What's Driving Alberta's Emissions? Decomposing Greenhouse Gases Emitted by Alberta's Road Transportation Sector

by

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Abstract

Alberta emits more greenhouse gases (GHGs) than any other province in Canada, despite having only the 4th largest population. Alberta's transportation sector produces 16% of these emissions, but has received little recent policy attention. I performed an index decomposition analysis of GHGs from Alberta's road transportation sector from 1990-2010, in order to design policies that maximally reduce transportation emissions. After comparing Alberta's results with those for B.C. and Quebec, I determined that policies should focus on three areas: reducing freight transportation volume, improving fuel efficiency of freight vehicles, and increasing use of low-emission fuels. I then suggested several policies to meet these objectives, and evaluated them for effectiveness, government affordability, and political acceptability. Finally, I recommended the simultaneous implementation of a new fuel tax and the mandatory use of speed limiters for heavy trucks as an effective set of short-term policies to reduce emissions.

Keywords: Alberta; road transportation; greenhouse gas emissions; index decomposition analysis; freight transportation

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List of Acronyms

AMDI	Arithmetic mean Divisia index
CCEMC	Climate Change and Emissions Management Corporation
CCEMF	Climate Change and Emissions Management Fund
CNG	Compressed natural gas
CO_2e	Carbon dioxide equivalent
GHGs	Greenhouse gases, or greenhouse gas emissions
GoA	Government of Alberta
IDA	Index decomposition analysis
J	Joule(s)
kt	Kilotonne(s)
LMDI	Logarithmic mean Divisia index
LNG	Liquid natural gas
Mt	Megatonne(s)
NG	Natural gas
NRCan	Natural Resources Canada
SDA	Structural decomposition analysis

Glossary

AMDI	Arithmetic mean Divisia index. A statistical measure of change used for index decomposition analysis.
CCEMF	Climate Change and Emissions Management Fund. The fund that receives Alberta's carbon tax revenues. Funds are used to mitigate or abate the effects of climate change.
CO_2e	Carbon dioxide equivalent. A measure of the net global warming potential of greenhouse gases released, made by comparing the warming effect of individual gases to that of CO_2.
IDA	Index decomposition analysis. A statistical method used to determine the change in a variable that can be attributed to each of its component parts.
joule	A unit of energy, work, or heat.
LMDI	Logarithmic mean Divisia index. Another statistical measure of change used for index decomposition analysis.
passenger-km	A unit of measure for passenger transportation. Measured by multiplying the number of passengers in a vehicle by the total distance travelled in km.
tonne-km	A unit of measure for freight transportation. Measured by multiplying the weight of freight (measured in tonnes) in a transportation truck by the total distance travelled.

Executive Summary

Alberta is Canada's most greenhouse gas (GHGs) intensive province, and produced over 233,000 kt CO_2 equivalent in 2010, equal to 1.22 kt per million $ of GDP (Environment Canada, 2012; Statistics Canada, 2012a). It is well-established that the bulk of these emissions come from Alberta's energy extraction industries and from electricity generation, which collectively produced almost half of the province's 2010 GHGs. Transportation-related emissions, while fewer, still form a significant component of Alberta's GHGs (approximately 16% in 2010; Environment Canada, 2012), and have received less attention from media, think-tanks, and political groups.

In order to devise effective policies to reduce GHGs from the transportation sector, I conducted an index decomposition of Alberta's road transportation emissions from 1990-2010. This analysis breaks up changes in GHGs into their component parts, which provides some insight as to where policy can best be applied: transportation volume, transportation mode, fuel efficiency, fuel type, and GHG intensity of fuels. By using this analysis, policies can be designed that target the component(s) most responsible for recent increases in emissions. Comparisons were made with British Columbia and Quebec. Both provinces have much lower per capita GHGs than Alberta, and so were used as a benchmark with which Alberta's results could be judged.

From the decomposition and subsequent analysis, 3 major trends stood out. First, Alberta has an exceedingly high volume of freight transportation, which cannot be explained by economic or population growth. It is possible that this trend is linked to the energy extraction sector, although findings were not conclusive. Second, road freight transportation vehicles throughout Canada appear to have made relatively few gains in fuel efficiency over the 21-year period studied. Third, low-emission fuels have played a negligible role in reducing emissions in any of the provinces studied.

Based on these observations, I devise four policy options that the Government of Alberta (GoA) could implement to reduce transportation GHGs. From the analysis of all options, I make the following recommendations. In the short-term, the GoA should implement a new fuel tax for heavy trucks. This tax would reduce the amount of freight transport, and the funds from it could be used to fund climate change mitigation and

prevention initiatives. This policy also has the benefit of being simple to implement and virtually cost-free for the GoA. Simultaneously, I recommend implementing a requirement for heavy trucks to use speed limiters to reduce maximum travel speed to 105 km/h. This will increase the fuel efficiency of heavy trucks, which will reduce GHGs and provide monetary savings for truck owners, while still being relatively simple to implement. Finally, I recommend that the GoA collect more detailed information on freight transportation within the province in order to help determine why Alberta's freight transportation volume is so high.

For the long term, Alberta needs to make more drastic policy changes, including (likely) a larger and broader fuel tax, and a reduction in the GHG intensity of electricity production. As the most viable long-term low-carbon fuels currently rely on electricity generation, it will be difficult for Alberta to significantly reduce its road transportation emissions without first cleaning up its power generation.

1. Introduction: Why study transportation emissions in Alberta?

1.1. Background information and problem description

Rising levels of greenhouse gas emissions (GHGs) are a global problem. Composed primarily of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), greenhouse gases have various adverse effects on the planet, ecosystems, and human health (Rosenzweig et al., 2007). In response to the threat of global climate change, many countries and smaller jurisdictions have implemented policies in an effort to reduce GHGs. Such policies have been implemented primarily in developed countries, which tend to have higher per capita emissions (as per World Bank, 2013) as well as greater disposable income, and so are better able to afford these policies, many of which are expensive.

While most policies are intra-national, international agreements have also been made in an attempt to comprehensively address climate change. The most notable of these is the United Nations Framework Convention on Climate Change (UNFCCC), a treaty that was established in Rio di Janeiro in 1992 to provide a framework for establishing future treaties. Another well-known agreement is the Kyoto Protocol, established in 1997 under the UNFCCC, which obliged developed signatories to reduce annual carbon emissions to 5.2% below 1990 levels by 2012. However, to date, such international agreements have had only limited effect in reducing GHGs, as enforcement is difficult, and negotiations for additional agreements have proven largely intractable. Notably, Canada formally withdrew from the Kyoto protocol in late 2011, and the protocol was never ratified in the United States.

Despite not attempting to meet its Kyoto targets, Canada has nonetheless put into place various policies to reduce GHGs. Examples include fuel and energy efficiency regulations for household appliances and automobiles, as well as emissions regulations for energy generation, and minimum insulation levels for housing.

Compared to the rest of Canada, Alberta has a poor record of GHG emissions. In 2010, it emitted approximately 233,000 kt of CO_2 equivalent (CO_2e; calculated based on the weighted average global warming potential of all GHGs emitted relative to CO_2), more than any other province (Environment Canada, 2012). Given that Alberta has only the fourth largest population of all provinces [3,723,800 in 2010 (Statistics Canada, 2012b)], this means it has the second highest per capita GHG emissions among provinces, bettering only Saskatchewan (Environment Canada, 2012).

Many of the GHGs produced in Alberta are a result of electricity generation. Alberta generates most of its electricity from coal-fired power plants and thus has a much higher GHG emission intensity for power generation than any other province, at 1060 g CO_2e per kWh (Environment Canada, 2012). In 2010, electricity generation was responsible for approximately 48,100 kt CO2e, over 20% of Alberta's emissions (Environment Canada, 2012). Alberta also generates many GHGs from the extraction and processing of fossil fuels, which were collectively responsible for 61,800 kt CO2e in 2010 (over 26% of 2010 emissions). Both of these sectors have been widely criticized by think tanks, political groups, and other jurisdictions, and have been the object of many reports (e.g. Bell & Weis, 2009).

Another sector of Alberta's economy that produces high emissions has received considerably less recent attention: the transportation sector. Alberta's transportation sector produced 38,000 kt CO_2e in 2010, over 16% of the province's total. Transportation emissions have increased as a proportion of total provincial emissions from 13.5% in 1990 to 16.3% in 2010 (Environment Canada, 2012). While there have been recent efforts to reduce GHGs from the transportation sector, there has been no concerted attempt to discern which sort of transportation policies would be most effective at reducing emissions.

Through the use of index decomposition analysis, I explore which facets of the transportation sector have been responsible for the largest increase in GHG emissions over the last twenty years. I compare results from Alberta with results from British

Columbia (B.C.) and Quebec, both of which have lower transportation emissions. In 2010, B.C.'s transportation sector generated 22,000 kt CO2e, and Quebec's generated 35,100 kt CO2e, both smaller amounts than Alberta's, despite their larger populations of 4,529,500 and 7,905,100 respectively. Beyond their lower emissions, both provinces have recently implemented carbon taxes that affect transportation fuel prices directly. By making comparisons with these provinces, I infer where policy change in Alberta would be most effective. After performing a subsequent literature scan, I provide and evaluate several policy options that will target the appropriate sub-sector of transportation.

1.2. Transportation GHG emissions reduction initiatives in Alberta

Before exploring what could be done in Alberta to reduce transportation-related GHGs, it is necessary to first discuss measures that are already in place. From a constitutional perspective, while environmental policy is both a provincial and federal issue, GHG emissions regulations should be in principle within federal jurisdiction due to the global reach. However, the provinces have authority under the constitution, and in practice, both federal and provincial governments have set regulations relating to emissions. I will now discuss, briefly, some of the actions taken by the Government of Alberta (GoA) that limit emissions from transportation.

First, like all other provinces, Alberta levies provincial excise taxes. At $0.09/L for gasoline and diesel fuel, Alberta's standard motor vehicle fuel tax is lower than anywhere else in Canada outside of Yukon. These taxes are higher than their historical levels ($0.05/L from June 1987-March 1990; $0.07/L April 1990-March 1991). The effect of a fuel tax should be to decrease consumption, so these taxes are already helping to reduce transportation emissions, albeit less so than most other provinces. It should be noted, however, that these taxes were not designed to reduce emissions, but as a revenue source for the province.

The GoA has also run several rebate programs to encourage fuel efficiency in the transportation sector. One recent program is the *Trucks of Tomorrow* program, administered from 2009-2011. This program provided $2 million in rebates to commercial vehicle operators for adopting fuel-efficiency measures on their trucks. Examples of rebated purchases include aerodynamic skirts, cab-heaters (to avoid unnecessary idling), and hybrid drive-trains, all of which directly reduce fuel consumption in trucks. A smaller example is the *Hail a Hybrid* program of 2006. This program provided money to several taxi-drivers in Edmonton and Calgary to enable them each to buy a hybrid vehicle instead of a more typical Ford Crown Victoria. For these and various other programs initiated by the GoA, there are little in the way of quantitative estimates of emissions savings, and so their effectiveness cannot be easily evaluated.

Beyond the rebate programs, the GoA has done little to intentionally reduce GHGs from its transportation sector. Other sectors of the economy have received greater attention. For example, there is a carbon tax in the province of \$15/t CO_2e covering 12% of emissions from large facilities, but this only applies to facilities that emit > 100,000 t CO_2e per year, and does not apply directly to transportation.

1.3. Transmission GHG emissions reduction initiatives in B.C. and Quebec

As discussed, both B.C. and Quebec have lower GHG emissions from their transportation sectors than Alberta, despite having larger populations. I will outline here some of the initiatives taken in each province to reduce GHGs from transportation. As both provinces have implemented carbon taxes in addition to their fuel taxes, these will be discussed separately from other initiatives in order to simplify direct comparison.

British Columbia

B.C. has introduced a number of measures over the past few years to reduce GHGs from its transportation sector, outlined in the 2008 B.C. Air Action Plan. First, the Greenhouse Gas Reduction (Vehicle Emissions Standards) Act was passed in the B.C. legislature in 2008. This legislation enables the B.C. government to create new emissions standards for vehicles, matching those set by California's *Low-Emission Vehicle (LEV II) Program* in 2004. The intended effect of this legislation is to reduce annual fleet-wide emissions for B.C. vehicles by 30% compared to 2008 standards by 2016.

In addition, several smaller actions were also outlined. One such was to continue a tax-break on hybrid vehicles, and provide a new tax break for other fuel-efficient vehicles. Another program outlined was the *Scrap-it* program. Similar to the efforts in Alberta, this program provided cash incentives for people to get rid of their old, highly-polluting cars in exchange for transit passes, or new, more fuel-efficient cars.

Further incentives were provided starting in 2007 when the Ministry of the Environment paired up with the Fraser Basin Council and others to create the *Green Fleets BC* initiative. This program has facilitated the purchase of 140 heavy-duty “enviroTrucks”, which are expected to reduce emissions by 17.5 t/year per truck compared to traditional tractor trailers. The government has also set up a *Community Charging Infrastructure (CCI) Fund* to help municipalities, businesses, and other organizations to purchase electric-vehicle charging stations that are accessible to the public.

Moving beyond direct monetary incentives, the B.C. government implemented an anti-idling information campaign called *Idle Free BC*. This program encourages people and corporations to stop idling their vehicles, by providing information about environmental harm caused by idling, and money saved on fuel through a reduction in idling. In sum, the B.C. government has engaged in a large number of recent efforts to reduce transportation emissions in the province, and appears more pro-active than Alberta when addressing GHGs from this sector of the economy.

