from international carbon trading.

It is possible that CCS technology could aid bitumen production and upgrading capacity as evident by the figures that follow. While it is difficult to assess just how much such technology would cost, relatively well researched power sector CCS costs[30] can be used to estimate them given that CO_2 emissions from bitumen production, and especially from bitumen upgrading, exhibit similar point source characteristics. In both CAP and KAB, the CCS technology keeps bitumen production producing. As for bitumen upgrading, the technology reduces the amount of leakage keeping a significant amount of capacity in Canada (see Figure 43). Technological breakthroughs like CCS could indeed 'save' Canadian bitumen upgrading capacity under strict climate controls as long as demand for oil abroad remained intact. However, there remains significant uncertainty with respect to the costs and capability of CCS in the oil sands region.

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[30] In this analysis, MIT's interdisciplinary study 'The Future of Coal' (Ansolabehere et al. 2007) is used to estimate CCS costs for bitumen production and upgrading.

Figure 42 - Bitumen Upgrading Capacity – Limited bio-fuels, CAP

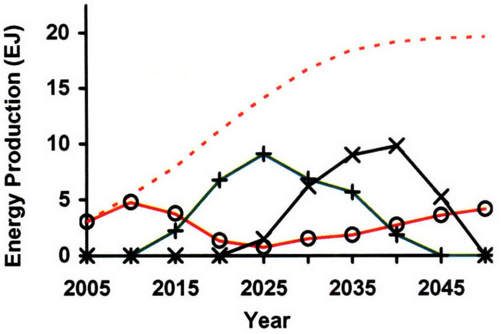


Figure 43 - Bitumen Upgrading Capacity – Oil Sands CCS included, CAP

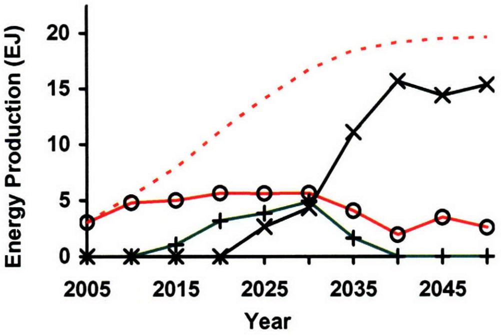


Figure 44 – Bitumen Upgrading Capacity – International CO_2 Trading, CAP

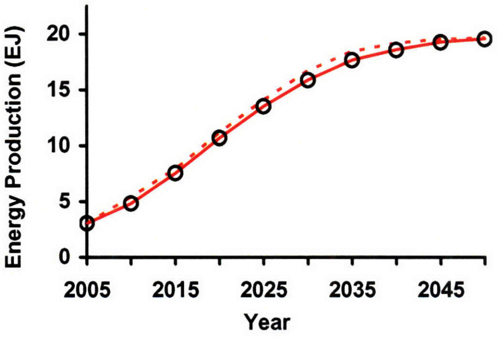
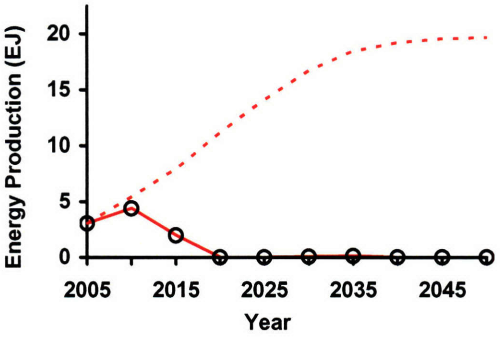


Figure 45 - Bitumen Upgrading Capacity – Strict International Policy, CAP



Canada - BAU	Canada - CAP
Annex 1 - CAP	nonAnnex 1 - CAP

Bitumen production capacity may be exposed to high CO_2 prices ($50-200 per ton of CO_2). However, if international carbon trading schemes are adopted and major oil consumers (ie. India and China) do not adopt and substantive CO_2 regulations, then bitumen production will probably continue growing because supply costs could be kept under control by purchasing carbon credits from other regions and demand would remain from the unconstrained consumers. Also, lack of oil substitutes (ie. bio-fuels) could, interestingly, reduce bitumen production if Canada adopts CO_2 policies stricter than major oil consumers (ie. India and China) as CO_2 prices would rise past the point of economical return. In such a scenario, the oil substitutes could act to moderate Canadian CO_2 prices thereby keeping bitumen supply costs lower. If all major oil consumers adopt international policies similar to the 'strict' case outlined in the scenarios section above then demand for carbon-rich bitumen could decline significantly.

Technology could have an important effect on the oil sands industry and its response to climate change regulation. Commercial CCS technology could allow for bitumen production growth under stricter CO_2 policies. Commercial CCS could also keep a portion (20-50%) of bitumen upgrading in Canada that would, under similar conditions but without the CCS technology, move out of the country. It may be prudent for the Canadian government and the oil sands industry to engage in a research effort to develop oil sands CCS and other potentially helpful technologies.

The primary purpose of this thesis is to predict effects on the oil sands industry from the proposed Canadian climate change policies. The oil sands main product is bitumen which is produced by SAGD (steam assisted gravity drainage) and surface mining. Emissions are about 40-60kg of CO_2 / bbl for bitumen production and 80kg / bbl for bitumen upgrading. There are major challenges facing the oil sands region - these include CO_2 regulations, water resources, natural gas supplies and limited infrastructure. In this analysis, I've considered, by means of the modifications to the EPPA model, primarily the effects of CO_2 regulations on natural gas supplies and bitumen production and upgrading.