Quebec

Quebec, like B.C., has similarly implemented a number of strong measures recently to reduce GHGs from its transportation sector, most of which are detailed in the 2006-2012 *Climate Change Action Plan*. Emissions regulations in line with California’s have recently been implemented as part of the *Regulation respecting greenhouse gas emissions from motor vehicles* within the *Environmental Quality Act*, increasing the fuel efficiency of the fleet of automobiles in Quebec. Another recent regulation introduced by the Quebec government requires the use of speed limiting devices in all road vehicles weighing more than 26,000 pounds, which prevents these vehicles from accelerating past 105 km/h. This requirement reduces unnecessary fuel consumption because speeds > 105 km/h are not optimally fuel efficient.

Beyond regulations, Quebec is also encouraging the reduction of GHGs from transportation by supporting the production of ethanol for use in vehicle fuels. Ethanol combustion produces less CO_2 than fossil fuels, and the Quebec government is promoting ethanol produced from forest biomass and agricultural by-products. And like B.C., they have provided financial support to municipalities, enabling information campaigns to promote a reduction in vehicle idling. Also similar to B.C., Quebec has created a financial assistance program to increase the uptake of fuel efficient vehicles (such as hybrid or electric vehicles). Finally, an additional assistance program has been implemented to help employers to incentivize their staff to promote non-vehicular modes of transportation, public transit, and carpooling.

Last, Quebec has recently adopted the *Regulation respecting a cap-and-trade system for greenhouse gas emission allowances*. This allows the Quebec government to implement a cap-and-trade system that, as of January 2013, applies to all regulated emitters (businesses, rather than individuals). It permits the government to set standards for GHGs and then let the effected businesses sort out how they want to meet those standards. While this policy does not directly affect transportation activity in Quebec, it will, as of 2015, cover the companies that manufacture and import motor vehicle fuels. Thus, the tax will eventually hit the transportation sector as costs are passed on from distributors to consumers.

Fuel taxes

As previously mentioned, all provinces in Canada tax vehicle fuels, and most do so more heavily than Alberta. B.C.'s fuel taxes, administered under the *Motor Fuel Tax Act*, vary by region as well as fuel type, and go into general government coffers, or for dedicated public expenditures (e.g. public transit). The fuel taxes on gasoline and diesel range from $0.145/L to $0.260/L, depending on region and fuel type. In all regions of the province, taxes on standard motor vehicle fuel are higher than in Alberta, and at least twice as high in the more populated regions of the province. Quebec too has different tax rates in different regions, ranging from \$0.1335/L to \$0.2120/L.

Carbon taxes

Another measure that both B.C. and Quebec have taken to reduce GHGs from transportation (and other sectors of the economy) is to introduce a carbon tax. Carbon taxes are designed to reduce emissions by taxing fuels that produce GHGs. Unlike Alberta's carbon tax, B.C.'s and Quebec's taxes apply quite broadly, so that consumers of motor vehicle fuel all pay the carbon tax, whereas in Alberta, only large-scale facilities are taxed.

B.C.'s carbon tax, introduced in July 2008, is the larger of the two. The tax was initially set at a rate of \$10/t CO_2e, but has increased by \$5/t annually over the four years since its introduction to its current rate of \$30/t, effective as of July 2012. This translates to \$0.0667/L of gasoline and \$0.0767/L of diesel fuel. This tax, unlike the fuel tax, is based on the GHG intensity of the fuel, so that all vehicles using each type of fossil fuel are taxed at the same rate per liter of fuel consumed, with only a few very specific exceptions. Revenues generated through B.C.'s carbon tax are returned to tax-payers in the form of lower income tax rates for individuals and businesses, and refundable tax credits for targeted groups (low income, rural). In this way, the B.C. government is attempting to keep the tax revenue neutral, although to date the province has actually returned ~\$500 million more in tax breaks than it has received in carbon tax revenue (B.C. Ministry of Finance, 2012). Initial results presented by Rivers and Schaufele (2012) suggest that this policy has indeed been successful at reducing fuel consumption in B.C.

Quebec's carbon tax, while it affects motor vehicle fuel prices, operates very differently than B.C.'s. Rather than tax the purchasers or end users of energy directly, Quebec's tax applies to energy producers and importers. Its initial rate at its introduction in October 2007 was \$3.20/t CO_2e, considerably smaller than B.C.'s rate, and thus expected to generate considerably less revenue. It is also spent differently; rather than being returned to taxpayers, the revenue collected from Quebec's carbon tax goes into a fund used to finance environmental initiatives.

1.4. Decomposition analysis

The policy measures implemented by Canada, Alberta, B.C., and Quebec to limit GHGs from transportation illustrate that there is a wealth of options available. However, to date, no jurisdiction in Canada has attempted to attribute transportation emissions to their causal components, in order to ascertain where policy could most effectively be applied to maximize the reduction of emissions. Changes in GHGs can be disaggregated thusly through a simple equation that breaks down the changes into their component parts. These components are listed by Ang (2005) as: total sector activity (amount of transportation), activity structure (which type of vehicles are being used), subsector energy intensity (fuel efficiency), subsector fuel mix (which fuels are used), and the GHG emission intensity for each fuel. This is similar to the more readily understood Kaya Identity, outlined by Waggoner and Ausubel (2002). An algebraic representation of these components is presented in Chapter 2.

When a decomposition analysis is used to compare changes over a range of years, patterns emerge which can be used to inform policy. The result of a decomposition analysis of GHGs is a set of index numbers, which show the amount of change in GHGs attributable to each component. This technique has become increasingly common, and is a useful when policy makers and researchers wish to understand GHG emissions and energy consumption (Ang et al., 2008; Ang & Zhang, 2000). Some recent examples from other jurisdictions include a study of GHG emissions and energy inputs in Germany (Jungnitz, 2008), a paper looking at factors underlying CO_2 emissions from Asian power generation facilities (Shrestha et al., 2009), and a study looking at the components of marginal abatement cost curves (Kesicki, 2012).

To clarify how this type of analysis can be used to inform policy, I will briefly review the findings of a recent decomposition analysis performed on the Turkish economy. Kumbaroğlu (2011) conducted a sectoral decomposition analysis of all CO_2 emitted by Turkey between 1990-2007. Aggregated over the entire time period, changes in energy intensity led to a decrease in GHGs in the transportation sector, indicating that the sector as a whole had become more energy efficient. However, Kumbaroğlu noted that during the final two years, the trend changed, and changes in energy intensity were responsible for *increases* in GHGs, indicating a shift towards less fuel-efficient vehicles.

Kumbaroğlu attributed this to the recent popularity of propane-powered vehicles. While propane-powered vehicles have reduced carbon intensity compared to traditional gasoline-powered cars (that is, produce fewer emissions per joule (J) of power), the inefficiency of propane-powered engines eroded this benefit, resulting in a net increase in GHGs. This example illustrates how decomposition analysis can be applied to policy: Kumbaroğlu's (2011) results suggest that a policy to discourage the use of propane-powered vehicles would result in a reduction in GHGs.

By examining trends in the index numbers from a decomposition analysis, I link observations to explanatory factors. This should help to illuminate which policies have been effective in other jurisdictions, and indicate which aspect(s) of Alberta's transportation sector would most benefit from new policies.

2. Methodology: decomposition analysis, data collection, and subsequent literature scan

2.1. Decomposition analysis methodology selection

Decomposition analyses have become a widely used tool to study energy demand and production as well as GHG emissions; by 2000, there were at least 124 published instances of this technique (Ang & Zhang 2000). However, there are many different ways of performing a decomposition analysis, all with various benefits and problems, and there is not a universally preferred methodology (Ang, 2004; Hoekstra & Van der Bergh, 2002). I review some of the different possible methodologies and discuss the rationale for the method chosen for this study.

Index decomposition analysis or structural decomposition analysis?

First, decomposition analysis can be broken up into two primary methodologies: index decomposition analysis (IDA) and structural decomposition analysis (SDA). Both methods are used to determine how various underlying factors affect changes in some sort of measurable output, but use different models to decompose changes in the output (Hoekstra & Van der Bergh, 2002). SDA requires the use of an input-output matrix, whereas IDA requires only aggregate sector- or subsector-level data. This difference leads to the inherent advantages and disadvantages of each methodology. Where possible (and applicable), SDA is desirable because it produces a higher degree of detail in the results, and through the use of SDA it is possible to look at indirect as well as direct effects (Hoekstra & van der Bergh, 2002). However, while IDA only provides results for direct interactions, and lower specificity of the results, the considerably lower data requirement makes this technique more broadly applicable (Hoekstra & Van der

Bergh, 2002). Indeed, in their (2000) survey, Ang and Zhang found that of the 124 decomposition analyses they uncovered only 15 used the SDA methodology. Another major difference is the type of determinant effects that are reported by each methodology. Both methods can distinguish a scale effect and the intensity effect, but only IDA can distinguish the sub-sector (or structure) effect, and only SDA can describe the Leontief effect (based on a change in the input-output model coefficients) and the final demand effect (a change in the measured output due to a change in demand for products from each sub-sector) (Hoekstra & Van der Bergh, 2002).

Thus, the available data and the effects a researcher is looking to distinguish will strongly affect which type of analysis is chosen. For this study, I chose to perform an index decomposition analysis, as it is simpler to perform and because the data requirements are considerably smaller.

Which index should be used, and how should it be specified?

After selecting whether IDA or SDA is more appropriate, the next choice to make is what type of index is preferable for the analysis. For energy-related research, most methods are based on one of two types of common index: the Divisia index and the Laspeyres index (Ang, 2004). Each index has several different methodologies associated with it, and Ang (2004) outlines 4 considerations that researchers should bear in mind when choosing a methodology: ease of interpretation, ease of application, versatility, and theoretical foundation. I provide a brief review of the performance of several different methodologies, as evaluated by Ang (2004), including the multiplicative and additive forms of each of: logarithmic mean Divisia index (LMDI), arithmetic mean Divisia index (AMDI), the refined Laspeyres index, and the Fisher ideal index (similar to Laspeyres). It should be noted that a complete review of all relevant aspects of these methodologies is beyond the scope of this paper, and interested readers should consult Ang (2004) for a more thorough discussion.

All decomposition analyses follow one of two forms: additive or multiplicative (Hoekstra & Van der Bergh, 2002). This reflects the specification of the model being used. An example of an additive form is:

$$O^t - O^{t-1} = c_1 + c_2 + c_3 + ... + c_N + residual$$

Where O^t is the value of the output being measured during time period *t*, and *c* variables are the component factors in the model. The residual represents changes in the output that are not explained by the component factors.

The multiplicative form of the same model would be specified as:

$$\frac{O^t}{O^{t-1}} = c_1 \times c_2 \times c_3 \times ... \times c_N \times residual$$

Generally, either specification can be used with relatively little consequence for the results (Hoekstra & Van der Bergh, 2002) but while both are common among studies employing IDA, SDA studies tend to use additive decomposition. While each study generally chooses only one specification, methodologies that exhibit a simple association between multiplicative and additive specification results are easier to interpret and have a more internally consistent theoretical foundation, meeting two of Ang's (2004) criteria. Additionally, methods which give perfect decomposition, and thereby have the residual equal to zero (for additive methods) or one (for multiplicative methods) also simplify interpretation.

According to Ang (2004), all 4 methods he reviewed provide perfect decomposition. However the AMDI method can produce large residual terms under certain circumstances, complicating its interpretation. The AMDI method is easier to apply than either LMDI or either of the Laspeyres methods, but cannot be applied to data sets that contain zero values. Another advantage that the Divisia index methods have is that their results can easily be converted from additive form to multiplicative form as there is a simple relationship between the two, whereas the Laspeyres methods do not have this property.

Therefore, because the Divisia index methods appear preferable to the Laspeyres methods, and the LMDI does not have some of the drawbacks of the AMDI (Ang, 2004), I will use an LMDI approach for this study. Because the choice of an additive or multiplicative specification does not appear to matter strongly, I will use an additive specification, in order to simplify the interpretation of results.

In order to implement this analysis, I will follow the methodology outlined by Ang (2005). This document provides a detailed description of the necessary calculations for both the additive and multiplicative forms of LMDI decomposition analysis.

2.2. Decomposition specifics

Ang (2005) indicates that changes GHG emissions can be decomposed using LMDI approach with the following equation:

$$C = \sum_{ij} C_{ij} = \sum_{ij} QS_i I_i M_{ij} U_{ij}$$

where: C_{ij} is the change in GHGs from subsector *i* (such as cars, school buses, light trucks, etc.) using fuel *j* (such as gasoline, diesel, etc.); *Q* is the amount of activity of the entire sector (measured in passenger-km or tonne-km); *Si* is the activity share of subsector *i* as a proportion of total activity; I_i is the energy intensity of subsector *i*; M_{ij} is the amount of fuel *j* used by subsector *i* as a proportion of the total fuel consumed by that subsector; U_{ij} is the GHG intensity of fuel *j* when used by subsector *i*. Rather than describing the specifics of how each component is calculated here, interested readers are directed to Ang's (2005) description in his explanatory paper, which provides full details on how all calculations are made.

2.3. Data collection

Data for use in the decomposition analysis was obtained from Natural Resources Canada (NRCan; 2013). NRCan's Comprehensive Energy Use Database, available online, includes GHG emissions for the entire transportation sector and its subsectors for each province, as well as some measure of output for each, and the amount and type of fuel consumed by each subsector. In short, it contains all the data required for a decomposition analysis with the model I have specified, and has records for all years between 1990-2010.

Unfortunately, data for B.C. within this database has been aggregated together with data for the territories. However, the effect on the overall results should be relatively small, as the population size of B.C. dwarfs the combined populations of all three territories. Therefore, the results of the analysis were interpreted as if they were B.C.-specific.

An additional consideration is that analysis was only performed on the road transportation sector. Province-specific data on GHGs is not available for other modes of transportation (i.e. rail, marine, or air), and so they were excluded from the analysis and were not considered for policy recommendations.

A final caveat is that the energy intensity for heavy trucks used in freight transportation (described below) has not been disaggregated at the provincial level. Data limitations mean the imposition of an assumption of identical energy intensity for heavy trucks in every province. Nothing could be done to address this as it is a data constraint identified by NRCan[1]. However, large trucks were not removed from the analysis, as the bulk of road freight transportation occurs in large trucks. For interpretation purposes, this means that any difference in energy intensity between provinces will be muted, so intra-provincial comparison is not possible for the freight sector.

For passenger transportation, travel was split up into six modes: car, school bus, urban transit bus, inter-city bus, motorcycle, and light truck. Freight transportation was broken down into only three categories: light, medium, and heavy trucks. Light trucks are those weighing less than 4.5 tonnes (gross weight). Medium trucks weigh at least 4.5

[1] I contacted NRCan officials to determine if this issue could be addressed, but was told that due to limitations in the Canadian Vehicle Survey, province-specific efficiencies are not available on a tonne-km basis. Efficiency estimates are made on a vehicle-km basis, but this does not take into account the mass of freight transported, and could not be used for the analysis.

tonnes, but less than 15 tonnes. Heavy trucks are all road vehicles that weight 15 tonnes or more. Fuel use for both sub-sectors of road transportation was broken down into 7 types: electricity, natural gas (compressed), motor gasoline, diesel fuel oil, ethanol, biodiesel fuel, and propane (liquid).

After collecting the necessary data from NRCan, yearly decomposition analyses were run for each of the three provinces examined in my study, with individual analyses conducted for freight and passenger road transportation. Passenger and freight transportation could not be combined into a single analysis because their different types of activity (passenger-km and tonne-km) are not directly comparable. After decomposing emissions between individual pairs of years, an additional decomposition analysis was run for each province, comparing only 1990 and 2010, in order to look at the aggregate changes over this time period.

2.4. Determination of policy directions and literature scan

By looking at the patterns in the results of the decomposition analysis, I determined how best to focus policy to reduce emissions from Alberta's transportation sector. My hope was that different patterns would emerge between B.C., Alberta, and Quebec, and help the interpretation of the results, and possibly suggest some useful policy directions.

The decomposition analysis yields information about major trends in the transportation sector. A literature scan was performed to examine polices appropriate to address the identified issues. While a variety of sources were consulted, many sources came from an initiative of the European Commission: Directorate-General, the *EU Transport GHG: Routes to 2050* project. This two-part project started in 2010, and the second part was recently completed. It is, in effect, an amalgam of case studies carried out to find the best ways to reduce GHGs from transportation in Europe. Since 2010, the project has summarized many of the considerations that go into transportation planning with regards to minimizing GHG production, and therefore this was used as a starting point for developing policies.

3. Decomposition results and further analysis

3.1. Passenger transportation decomposition results

NRCan (2013) indicates that the amount of passenger transportation has increased considerably in Alberta between 1990 and 2010. Total passenger road transportation activity has increased from approximately 46 billion passenger-km to 64 billion passenger-km, an increase of almost 50%. Over this same period, the proportion of passenger transportation comprised of personal car use dropped from 62.7% to 46.5%, while the use of light trucks (such as pick-ups, sport-utility vehicles, and mini-vans) increased from 21.6% to 36.9%. Due to the lower average fuel efficiency of light trucks, one would expect to see an increased energy intensity of passenger transportation. However, despite the increase in light truck use, energy intensity of the entire sector decreased by about 20% due to offsetting increases in fuel efficiency of cars. Thus, Alberta's passenger transportation over this time is characterized by a large increase in activity, accompanied by a noticeable shift towards larger personal vehicles, but also increasing fuel efficiency. Over this time, GHGs have increased from 8.1 Mt per year to 8.8 Mt per year. The decomposition allows one to delve deeper into these observations, and see if there is a difference between Alberta and other provinces.

Results for the passenger transportation decomposition analysis indicate no major differences across provinces throughout the time period of the study (Figures 1-3). All provinces exhibit similar patterns for each of the separate components of transportation GHG production. Before highlighting results of individual components, it should be noted that decompositions between individual pairs of years should be interpreted with caution. The GHGs, passenger-km, and tonne-km reported by NRCan (2013) are based on estimated fuel consumption for each type of vehicle class within each year, and so these data may be more accurate in some years than others. Therefore, strong changes in GHG components between individual pairs of years should probably not be used to inform policy. Instead, results should be interpreted by looking for patterns across larger time periods. Each component will now be discussed in more detail.

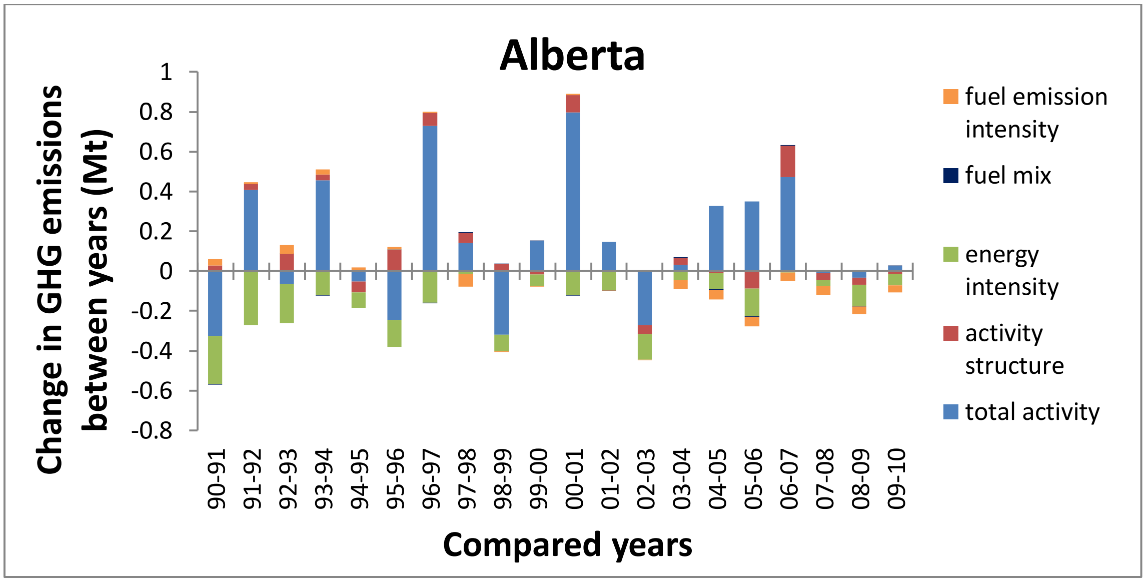

Figure 1. **Annual index decomposition of Alberta's greenhouse gas emissions from the passenger transportation sector between 1990-2010.**

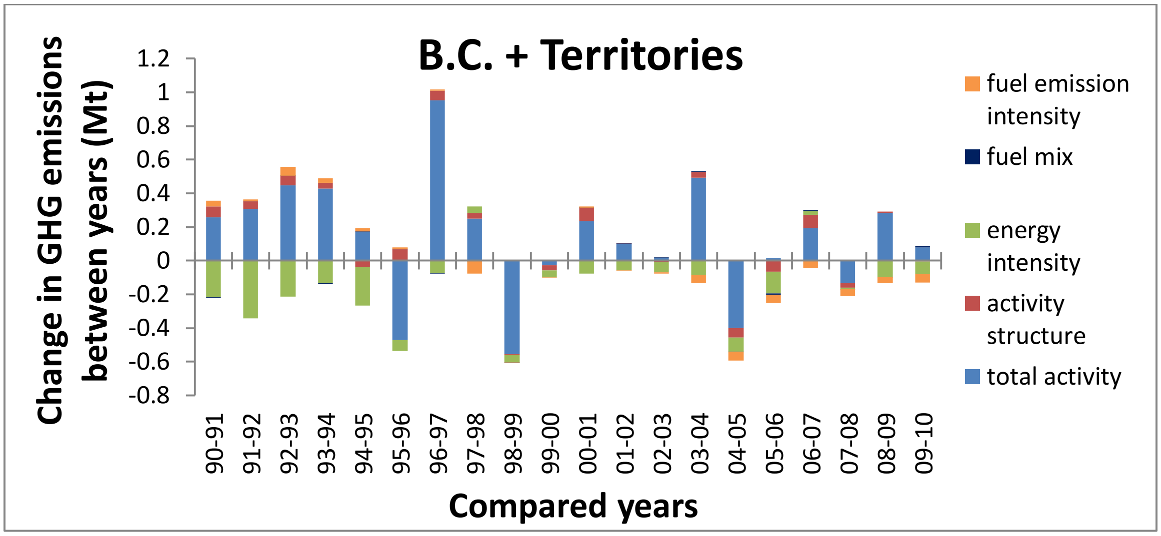

Figure 2. **Annual index decomposition of the greenhouse gases emitted by the passenger transportation sector of British Columbia and the Canadian Territories between 1990-2010.**

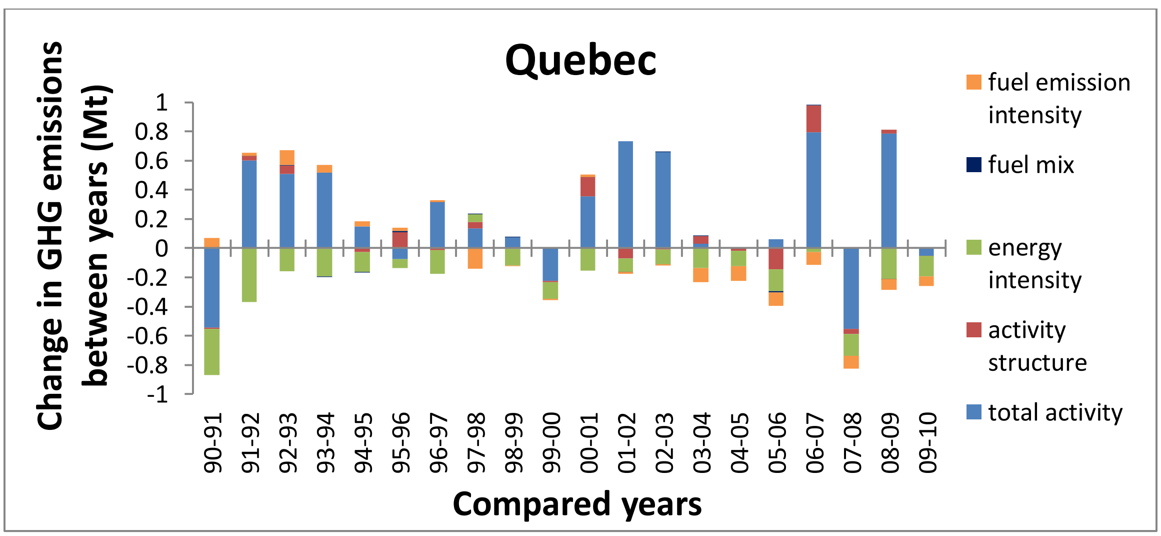

Figure 3. **Annual index decomposition of Quebec's greenhouse gas emissions from the passenger transportation sector between 1990-2010.**

Total activity, measured in passenger-km, was the component that most strongly impacted GHGs between 1990-2010 in each province. While the magnitude and direction of activity changed considerably between individual pairs of years, the overall trend is similar in each province: activity has increased GHGs in most years since 1990, and is the largest single component between almost every pair of years for each province. This finding is unsurprising given that all studied provinces have seen positive annual growth in population size and GDP almost every year since 1990, and transportation demand/activity is generally associated with economic growth (Tapio, 2005).

At the opposite end of the spectrum, neither the fuel emission intensity (GHGs emitted per unit of fuel type combusted) nor fuel mix (proportional use of different fuel types) played a significant role in GHG increase or decrease in any province across any subsequent pair of years. Most years exhibit near-zero values for both components. For years with non-zero values, the effect tended to be smaller than those of other components. Such a result was expected for fuel emission intensity, as the combustion of a specific volume of any particular fuel type should result in the emission of a constant amount of GHGs that vary only across fuels, not between multiple burnings of the same fuel type. The only noticeable pattern for this factor is that it is starting in the mid 2000s, this component consistently has a small and negative value across all three provinces. Looking at individual fuels' emission intensities, the data show that the emission intensity of gasoline decreased slightly but consistently over this period (see Appendix A), which would explain the fairly consistent results across all provinces[2].

The finding about fuel mix was not expected, however, and indicates one of two possibilities: 1) fuel mix in passenger transportation has stayed relatively constant within provinces across years; 2) the change in GHGs resulting from fuel switching in passenger transportation has been very small. The extent to which both of these possibilities are true can be deciphered by looking more closely at the data. In this instance, the first explanation seems to fit the observed data fairly well; there has been little change in overall fuel mix in any province (Appendix B). From 1990-2010, there was

[2] Possibly due to an increase in the ethanol content in gasoline.

a slight increase in the proportion of gasoline used, and a decrease in the proportion of propane fuel or diesel used. Propane has a slightly lower emission intensity than gasoline (60.5 kt/PJ vs. 67.6 kt/PJ in 2010; Appendix A), and so a decrease in proportional consumption might, therefore, be expected to have increased GHGs over this time. However, as gasoline was the dominant fuel type for passenger transportation in all provinces across the whole length of the time period, it seems that the small incremental changes to fuel mix were not enough to show a substantial effect between any individual pair of years in any province.