Conclusion

Climate change and CO_2 regulation pose significant challenges for the world. To effectively reduce CO_2 emissions will require global agreements which in turn will require a better understanding of the impact of climate change on individual nations. In this work, two Canadian policies, in line with the stated goals of the two largest Canadian political parties, have been modeled using MIT's Emission Prediction and Policy Analysis tool to better understand the costs of the policies and the emission reductions that they will achieve. Welfare losses reaching 3.3% (in 2050) for the goals outlined in the Canadian government's "Climate Action Plan" and 8.3% (in 2050) for the goal to meet Kyoto and post-Kyoto targets put forward by the opposition are predicted. The results are highly dependent on whether an international carbon trading regime exists and whether bio-fuels emerge as a large scale, affordable, alternative to fossil fuels. The results are also dependent on international CO_2 policy.

Any Canadian emission reductions outside the context of an international emissions agreement will, according to the model, do little to reduce global emissions unless it is able to influence the domestic CO_2 policy by its own CO_2 policy. It could be useful for Canada to understand how her own policy might affect, if at all, the decision making in other countries.

Under the core assumptions, and to achieve stated emission reduction goals, CO_2 prices ranging from \$5-\$130 / ton of CO_2 in CAP and \$50-\$800 / ton of CO_2 in KAB over the next 45 years are possible, according to the model. Depending on the timing, one might expect significant reductions in Canadian energy production when CO_2 prices reach \$50-\$200 per ton of CO_2 as at this price the supply costs of bitumen production gets too large to continue expanding production. Other sectors which also emit a lot of CO_2 in production, such as the power sector, could experience significant increases in the supply prices of their products. The power sector should expect more Nuclear and/or IGCC with CCS to replace conventional generation. The transition from conventional generation (coal and natural gas plants) may begin with natural gas combined cycle (NGCC) shift to NGCC with CCS and then, as the price of natural gas gets higher, settle on integrated gasification combined cycle plants with CCS where coal, coke and heavy oils are the primary fuels.

International policy could have important effects for Canada as well. An integrated international CO_2 trading scheme could reduce the costs of meeting emission targets, especially for countries with strict policies relative to other carbon trading countries. As international CO_2 emission targets get more ambitious, Canada might benefit from the development of a large-scale Canadian bio-fuels industry to help countries meet those targets. However, such international policy could also cripple the oil sands by reducing global demand for carbon-rich fuels, such as bitumen.

Bitumen upgrading/refining capacity is vulnerable to relocating to weakly constrained countries - even at CO_2 prices as low as \$25 / ton of CO_2. Even the weaker of the two policies analyzed experiences an average of 87% carbon leakage during the 2010 to 2050 time period. In reaction to this prospect, the government might consider export energy tariffs, or other interventions such as exceptions for the oil sands industry, to combat such leakage if the economic losses associated with such action are perceived to be lower than the benefits. According to the modified EPPA model, the locating of bitumen upgrading/refining capacity is highly dependent on regulatory policy in Canada, the US and Asia.

Demand for Canada's underlying bitumen resource will likely remain strong, regardless of policy; unless a combination of commercially viable bio-fuel technology and widespread CO_2 policies emerge. The world's appetite for new energy supplies renders an investment in bitumen production, without upgrading capacity, less risky because bitumen production remains economical under various regulatory environments while locating bitumen upgrading optimally is more sensitive to regulation. Given the risks associated with bitumen upgrading/refining capacity in an uncertain regulatory environment, companies may over-invest in bitumen production relative to bitumen upgrading/refining thereby flooding the market with an even heavier crude slate than currently is the case.

Under conditions where Canada takes on stricter policies than the a large part of the world (for example, if Kyoto signatories attempt to meet their targets, the US makes similar CO_2 reductions and India and China undertake no CO_2 policy – a plausible scenario), bio-fuel entry into the market may, paradoxically, benefit oil sands production by moderating CO_2 prices. Under the above world conditions, demand for Canada's bitumen will remain strong – especially in those countries with less or no CO_2 policy while the supply costs of bitumen production would increase as the price of CO_2

increased. Under a cap and trade system, the price of carbon would increase if bio-fuels and other carbon free technologies are unavailable to lower the marginal cost of abatement. The resulting higher carbon price would increase supply costs for the oil sands industry and, at some point, make it unprofitable. Thus, low-carbon technologies with higher supply costs per boe produced than bitumen could benefit the oil sands industry by keeping CO_2 prices relatively low.

Natural gas supplies are another major concern for Canada's oil sands. Gasification holds much promise for providing the oil sands with synthetic gas – a substitute for natural gas. According to the model, under even moderate policy, and without optimistic CCS technology, it is unlikely that gasification will achieve scale given the large volume of CO_2 emitted by and the high capital costs of synthetic gas production. Canada could even become a natural gas importer if her policy is strong enough to hold back synthetic gas production but weak enough to keep oil sands production going.

Technology might play an important role for the oil sands industry and its response to climate change regulation. Commercial CCS technology may allow for continued bitumen production under stricter CO_2 policies. Commercial CCS could also keep a portion of bitumen upgrading in Canada that would, under similar conditions but without the CCS technology, re-locate outside the country. It may be advisable for the Canadian government and her oil sands industry to engage in an intense research effort to develop oil sands CCS and other low-carbon technologies for producing and upgrading bitumen.

A warming Canadian Climate likely presents some new opportunities and challenges for the country's environment. Agricultural yields may change and more tourism could be in store for Canada if the climate continues to warm. Also, damage from sea level rise in the Atlantic Provinces, and sea level retreat in the great lakes region, could also result. Regardless, there remains a lot of uncertainty in any impact predictions from temperature rise.

The action that Canada takes on climate change is for its people to decide. Hopefully, this work can aid in lending understanding into the costs of CO_2 mitigation for Canada and her oil sands. Whatever Canada's action, climate change is a vital issue of our time and one that needs to be discussed and debated to achieve an optimal solution for Canada and the world.

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