The activity structure component (the modal composition of transportation activity), while more prominent than fuel mix or GHG intensity, still had a small overall influence on changing GHGs in passenger transportation across provinces. Alberta showed the largest change in emissions due to structural changes (that is, a modal shift in passenger transportation). After looking at these data for individual vehicle types, several patterns emerge: 1) Car use, as a proportion of the total passenger transportation activity, has decreased between almost every consecutive pair of years, resulting in a decrease in GHGs; 2) Light truck use has increased consistently during this time period, resulting in an increase in GHGs; 3) Urban transit bus use has fluctuated, but not really increased throughout this time period (Appendix C). Interestingly, while increased transit bus use would typically be expected to decrease GHGs, the data show that the amount of GHGs per passenger-km travelled is often comparable to those of a car. As a proportion of car GHGs per passenger-km, transit buses have fluctuated from 70%-90% between 1990-2010 in Alberta (Appendix D). A similar pattern was also observed in B.C. + Territories or Quebec. In B.C. + Territories, buses have produced 67%-85% as many GHGs on a per passenger-km basis as cars, and in Quebec, the percentage ranges from 61%-76% (data not shown). Possible reasons for this pattern include inefficient bus routes, idling, and underused capacity (i.e. buses travelling with few passengers). While the use of transit buses does reduce GHGs on a per passenger-km basis, the difference with car use was smaller than I had expected[3], but comparable to results reported by Davis and Hale (2007) for public transit in the United States.

Finally, looking at energy intensity (fuel efficiency), changes in energy intensity have resulted in decreasing emissions in all three provinces during almost every consecutive pair of years. The effect is usually not as large as that of activity, but energy intensity the second largest component of changes in GHGs. This was somewhat unexpected, as this trend is opposite of that observed during the 1990s in the USA (IEA, 2012).

Because the annual decompositions are fairly noisy and often showed high variation between years, I ran an additional decomposition for each province, comparing 1990 with 2010 directly. This decomposition is an aggregation of the changes that took place across that entire time period studied. The results are displayed in Figure 4.

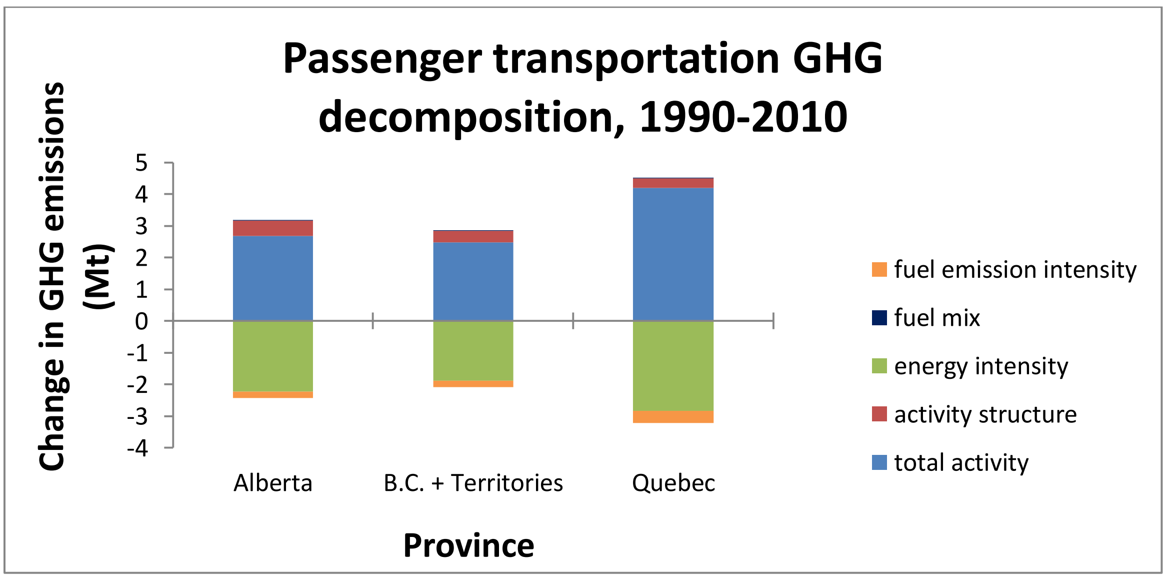

Figure 4. **Index decomposition of the greenhouse gases emitted by the passenger transportation sector of three regions of Canada between 1990-2010.**

[3] This pattern may be due to the aggregation across an entire province. Inter-city emission intensities may show a very different pattern.

This aggregate decomposition clarifies the observed trends. All three provinces still show total activity as causing the most amount of change in GHGs. Similarly, fuel emission intensity, fuel mix, and activity structure all have a relatively small effect on changes in GHGs. However, a new pattern also emerged: in all three provinces, the change in emission intensity over this time has decreased GHGs almost as much as activity has increased them. That is to say, while there is more and more passenger transportation occurring almost every year, the increase in transportation has been mostly offset by increases in fuel efficiency, so that each province has had a relatively small increase in overall GHG output since 1990.

3.2. Freight transportation decomposition results

While initially responsible for fewer GHGs than passenger transportation, freight transportation activity has increased considerably more than passenger transportation in Alberta during this time (as per NRCan, 2013). Total road freight activity more than tripled, increasing from almost 17 billion tonne-km in 1990 to 73 billion tonne-km in 2010. At the same time, the use of heavy trucks increased from 70% of total freight activity to 85%, displacing the (proportionate) use of medium and light trucks, which are less fuel efficient on a per tonne-km basis in moving freight. Because of this transition, and because the fuel efficiency of all freight vehicle classes increased between 1990-2010, the total energy intensity of freight transportation decreased by approximately 1/3 over this time. However, the huge increase in total activity offsets these fuel efficiency gains. As a result, GHGs from freight transportation have increased from 5.5 Mt in 1990 to 16.1 Mt in 2010. The sections below go into detail on these changes, and the results of the decompositions are presented in Figures 5-8.

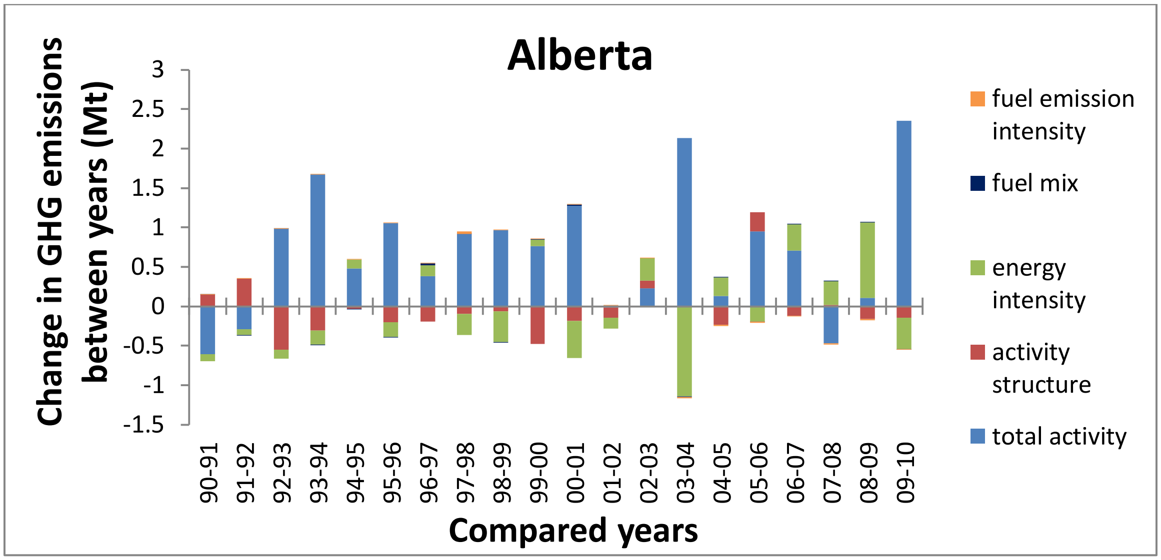

Figure 5. Annual index decomposition of Alberta's greenhouse gas emissions from the freight transportation sector between 1990-2010.

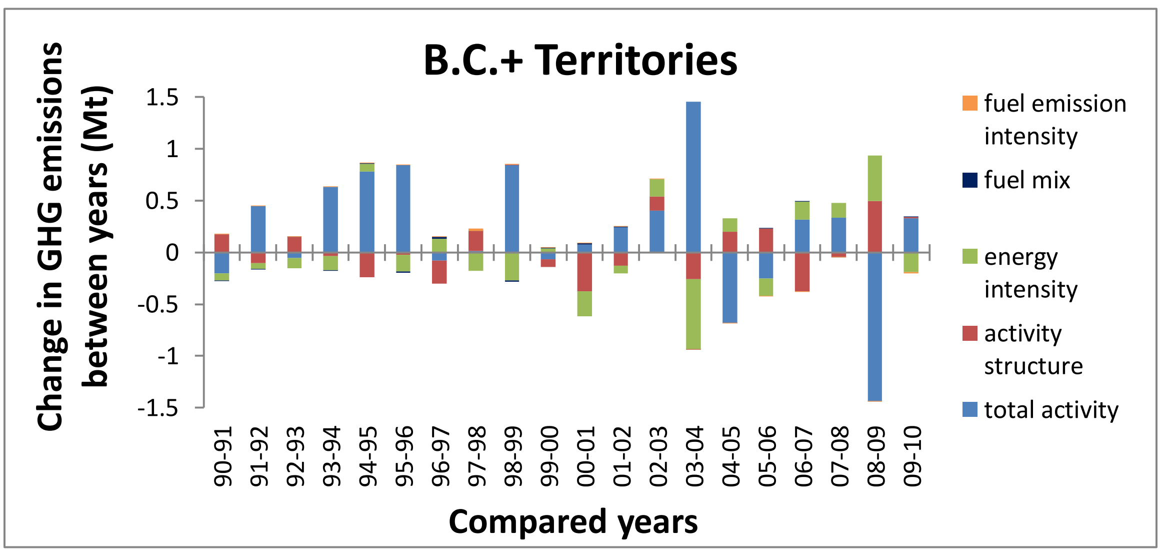

Figure 6. Annual index decomposition of the greenhouse gases emitted by the freight transportation sector of British Columbia and the Canadian Territories between 1990-2010.

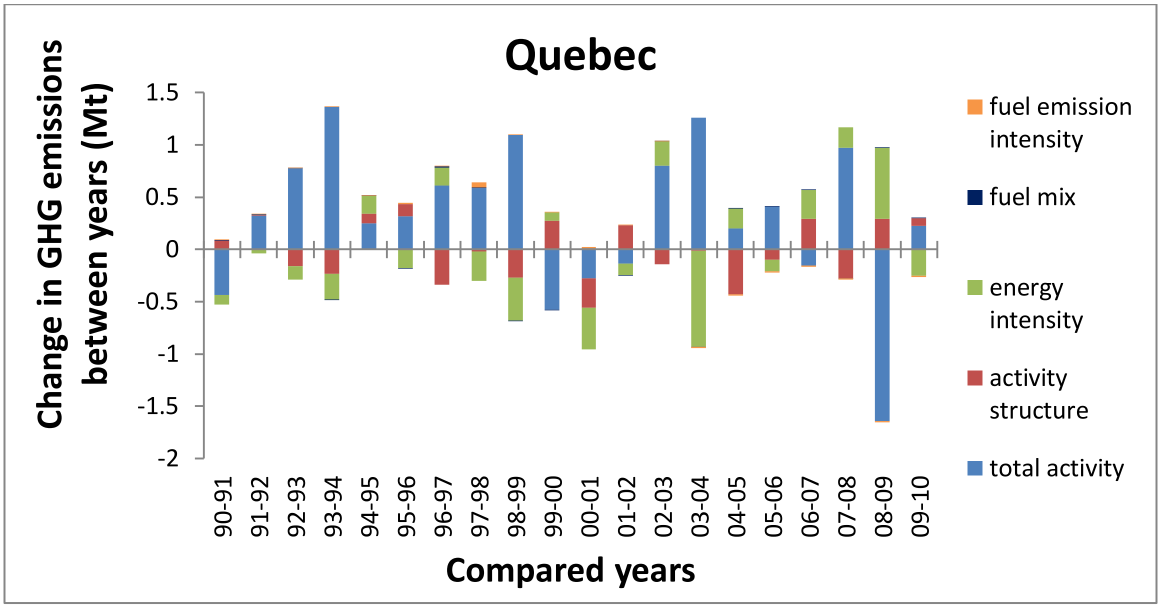

Figure 7. **Annual index decomposition of Quebec's greenhouse gas emissions from the freight transportation sector between 1990-2010.**

As with passenger transportation, the largest individual component contributing to the changes in GHGs in each province's freight transportation sector was activity (measured in tonne-km, or the total distance freight was moved multiplied by the mass of the moved freight). Activity increased GHGs between most pairs of years in every province. A notable exception is between 2008-2009, when both Quebec and B.C. + Territories experienced a massive decrease in freight activity. This is likely due to the financial crisis that began in early 2008. Interestingly, Alberta does not exhibit this trend, and shows a slight increase in transportation activity between 2008-2009. Contrasting this is the pattern for 2007-2008, where both B.C. + Territories and Quebec showed increases in freight activity, while Alberta, on the other hand showed a substantial decrease. This suggests that the financial crisis may have affected Alberta's freight transportation sector earlier than the other two provinces, or that Alberta's energy exports allowed it to better weather the recession in later years. Overall, however, the effect of activity has strongly increased emissions, particularly in Alberta.

The patterns observed in freight transportation fuel emission intensity and mix are also similar to those in passenger transportation. Neither has had much effect on

GHGs since 1990. However, there is even less evidence for a decrease in fuel emission intensity taking at any point during this time.

Unlike passenger transportation however, the fuel mix of the freight transportation sector did change considerably over the studied time, as there has been a dramatic shift from gasoline to diesel fuel in Alberta, and a smaller shift in B.C. + Territories (Appendix E; only data for Alberta is reported). Quebec, on the other hand, shows no strong change in fuel use composition in freight transportation during this time. Comparing the emission intensities of gasoline versus diesel fuel explains why all provinces show similar decomposition results, despite differing changes in fuel mix: they are virtually identical for a given amount of energy, with diesel fuel producing slightly more GHGs per unit of energy (see Appendix A). As these are the predominant fuels across both passenger and freight transportation activities in all years across all provinces, it is logical that a shift between them has not strongly impacted emissions. Diesel-powered engines have greater fuel efficiency per unit of energy than gasoline-powered engines (USDE, 2013a), but this does not appear in these results for two reasons.

First, the shift from gasoline to diesel in Alberta's and B.C. + Territories' freight sectors only occurred in medium and light trucks, as NRCan reports that heavy trucks have used diesel exclusively this entire time. Because the fuel efficiency of heavy trucks is considerably higher than medium and light trucks, and because the increased diesel use was accompanied by decreased propane use and a proportional increase in heavy truck use, this may explain why a large shift towards diesel in this sector did not lead to much reduction in GHGs.

Second, the changes in GHGs attributable to fuel mix do not incorporate the number of tonne-km achieved from each fuel (and such data are not available, in any case). This is because this component simply compares the emission intensity per amount of energy produced through consumption, and does not include a measurement how well that energy produced translates into transportation. This measurement is incorporated into the energy intensity component. Therefore, while diesel engines tend to have a higher efficiency than gasoline engines, this does not translate to GHG reductions attributed to the fuel mix component.

Looking at activity structure of freight transportation within Alberta, this factor appears to have more strongly influenced freight than passenger transportation. This was to be expected, as freight transportation generally makes up the largest component of road transportation worldwide (Chapman, 2007). Many years show this factor as noticeably negative or positive, with most years being negative until recently. This can be primarily attributed to changes in the proportional use of heavy trucks (Appendix F), which have considerably higher fuel efficiency on a per tonne-km basis. Variation in activity between medium and light trucks is unlikely to strongly impact this component, as the fuel efficiencies of both are very similar; they each consume approximately 3x as much fuel as heavy trucks per tonne-km. However, Alberta stands out somewhat in this component, as the increase in proportional heavy truck use in Quebec and B.C. + Territories was considerably smaller during this time (data not shown).

Last, the changes in GHGs attributed to energy intensity in freight transportation were unexpected. The effect of energy intensity was generally large, but not consistently negative. A positive pattern has become noticeable in recent years, and indicates that rather than increasing, fuel efficiency in the freight transportation sector has actually been *decreasing* in several recent years. This trend is noticeable in the years following the introduction of new federal emissions regulations that came into place on Jan. 1, 2004 (the *On-Road Vehicle and Engine Emission Regulations*). Looking at the decomposition of GHGs between 2003-2004, we can see that a large decrease in GHGs is attributed to fuel efficiency. From this, we can tentatively conclude that the new emissions standards had a strong impact on GHG production immediately after their introduction, but this did not extend into the future, as backsliding is evident starting the following year. Interestingly, these new regulations did not have a similar effect on fuel efficiency in passenger transportation, as fuel efficiency reduced GHGs by only a small amount in each province between 2003-2004 (Figures 1-3). As noted previously, however, such variation between individual years should be interpreted with caution, and so these results are only indicative, rather than conclusive.

A decomposition across the entire period from 1990-2010 for each province is displayed in Figure 8. As was the case for passenger transportation, this additional analysis provides some clarity to the freight transportation analysis. While total activity is strongly positive for all three provinces, energy intensity was not found to be strongly negative. This is because of the inconsistent effect that changes in energy efficiency have had on the freight transportation sector between individual pairs of years. Interestingly, while structure activity seemed to have a noticeable effect in both B.C. + Territories and Quebec when decomposed yearly, the overall effect across the entire time period is quite small; only Alberta seems to have shown much change in GHGs as a result of changing modes of freight transportation. Regardless, both of these effects are much smaller than the activity effect, to a much greater extent than was observed in passenger transportation, across all provinces. Therefore, the increased GHGs from freight transportation have largely been unmitigated by increases in energy efficiency or changing sub-sector composition. This is most noticeable in Alberta, where the overall activity effect is shown to have increased emissions to a much greater extent than in in B.C. + Territories or Quebec.

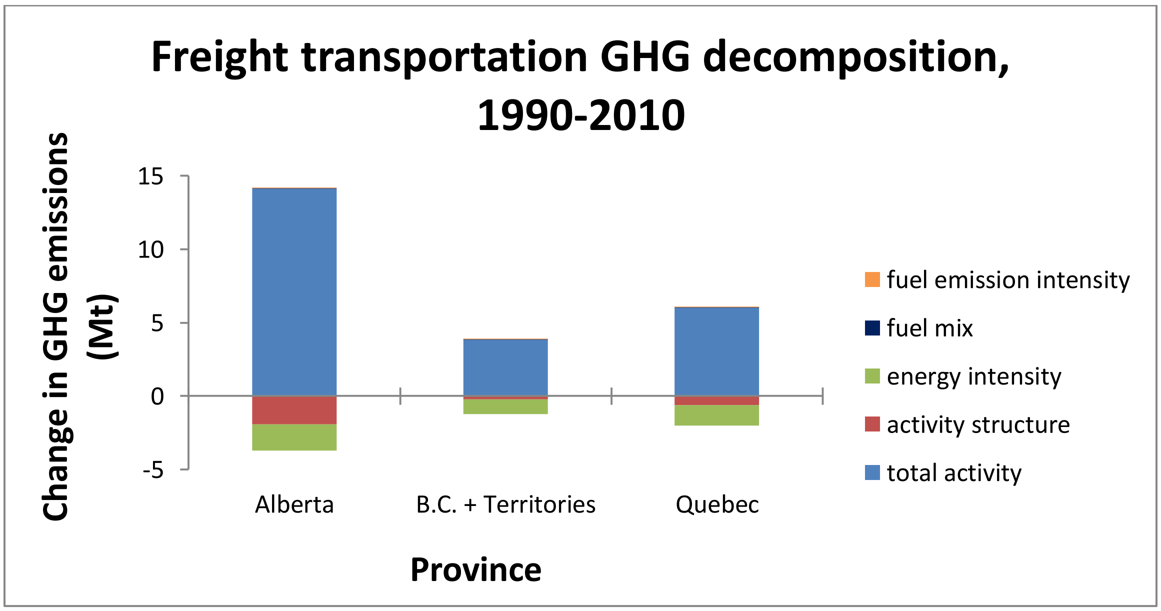

Figure 8. **Index decomposition of the greenhouse gases emitted by the freight transportation sector of three regions of Canada between 1990-2010.**

3.3. Summary of decomposition findings and further analysis

In sum, from the decomposition of road transportation GHGs across provinces, three major findings are evident. First: total activity has increased considerably in all provinces in both freight and passenger transportation. Second: there have been almost no emission reductions achieved through fuel switching, despite the increasing availability of lower-emission fuels. Third: the activity increases in passenger transportation have largely been mitigated by increases in fuel efficiency, but this is not true for freight transportation, where increased energy efficiency has not had a large impact on GHG reductions. Looking at Alberta more specifically, an additional pattern is clear. Alberta's increase in transportation activity is larger than the other two provinces in both passenger and freight transportation. This is particularly so for freight transportation, where activity-associated GHGs have increased by more than twice as much as Quebec's, and more than thrice that of B.C. + Territories'.

To explore this latter finding further, I compared freight activity with GDP and population for all three provinces between 1990-2010. All provinces have had considerable growth in GDP and population since 1990, both of which may well have driven the observed increase in activity. So, I standardized annual freight activity by population, and then by GDP, to see if Alberta's large increase in activity could be attributed solely to population and or economic growth. Comparisons with all provinces in Canada are shown in Figures 9 and 10.

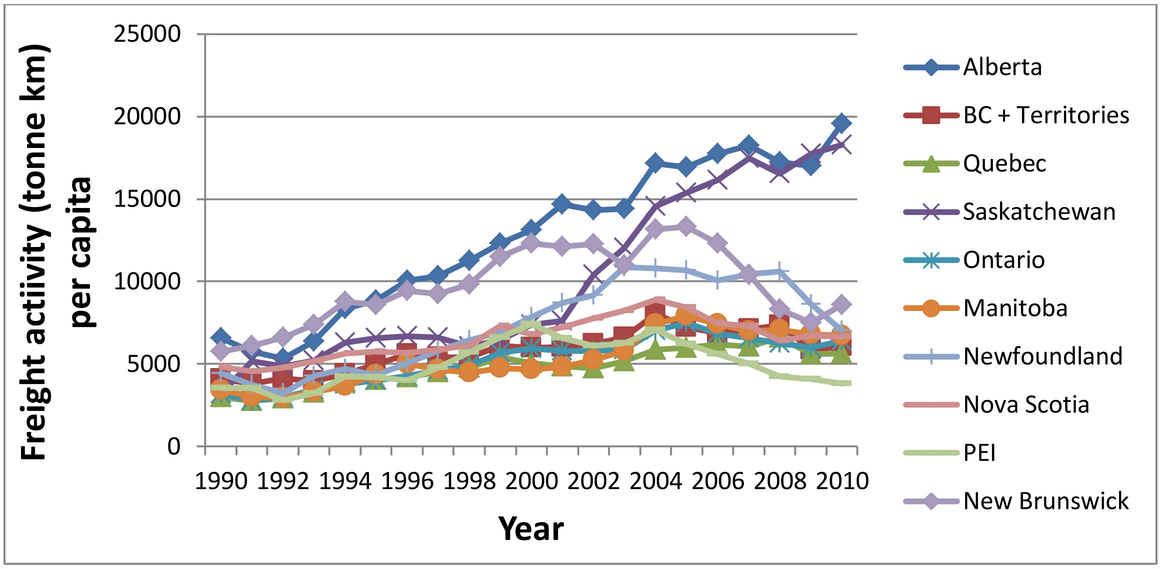

Figure 9. **Comparison of per capita freight transportation activity among Canadian provinces between 1990-2010.**

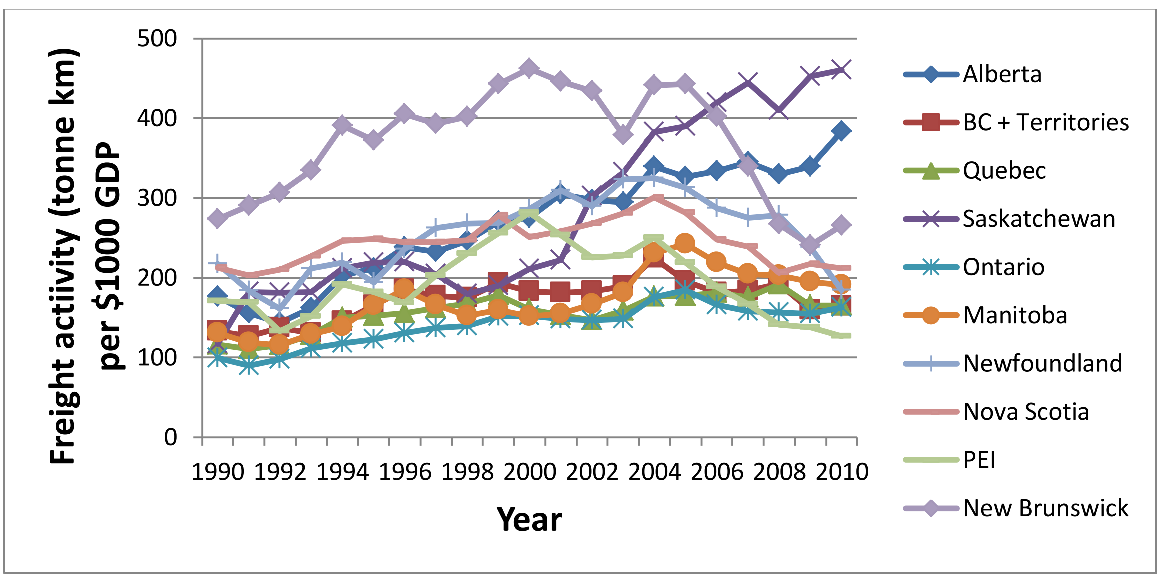

Figure 10. **Comparison of freight activity standardized by GDP for Canadian provinces.**

From Figure 9, we can see that all provinces started at similar levels of per capita freight activity. However, between 1990-2010, Alberta's and Saskatchewan's per capita freight activity increased almost 3-fold, from approximately 7000 tonne-km per person to almost 20,000 tonne-km per person, whereas the increases in all other provinces were considerably smaller. Notwithstanding large variation in New Brunswick and Newfoundland, the result is that by 2010, the per capita freight activity in Alberta is almost three times that observed in almost all other provinces.

A similar pattern is evident when standardizing freight activity by GDP (Figure 10). In 1990, freight activity per GDP was fairly similar across provinces except for New Brunswick. However, by 2010, Alberta's and Saskatchewan's per GDP freight activity had more than doubled, while most other provinces' had increased by a much smaller amount. Again the result is that, despite very high initial freight demand in New Brunswick by 2010, per GDP freight emissions in Alberta are over twice what they are in most other provinces.

Combined, these findings indicate that the increased freight activity observed in Alberta between 1990-2010 cannot be attributed solely to increased population size and/or economic growth. For some reason, per capita and per GDP freight activity has increased more quickly with increased population and GDP (respectively) in Alberta and Saskatchewan than in the other provinces. This suggests that there may be large behavioural or economic differences underlying these trends.

One possible explanation for high freight transportation activity could be high volume of exports. Indeed, Alberta's per capita exports are higher than any other province in Canada as of 2010, lower only than the Northwest Territories, and Saskatchewan's exports per capita are the third highest (B.C. Stats, 2012). Each of Alberta and Saskatchewan has per capita exports that more than double those of B.C. or Quebec. However, this is unlikely to be the cause of Alberta's high freight activity for two reasons. First, most of Alberta's international exports occur via pipeline, with only 9% (by $ value) transported by truck, and 23% using rail, marine, or intermodal transport (Alberta Transportation, 2012). Second, approximately 58% of all Canada-U.S. trade that took place in 2010 was shipped by truck, and 80% of this trade crossed the border at either Ontario or Quebec (Transport Canada, 2011a). While not wholly conclusive, together, these facts make it seem unlikely that Alberta's high freight transportation activity is due to its high export rate alone.

Because Alberta and Saskatchewan have similar trends over this time period, it is conceivable that the high freight activity observed is related to energy extraction (i.e. oil and natural gas). Both provinces have large proportions of their economies centered on energy extraction, and it is possible that the need to transport heavy machinery or other related products is impacting the amount of freight activity taking place within these provinces. Other provinces, such as Ontario and B.C., also rely on resource extraction (e.g. lumber). Therefore, it is possible that either something specific to the energy extraction industry is driving transportation activity, or that because both B.C. and Ontario's economies are more diversified than those of Saskatchewan and Alberta that the per capita and per GDP freight activity is considerably lower.

Unfortunately, while such speculation may be plausible, it is very difficult to demonstrate such a relationship empirically. Although Alberta Transportation keeps a numerous records pertaining to highway infrastructure, traffic, and safety, there is a dearth of other information related to freight movement within the province, a situation that the Centre for Transportation Engineering and Planning (2011) determined was "inadequate at best". While there are available vehicle counts, and vehicle-km estimations for many different types of vehicle, there is no data on where freight trucks are travelling to and from, or what sort of cargo they carry. Additionally, while all commercial vehicles operating in the province must be registered, they are not required to disclose which industry they are affiliated with. Combined, these factors make it difficult to determine with any certainty which, if any, industry is driving the observed demand for freight transportation.

In an attempt to explore the intuition about energy extraction further, I calculated the number of vehicle-km travelled in 2011 by heavy trucks on the two highways that lead north to Fort McMurray, the location of much of Alberta's oil sands developments (Highway 63 and Highway 881). Highway 63 is the most direct highway if one is travelling north from Edmonton, and highway 881, while less direct, leads north from Lac la Biche until it hits highway 63, about 20 km south of Fort McMurray. Highway 63 continues past Fort McMurray for another 150 km through additional oil sands development. Across their entire lengths, neither highway goes through any community larger than a hamlet. Highway 63 only intersects with other highways at its southern-most portion, and highway 881 intersects only at Lac la Biche and with highway 956 that goes east into Saskatchewan. Therefore, it seems likely that most of the heavy truck traffic on these highways, particularly highway 63, is associated with oil sands development.

To look for travel patterns along these highways, I calculated heavy truck vehicle-km along the entirety of each highway, as reported by Alberta Transportation, and compared them to all the other highways in the province. Collectively, these highways account for 5.91% of all vehicle-km travelled by heavy trucks in the province, despite comprising only 3.18% of the length of all highways in the province (calculated from data reported in Alberta Transportation, 2011). While inconclusive, this finding does indicate that oil sands developments do make use of a disproportionately large amount of freight transportation.

4. Literature scan for policy options

4.1. Targeting emission reduction strategies

The decomposition analysis discussed above provides some guidance for targeting policy towards reducing Alberta's road transportation emissions. First and foremost, it is clear that freight transportation must be given priority over passenger transportation. The absolute increases in GHGs in the freight sector are far greater than those in passenger transportation, a finding that is much more prominent in Alberta than the other provinces studied. Unfortunately, this is the only strong pattern from the decomposition analysis that distinguished Alberta from the other provinces, and so a comparison of policies beyond those previously discussed is unlikely to be fruitful.

However, if policy-makers wished to target passenger transportation specifically, several other considerations should be noted. Within passenger transportation, there have already been considerable gains in fuel efficiency, and so it is likely that additional policy in this area would have diminishing returns. Additionally, activity, while increasing overall, has actually decreased on a per capita and per GDP basis, suggesting that people have already been modifying their behaviour, resulting in GHG reductions. More useful would be to target activity structure. Alberta, as well as B.C. + Territories and Quebec have all seen huge increases in light truck use over the studied time period, in both absolute and proportional terms. As light trucks have a higher fuel consumption rate (per passenger-km) than any other mode of passenger transportation, policies aimed at reducing light truck activity may help to provide significant reductions.

Thus far, changes in type of fuel used have not had much impact on passenger transportation GHGs. This indicates that there is room for improvement in this area. Liquid and condensed natural gas have lower emission intensities than gasoline or diesel fuels, and so implementing policies encouraging a fuel switch to natural gas may be more effective than targeting fuel efficiency, which is constantly improving. Similarly, the use of kinetic hybrid cars would also help, by effectively increasing the mileage obtained through gasoline use[4].

Freight transportation, as discussed, has had a much larger impact on GHGs emitted from Alberta since 1990. This appears to be primarily a result of increased activity in this sector not simply caused by increases in population and GDP. Therefore, policies that aim to reduce freight transportation activity in Alberta are likely to have the largest impact on reducing GHGs. Further, unlike the passenger sector, the increase in activity has not been accompanied with a large increase in fuel efficiency. Unfortunately, fuel efficiency data for heavy trucks, which form the bulk of freight transportation, are not separated out by province, and so comparisons between provinces for fuel efficiency of the freight sector are not as meaningful as desired. However, the constant trend across provinces is that there have been only small gains in fuel efficiency for the freight sector. While there were gains almost annually during the 1990s, most of these gains were subsequently lost in recent years, where fuel efficiency has appeared to decrease considerably. Therefore, policy-making in this area should be able to help reduce GHGs considerably, as little net progress has been observed so far.

Activity structure, on the other hand, is unlikely to benefit from new policy measures. Heavy trucks have increased in use since 1990, accounting for 70.2% of tonne-km in 1990, and 85.1% by 2010. Because heavy trucks are more fuel efficient than lighter trucks, the industry is, by itself, already moving towards reducing its emissions via activity structure. Fuel mix, however, could well benefit from additional policy. So far, fuel mix has had almost no impact on freight transportation, but initiatives to encourage the use of alternative fuels rather than gasoline or diesel should help to reduce GHGs, because, if anything, recent years have shown an *increase* in gasoline and diesel use, and a relative decrease in the lower-emitting propane and natural gas fuels.

[4] Kinetic hybrid cars reduce fuel consumption by generating electricity from kinetic energy during braking, and using this electricity to power an electric engine

From the above analysis, it is clear that Alberta should take steps towards reducing road transportation GHGs in three primary ways: reduce activity of the freight sector, improve energy efficiency of the freight sector, and transition to lower emission fuels. The remainder of this section is dedicated to a literature scan which was used to derive policy options.

4.2. Reducing freight activity

In the literature, road transportation activity has been assumed to be coupled with economic growth, increasing with GDP (Tapio, 2005). In recent years, various countries have made an attempt to decouple freight activity from economic growth, particularly in Europe (Schroten et al., 2012). There, economic growth is a more pressing concern than population growth, as most European countries are no longer increasing in population size. Decoupling does not necessarily mean keeping freight activity constant despite continual economic growth, but rather decreasing the rate at which freight activity grows with GDP, so that the economic elasticity of road transportation activity is less than 1 (Tapio, 2005). Decoupling would thus entail that a 1% increase in GDP growth would be accompanied by < 1% growth in road transportation activity. From Figure 9 and Figure 10, we can see that transportation freight has had positive elasticity with respect to population size and GDP, and that this elasticity is larger in Alberta and Saskatchewan than in other provinces.

In general, decoupling transportation demand from economic growth is considered very difficult to accomplish (Dargay & Gately, 1999; Schafer & Victor, 2000). However, Schroten et al. (2012) identify three main ways that decoupling can be brought about, and I review these here and discuss their applicability to policy change in Alberta.

First, there is dematerialization of the economy. This can happen in two primary ways: restructuring the economy towards service and information-based activities, or using fewer and lighter goods in production processes (Schroten et al., 2012). While this may be an appealing notion, dematerialization is unlikely to be successful in Alberta. Most importantly, Alberta’s economy relies on energy extraction, primarily in the form of natural gas and oil. It would be a massive undertaking in order to try to change this, and this would not be a reasonable short-term goal. While possible in the long term, it must be accepted that the energy extraction industry is going to be prominent in Alberta's economy in the near future. Additionally, even if it were possible to transition to a service and information-based economy in the near term, it could be argued that this would not decrease the global demand for oil and natural gas, and so production would just be increased elsewhere, producing GHGs that would negate those saved in Alberta.

The miniaturization or reduction of goods used in production would also be difficult to implement. We cannot be certain of the industry or industries responsible for Alberta's high freight activity, and without that knowledge it is difficult to devise effective measures. Additionally, if it turns out that energy extraction is driving much of the freight activity, there may be little that could be done in any event, as it is not likely possible to significantly reduce the size or amount of machinery or construction materials used by the energy industry.

Second, the spatial distance that goods travel could be reduced. By decentralizing production and distribution facilities, the distance that intermediary and final products have to travel could be reduced (Schroten et al., 2012). For example, moving construction or manufacturing facilities used by the oil sands closer to Fort McMurray may help reduce required freight transportation. Another mechanism for accomplishing this would be to reduce the number of links in supply chains (Schroten et al., 2012).

This too would be difficult to apply successfully to Alberta. In general, these kinds of strategies work best on a global scale (Schroten et al., 2012), i.e. by shipping fewer goods between countries. It is more difficult to apply to smaller regions. Another issue is that the cost of decentralization would be very high for many businesses, and so the price of freight transportation would have to increase substantially in order companies to decentralize willingly (McKinnon 2008). In fact, McKinnon (2008) suggests that for some industries, transportation costs would have to increase by 100%-500% before decentralization becomes an economically viable strategy. Therefore, any move by the GoA to force decentralization would likely be strongly opposed by businesses throughout the province.

The final major pathway suggest by Schroten et al. (2012) is to improve upon transportation organization. For instance, reduce the number of trips made by empty transport trucks, and increase the amount of weight carried by each truck. In effect, the goal is to reduce vehicle-km without reducing tonne-km of activity.

The problem with implementing a re-organization of freight transportation in Alberta is that it is not clear to what extent this is currently a problem. Logically, businesses will not be running transport trucks devoid of cargo any more than necessary, and should maximize weight per trip in order to minimize transportation expenses.

van Essen et al. (2009) suggest a couple of additional strategies for reducing transportation demand. These include: urban planning to make cities more compact and reduce sprawl; transportation pricing such as road pricing; limiting available infrastructure; and reducing maximum speed. Opportunities for significant changes in urban design and road infrastructure are limited. Alberta's cities, towns, and infrastructure are already in place, and planning would likely be more effective at reducing transportation activity for passenger vehicles and short-haul trucks than the bulk of transportation taking place in heavy trucks. Limiting urban sprawl would likely prove difficult in any case as both Edmonton and Calgary, Alberta's largest cities and financial hubs, are expanding outwards quickly, sped along by high population growth (Statistics Canada, 2013). And regarding infrastructure, while having poor available infrastructure may limit personal car use where other modes of transportation are available, it is unlikely to limit demand for freight transportation, as demand for the products they supply would not be reduced.

Transportation pricing and limiting speed, however, may be more possible. The theory behind these is that by increasing the cost to transportation, whether it is monetary cost or time cost, should decrease demand. While both may be unpalatable to the general public, they would be simple enough to implement. A reduction in speed, however, is unlikely to reduce demand for freight transportation, as commercial goods are unlikely to decrease in demand significantly due to an increase in travel time. Rather, it is more likely that reducing speed limits for transportation vehicles would alter the cost of transportation, although whether this increases or decreases costs would depend on the particulars of the policy.

4.3. Increasing fuel efficiency of freight vehicles

Vehicles with fossil fuel-powered engines are expected to compose a significant proportion of road transportation even beyond 2030 (Sharpe, 2010), and so improving their fuel efficiency will likely be important for reducing transportation emissions in the coming years. There are various approaches that can be taken to increase the fuel efficiency of road vehicles, outlined by Sharpe (2010): improving the efficiency of combustion; decreasing mechanical losses of energy in the engine and during transmission to the wheels; reducing energy lost due to inertia (such as air resistance and rolling resistance); recovering wasted energy (e.g. heat from exhaust or kinetic energy from braking); reducing energy consumed by peripheral devices (such as air conditioners). All these approaches are applicable to most vehicles, regardless of whether they are used for freight or passenger transportation, and so are widely applicable to all transportation emissions in Alberta as well as most other jurisdictions.

Increasing the efficiency of a vehicle's engine is not possible without replacing the engine itself, making increases to engine efficiency or energy transfer very expensive. There is a similar problem with recovering wasted energy, and this approach is most commonly implemented in kinetic hybrid vehicles. Measures related to increasing the aerodynamics, however, are generally much more feasible ways of retrofitting vehicles in order to achieve fuel and GHG savings. Such measures are commonly used on heavy trucks where there tends to be high aerodynamic drag due to their box-like shapes (Sharpe, 2010). Popular aerodynamic modifications include trailer skirts, gap fairings, end fairings, and fuel tank fairings. All of these modifications reduce air drag around the vehicle when it is moving, which results in considerable fuel savings when the vehicle is travelling at high speed.

Speed in itself is a cause of aerodynamic drag, and increasing a heavy truck's speed beyond 105 km/h decreases fuel efficiency, which gets continually worse as the speed increases (Ogburn & Ramroth, 2007). Therefore, a common method of saving fuel is to enforce a maximum speed limit through the use of a speed limiter. These devices, which have come pre-installed in heavy trucks since the mid 1990s (Transports Québec, 2008), prevent the vehicle they are in from exceeding a set speed limit when they are engaged. It is estimated that 77% of heavy trucks in the US already make use of their speed limiters in order to reduce fuel consumption (Transport Canada, 2008a).

Another common way to increase fuel efficiency is to use tires with low rolling resistance. The most effective type is wide-base tires, sometimes called super singles, which are almost as wide as two conventional trailer tires. Super singles are used to replace 2 tires at once on trailers, reducing the number of wheels on each axle from 4 to 2. They reduce fuel consumption at all speeds as both aerodynamic drag and friction with the pavement are reduced, meaning that less power is required to move the vehicle (Bachman et al., 2005). However, many jurisdictions, including Alberta and B.C, require trucks hauling trailers with super single tires to carry less weight than trucks hauling trailers with traditional tires. This means that, in Alberta, a typical tractor pulling a 2-axle trailer can carry 1600kg less freight than a tractor pulling a trailer running traditional tires.

A final type of popular fuel efficiency measure that can be adopted is the use of idle-reducing technologies. These generate the highest fuel savings in heavy trucks which often idle for long periods of time each day (Gaines et al., 2006). Idle limiters can be installed in order to shut down idling vehicles after a short period of time (often 3-5 minutes). However, heavy trucks are regularly left idling intentionally in order to keep the engine or the cab warm or cool. In these cases, the use of auxiliary power units, auxiliary cab heaters, or auxiliary coolers is effective, as all consume considerably less fuel than an idling engine while still performing the desired functions.

Recently, the federal government announced the forthcoming *Heavy-duty Vehicle and Engine Greenhouse Gas Emissions Regulations*. These regulations impose restrictions on GHGs emitted by all road vehicles of the 2014 and later year models that weigh over 4 tonnes. Rather than specifying particular measures or technologies that must be used, these regulations, which are matched with California's, require that, on average, trucks emit only so many GHGs per tonne of weight[5]. The regulations permit the use of any fuel efficiency measures to achieve the target emissions, whether they pertain to engine efficiency, aerodynamics, idle-reduction technology, etc. Therefore, it will be challenging for Alberta to implement policies related to fuel efficiency that are not made somewhat redundant by the impending GHG emission regulations.

4.4. Switching to less carbon-intensive fuels

Numerous types of fuels for road vehicles have been explored in recent years in order to reduce GHGs. Hill et al. (2009) outline 4 main types of alternative fuels, all of which result in fewer GHGs than conventional petroleum-based fuels: biofuels, natural gas, electricity, and hydrogen. The benefits and drawbacks of each fuel type are highlighted below.

The simplest fuel switch possible would be to increase the use of liquid biofuels such as biodiesel and ethanol. Although both of these fuels release considerable GHGs when combusted, they can reduce the total lifecycle GHGs produced compared to petroleum fuels. Unlike petroleum, biofuels are generated from some sort of biological material, such as vegetable oils. This means that to generate biofuels, we must first plant crops, which reduce atmospheric CO_2 in order to grow. Therefore, the CO_2 emitted by biofuels originates from the atmosphere, rather than underground petroleum, and so the net emissions over the lifecycle of the fuel generation are reduced considerably. Net emissions are not reduced 100%, of course, because energy is expended in order to raise the crops used to generate the fuel. Because biofuels can be produced from a large variety of biological components, both the price and the net emissions reduction vary heavily (Hill et al., 2009). One distinct advantage these fuels have over low-carbon fuels is that they do not require additional infrastructure in order to consume. Mixed with petroleum fuels, they can be used in the vehicles already on the road, and supplied through conventional fuelling stations.

[5] Actual requirements are fairly complex, based on loaded and un-loaded truck weight and the number of trailers pulled. Requirements will be applied as minimum fleet-wide averages for individual vehicle manufacturers.

Another low-carbon vehicle fuel is natural gas (NG). NG has been developed as a vehicle fuel in liquid (LNG) and compressed (CNG) forms, both of which reduce CO_2e emissions by approximately 25% compared to gasoline (Hill et al., 2009). NG has been historically cheaper than petroleum fuel (Natural Gas Use in Transportation Roundtable, 2010) and Alberta in particular is fortunate to have large stores of natural gas, making this a cheap and abundant resource in the province. However, several barriers exist to the widespread use of LNG or CNG as vehicle fuel. First, these fuels are incompatible with conventional engines, and would require vehicle owners to purchase new vehicles in order to use LNG, or (at the least) make expensive engine modifications to use CNG. Second, while the availability of NG fueling stations is increasing, there are still relative few of them, meaning that in order for a significant proportion of Alberta's vehicles to use NG, heavy investment in infrastructure would be necessary. Finally, LNG and especially CNG have a lower energy density than petroleum fuel, meaning that vehicles must fill up more frequently, and natural gas fuel tanks on vehicles are larger than petroleum fuel tanks (Hill et al., 2009).

Electricity and hydrogen fuel cell powered vehicles, unlike vehicles powered by biofuels or natural gas, have the potential to be near emission free. The consumption of electricity produces no GHGs, however, there are still going to be emissions from the production of electricity. Similarly, while the consumption of hydrogen in a hydrogen fuel-cell vehicle produces no GHGs, electricity or NG must be consumed in order to manufacture the hydrogen in the first place (IEA, 2006) and using NG produces CO_2 as a by-product. Therefore, the potential for both of these fuel types to reduce GHGs in transportation requires a low-emission source of electricity. In many jurisdictions, such as B.C. and Quebec, which rely primarily on hydro-electric dams to produce electricity, both of these fuels could provide huge reductions in GHGs. Alberta however relies primarily on burning coal to generate electricity, and electricity generation in the province has a GHG intensity several hundred times as large as B.C. or Quebec (as indicated by data in Environment Canada, 2012). Beyond this limitation, both technologies suffer from the same issues as NG surrounding available infrastructure (particularly hydrogen) and driving range (WADT, 2012; USDE, 2013b). Additionally, electric vehicles suffer from longer refueling times than most other fuel types (USDE, 2013b).

5. Proposed policy options

After performing the literature scan above, four potential policies were designed to reduce GHGs from Alberta's transportation sector. Each policy targets one of the three areas identified in the decomposition analysis: freight activity, freight fuel efficiency, and fuel mix. Each option is discussed in detail in the following section.

It should be noted that all proposed options are designed for relatively short-term implementation (fully implementable within 3 years). This is because longer term policies are considerably more expensive, and require much more political and public buy-in to implement. Alberta's electricity generation currently prevents a switch to fuels with near-zero emissions, which substantially inhibits the transportation sector's options for GHG reductions. So, while all options presented here are for the short term, there are certainly longer-term measures that could be taken, which would likely prove more effective.

5.1. Option 1: extended carbon/fuel tax for heavy trucks to reduce freight activity

Most mechanisms to reduce freight activity identified in the literature scan are either not applicable to Alberta, not feasible, or likely to be ineffective. With that in mind, the most logical step to reduce freight activity is to introduce some form of additional road/carbon/fuel pricing. One of the primary benefits of using a tax as opposed to introducing new regulations or standards, or restructuring the economy or its material flows, is that the efficacy of the tax does not depend on the underlying cause of the high freight demand. So while we cannot be certain about what is driving the high freight transportation volume in Alberta, this is a moot point, as a tax will affect all industries equally.

In particular, I would suggest extending the carbon tax that is already in place for large facilities in Alberta. This tax currently applies to facilities which emit at least 100 kt of GHGs per year, and is currently set at $15/t, unless the facility is able to reduce its emission intensity by 12% of its 2003-2005 average. For facilities unable to comply with the emission intensity reduction, they must pay $15/t for each tonne that would need to be offset in order to meet a 12% reduction in intensity. For simplicity's sake, rather than creating a "new" tax for freight transportation, this tax could simply be extended to cover all fuel consumed by heavy trucks. At the current rate of $15 per tonne, this would increase fuel costs by approximately $0.041/L. This tax should not, initially, apply to passenger transportation because, as determined by the analysis, passenger transportation has been decreasing on a per capita and per GDP basis without taxation. Excluding passenger transportation would dramatically reduce the number of individuals directly impacted by the tax, and therefore reduce political opposition.

Going into more detail, this tax would apply only to heavy trucks, and not to light or medium trucks used for freight transportation. This specificity is suggested for a couple of reasons. First, light trucks, such as pick-up trucks and minivans, can be used for both passenger transportation and freight transportation, and it would not be possible to easily distinguish between these uses, making it hard to enforce this tax on those types of vehicles. Additionally, heavy trucks do not generally fill up at the same fueling stations as smaller vehicles, and consume only diesel fuel, which makes applying the tax administratively simple. Secondly, the bulk of freight transportation volume, measured by tonne-km, occurs in heavy trucks, and as a result, they produce most of the GHGs from the freight sector. Between 1990-2010, this trend has increased considerably, and therefore this tax would apply to the portion of the freight transportation sector that is responsible for the most emissions.

It should be applied directly on top of the fuel tax that Alberta already charges for diesel fuel ($0.09/L) in order to make it administratively simple. No additional collection infrastructure would be required, as tax is already collected wherever fuel is sold. While increasing the fuel tax could arguably reduce the competitiveness of Alberta's trucking sector, or otherwise inhibit economic growth, the impact should be relatively small, as even with the additional proposed tax, Alberta will still have a lower fuel tax on diesel than any other province in Canada.

Instead of using the additional carbon tax for general provincial revenue, it should be put into the Climate Change and Emissions Management Fund, the same fund the current carbon tax revenues go into. This fund is managed by the Climate Change and Emissions Management Corporation (CCEMC), whose responsibility is to use the fund to invest in GHG reduction and mitigation efforts and technology in Alberta, as well as to make Alberta more adaptable to climate change. By earmarking the money this way, GHGs should be reduced by both reducing the demand for freight transportation, while simultaneously funding efforts to reduce or mitigate GHGs.

5.2. Option 2: require heavy trucks to use Auxiliary processing units

There are many ways that inefficient trucks can improve their fuel efficiency, as outlined in the literature scan. However, one large problem stands in the way of any regulation or subsidy for most of these measures: the upcoming federal legislation on emissions from large vehicles in the *Heavy-duty Vehicle and Engine Greenhouse Gas Emissions Regulations*.

These regulations do not require specific technologies to be implemented on transport vehicles. Rather, they require that Canada's trucking fleets meet certain emission standards, and leave it up to truck manufacturers to figure out the best way to comply, whether it is by using more efficient engines, skirts, low-resistance tires etc. This means that any additional regulation on Alberta's part to mandate the use of any of these fuel efficiency measures may be somewhat redundant, as new trucks may have included the upgrade anyway to comply with federal regulations.

Therefore, any policy to improve fuel efficiency must include measures that would not likely be used to meet federal regulations. Auxiliary power units (APUs) are one such measure, and with this policy would be made mandatory for all new trucks and those under three years of age registered in Alberta. Truck manufacturers are unlikely to include APUs on their new vehicles for two reasons. First, they are expensive, and there are likely cheaper options for meeting the new federal regulations (e.g. include skirts, fairings, low resistance tires, etc.). Second, as few provinces provide a weight exemption for APUs, their inclusion would reduce the weight a truck can haul in most provinces, making them unappealing. Making installation mandatory for only relatively new trucks will ensure that truck-owners receive the maximum fuel savings possible. While older trucks would also benefit from their use, they are less likely to be as cost effective as the lifespan of older vehicles will necessarily be shorter than those of newer vehicles.

APUs are used to provide heat, cooling, and power for heavy truck cabs, reducing considerably the amount of fuel used when the truck is not in motion. In particular, this would save fuel consumed by truck-drivers who sleep in their cabs overnight on long trips, because without auxiliary power units, the truck engine is often kept running intentionally. This is especially important in winter months, when truck drivers need to keep both the cabs and the engines warm.

Because APUs have a high up-front cost of approximately $8500 per unit (Transport Canada, 2011b), the GoA should provide some financing options for truck owners. While simply putting the regulation in place would be a cheaper option for the GoA, the up-front costs may be prohibitively expensive for some truck owners, particularly those running small businesses that may not have readily available capital. In particular, low or zero-interest loans should be considered. Loans made for 50% of the purchase and installation cost would considerably reduce costs to operators. A long pay-back time of five years would allow ample time for truck operators to recoup capital costs and benefit from the investment. Using a loan scheme instead of a rebate scheme would help the GoA to minimize costs.

Alongside the financial aid provided to truck drivers and businesses in Alberta, a modification of weight regulations should also be included in this policy. APUs are heavy, weighing approximately 400 lbs. As such, many US states include weight exemptions for heavy trucks using APUs. This allows trucks to install APUs without reducing the amount of freight they can carry. Alberta should implement a similar weight exemption, perhaps following B.C.'s 225 kg exemption.

5.3. Option 3: require heavy trucks to use speed limiters

Option 3, the requirement for heavy trucks to use speed limiters, is also designed to increase the efficiency of Alberta's heavy trucks without overlapping with efficiency gains that will otherwise be realized due to the upcoming federal regulations. While the federal government will permit the use of speed limiters to meet the required emissions standards, speed limiters do not come pre-set from manufacturers, and so the federal legislation is unlikely to increase their use in practice.

Speed limiters are routinely included on heavy trucks during manufacturing, but their use is not enforced in most jurisdictions (Ontario and Quebec are the only Canadian exceptions). The entire truck fleet in Alberta should thus already have them installed, and they can be activated with little difficulty (Transport Canada, 2008a). They are used by many trucking companies in order to reduce fuel consumption, because fuel efficiency decreases above 105 km/h (Transport Canada, 2007). Therefore, the use of speed limiters would help to reduce fuel consumption by heavy trucks.

Speed limiters would be required to be activated at 105 km/h in all heavy freight trucks. This speed cap would match that of Ontario and Quebec, which have had this requirement since the beginning of 2009. While some Alberta highways have speed limits of 110 km/h, such speed limits only occur on highways with two lanes in each direction, and therefore this speed limit does not apply to most highways in the province, including highways 63 and 881 leading to Fort McMurray. Increasing speed above 105 km/h decreases fuel efficiency, and despite current legislation, a large proportion of the large trucks in Alberta travel at speeds above the posted limits (Transport Canada, 2008a). Because most or all heavy trucks in Alberta should already have speed limiters installed, the only cost would be the cost of the mechanic or device necessary to activate the limiters. However, money would subsequently be saved due to the reduced fuel consumption.

5.4. Option 4: require an annual average of 4% biodiesel in Alberta's diesel pool

As noted in the literature scan, most fuel switching options are quite expensive and the two most promising in terms of GHG reductions (electric and hydrogen fuel cell vehicles) are not applicable to Alberta because of the high GHG intensity of Alberta's electricity generation. Natural gas, another vehicle fuel for which there has been considerable recent interest, would afford relatively few GHG savings as the emission intensity of NG is not that much lower than diesel or gasoline fuel. On top of that, considerable capital expense must be incurred in terms of new vehicle engines and new fuelling infrastructure. Given these concerns, the inclusion of additional biodiesel in Alberta's diesel pool should prove to be a good short-term option that doesn't incur extremely high capital and logistical costs. While the inclusion of biofuel to replace gasoline was also considered, diesel was chosen as the focus because it is the primary fuel type consumed by the freight transportation sector.

An amendment to Environment Canada's *Renewable Fuels Regulations* that came into effect on July 1, 2011, stipulates that 2% of Canada's diesel fuel must be composed of biodiesel. The proposed policy would require the doubling of that minimum for Alberta, matching restrictions currently imposed in B.C. This would decrease the life-cycle carbon emissions from diesel fuel, without requiring additional infrastructure or capital costs to vehicle owners. As Alberta grows approximately 1/3 of Canada's canola crop (LMC International, 2011), it is well positioned compared to most provinces to increase biodiesel production. However, this will still likely result in an increased price of diesel fuel at the pump, but that would reinforce incentives to minimize fuel use.

The 4% limit allows some flexibility in how the biodiesel is distributed among the total diesel consumption of the province. This is important because many car manufacturers do not yet warranty their engines for use with diesel with more than 5% biodiesel (NREL, 2009). Because the first-generation biodiesel that is available in Canada can cause problems in winter (NREL, 2009), it may be desirable to have a smaller component of biodiesel during winter, particularly in the northern regions of the province. Keeping the limit at 4% will allow diesel producers to produce some diesel fuel with a higher component of diesel (5%) during non-winter months and/or for distribution to more southern areas in order to compensate for reducing the biodiesel component during other seasons or in other areas, without producing diesel that would void vehicle warrantees. As was done in B.C., the biodiesel requirement should be increased in stages over time, with plenty of advance notice, so that industry has time to increase production of biofuels and figure out the optimal temporal and geographic distribution in order to meet the requirement.

Currently, Alberta supports biofuel producers through the *Bioenergy Producer Credit Program*. This program provides a subsidy to producers based on the type and volume of biofuel they produce. While applications for program support are accepted on an annual basis, the guidelines stipulate that the acceptance of new applications is subject to available funding (Alberta Energy, 2013). After implementing the new biodiesel requirement, the GoA should not approve any new applications for subsidy, as increased demand for biodiesel caused by the regulation should enable biodiesel production to be economically feasible without subsidy. Similarly, the *Bioenergy Producer Credit Program* should not be renewed after it expires in early 2016.

6. Criteria and measures to evaluate policy options

In order to help decide which of the preceding policies may be most viable for Alberta, a set of criteria were designed with which to evaluate each policy. For each criterion, there are at least two measures used to evaluate how well each policy meets the criterion. Some measures involve numerical calculations, and others simply draw on logic or reference other jurisdictions or implementations. As such, after evaluation of measures, each criterion for each policy is scored as “very low”, “low”, “medium” or “high”. This makes it simple to compare the different criteria so that they can all be taken into account simultaneously. In all cases, a score of “high” is considered better than a score of “low”, meaning that all criteria represent desirable outcomes. Four tiers were chosen so that policies could be ranked if necessary, for measures where specific measurements are difficult to assess. Each of the criteria and their measures are described below, explaining why the criterion was included, and how each measure is evaluated.

6.1. Effectiveness

This criterion is included to evaluate how well each policy addresses the issue at hand: Alberta’s transportation sector is producing too many GHGs. This is an important criterion, as if a policy does not impact the problem it is intended to solve, then there is no point in implementing it.

Effectiveness was evaluated using two measures. The first measure is called “GHG Reduction” and is simply an estimate of how many GHGs, measured in tonnes of CO_2e, will be avoided on an annual basis as a direct result of the policy. GHG reduction for each policy is calculated based on the specifics of the policy, and estimates of fuel savings, number of vehicles, etc. based on Alberta-specific data, where available.

In all cases, GHG reduction estimates are based on the most recently available historical data. Ideally, however, GHG reductions would be estimated based on a projection of the size, average fuel efficiency, transportation activity etc. of the Alberta fleet that is predicted to occur in future years without the addition of new policies, under a business-as-usual (BAU) scenario. Then emissions from this BAU scenario could be compared to emissions from scenarios where each policy had been included separately, in order to better estimate emission reductions resulting from the policy. With a reliable BAU scenario, this would provide better GHG reduction estimates than those generated based on historical data.

However, modeling transportation use scenarios is very complex (Crainic & Laporte, 1996) making fleet composition, transportation activity, and fuel use patterns time consuming and difficult to project reliably. Because GHG reduction estimates comprise only one component of the policy evaluation, the sophisticated modeling required to generate a BAU scenario was deemed to be beyond the scope of this project. Therefore, historical data were used in place of the BAU scenario to simplify the estimates. The estimates are thus indicative only of the *potential* impacts of each policy option.

The second measure for this criterion is called "Implementation Speed". This refers to the relative speed with which a policy could be implemented, and is important because all measures being considered are short-term options. Implementation time will be estimated for each policy based on their complexity, with shorter times being preferable. As all proposed policies would require additional legislation, the time to pass through the legislature is not included in this estimate.

6.2. Government Affordability

The Government Affordability criterion is included so that the costs to the government of each policy can be accounted for. The GoA, like many governments around the world at this time, is facing budgetary constraints, and it is desirable to minimize expenses where possible.

Government Affordability is evaluated with three measures. “Up-front Affordability” is a measure of the immediate costs to the government, excluding administration costs. This would include capital costs, and any short-term cost that occurs during the implementation of the policy. Up-front Affordability will be estimated in dollars, with a higher number of dollars resulting in lower affordability.

“Long-term Affordability” is a measure of costs on-going into the future, after the implementation of the program. These could include maintenance costs or program costs. Long-term Affordability will also be evaluated in dollars, with high cost meaning low affordability.

Finally, the last measure is “Administrative Simplicity.” This will reflect the costs of administrating the policy, separate from other expenses. Because the monetary cost of administration is difficult to ascertain, this will be measured by estimating the administrative complexity of each option, assuming that policies that are more administratively complex will be more expensive.

It is important to note that lost fuel tax revenues resulting from policy options will not be included in any of these measures. Under the assumption that fuel taxes are used to build and maintain road infrastructure, any reduction in tax revenue would be accompanied by a reduction in spending. Therefore, tax revenue losses are not counted as costs.

6.3. Political Acceptability

Political acceptability is important for any policy, because if the public disagrees with the policy, there may be backlash against the government who implemented it. Depending on the size of the backlash, this may not matter, but in general it is desirable for the public to approve of policies that elected governments implement.

To evaluate Political Acceptability, two measures were used. The first is called “Public Affordability” and is an estimate of the amount of money that the policy will cost the general public, rather than the government.

The second measure is "Freedom of Choice." This is a simple assessment of whether or not the policy affects people's ability to make decisions for themselves about how they behave. As there is no clear way to measure this among widely differing policies, the policies were ranked based on how strongly they were thought to reduce people's freedom of choice.

7. Evaluation of policy options

Table 1 displays the results across all 4 policies for each criterion and its associated measures. It should be noted that all numerical calculations are approximate. Assumptions involved in numerical calculations are reported where necessary. Following the table, details are provided for how each measure was evaluated for each policy. At the end of the section, the qualitative scores were converted to a numerical score so that policies could be compared across all criteria and measures in order to determine the preferred option.

Table 1. **Evaluation results of policy options.**

Criterion	Measure	Option 1: fuel tax increase	Option 2: APU regulations	Option 3: Speed limiter regulations	Option 4: biodiesel increase
Effectiveness	GHG Reduction	HIGH	HIGH	LOW	MEDIUM
	Implementation Speed	HIGH	LOW	HIGH	VERY LOW
Government Affordability	Up-front Affordability	MEDIUM	VERY LOW	HIGH	HIGH
	Long-term Affordability	HIGH	MEDIUM	HIGH	HIGH
	Administrative Simplicity	HIGH	LOW	MEDIUM	LOW
Political Acceptability	Public Affordability	VERY LOW	MEDIUM	HIGH	VERY LOW
	Freedom of Choice	HIGH	MEDIUM	LOW	MEDIUM

7.1. Option 1: extended carbon/fuel tax for heavy trucks to reduce freight activity

Effectiveness

GHG Reduction

In order to reduce GHGs from the freight transportation sector, this tax must reduce demand for freight transportation (or fuel), and thereby reduce freight activity. Fuel and carbon tax increases have been observed to reduce freight activity in other jurisdictions. Price elasticities for transportation differ considerably across regions (e.g. Litman, 2012), and to further complicate matters, Rivers and Schaufele (2012) argue that the price elasticity of demand associated with a carbon tax may be almost five times that of market price, possibly due to the psychology underlying people's behavioural responses to taxation. A final concern is that most studies concerned with the elasticity of transportation demand have focussed on passenger or aggregate transportation, not freight. Thus, the available data on the elasticity of road freight transportation is fairly limited.

For this scenario, a variety of sources were considered. de Jong et al. (2010) report that in Europe, fuel price elasticity of demand for tonne-km, vehicle-km, and fuel were -0.1, -0.2, and -0.3 respectively. Bjørner (1999) reports a similar pattern in Denmark, where he found elasticies of -0.47 and -0.81 for tonne-km and vehicle-km, respectively. Oum (1979) found the price elasticity for freight transported by road (comparable to tonne-km) to be -0.155 in Canada. Given that what is required here is the elasticity with respect to fuel consumption, and that Oum's (1979) elasticity is comparable to de Jong et al.'s (2010) estimation, I will use de Jong's estimation for elasticity of freight fuel consumption (-0.3).

Using this estimate of price elasticity of road freight fuel demand and 2010 heavy truck fuel consumption, combined with the average after-tax diesel price in Alberta (from Statistics Canada, 2012c), and the energy density of diesel (as per NEB, 2012), I calculated a predicted reduction in fuel consumption from Alberta's heavy trucks

(Appendix G). This worked out to a reduced annual fuel consumption of approximately 46 million L, and approximately 120 kt of GHG reductions per year.

Another aspect of this policy that must be considered is that the additional tax revenue that would be collected would be put towards the CCEMF, which is used to help Alberta mitigate, abate, or adapt to climate change. At a rate of $0.041/L, the total estimated tax revenue from this policy would be over $150,000,000 (Appendix G). If this money were to be used by the CCEMC to abate or mitigate emissions, even at the exorbitant cost of $1000/t, this additional tax revenue would negate an extra 150 kt of GHGs per year, more than doubling the GHG reductions due to reduced consumption alone. This would bring the total to a (conservatively estimated) 270 kt per year, although if the abatement cost is assumed to be a more reasonable number, the number of GHGs abated would increase dramatically. As such, this measure was given a score of **high**.

Implementation speed

The implementation of an additional tax on fuels should be able to take place relatively quickly. After the new tax legislation passes the provincial legislature, implementation can happen quite quickly. B.C., for instance, announced their proposed carbon tax on Feb. 19, 2008, and had it in place by July 1, 2008. No new infrastructure or administration is required, and tax collection will take place as it has previously. The only change is that owners of gas stations that service heavy trucks will have to adjust their prices to reflect the increased tax price. Therefore, I scored the implementation speed as **high**.

Government Affordability

Up-front Affordability

There are no capital or infrastructure costs for this policy, and there is therefore little up-front monetary cost. The one expense that the government might incur would be information-related. People do not like to have their taxes raised, and while this tax only pertains to heavy trucks, it is likely that the GoA would want to produce some television and radio advertisements to make the public aware of the reasons surrounding the decision so as to minimize political fallout.

The cost of this communications strategy would be the only up-front (non-administrative) costs to the GoA, and so this was scored as **medium**.

Long-term Affordability

There would be no costs associated with the upkeep of this tax that are not already in place for maintaining the current provincial fuel tax on diesel fuel. Therefore, this was scored as **high**.

Administrative Simplicity

The only administrative costs of implementing this policy are in the form of having to draft and pass the new legislation. No new bureaucratic infrastructure is required in order to collect the tax, as it can be simply included with provincial fuel tax collection from owners of gas stations that serve heavy trucks. While the administration costs are not zero, they are about as little as could be expected, and this was scored as **high**.

Political Acceptability

Public Affordability

The cost to the public of this policy will be the increased monetary cost of diesel. It could be argued that there may also be lost consumer surplus, because if freight activity decreases, this would likely increase the prices of commodities and commercial goods within the province. However, most of this loss is compensated by the increased services from the tax revenue (in this case, GHG mitigation research and implementation) and so lost consumer surplus will not be considered.

The monetary cost to the public was calculated as the additional taxes that would be paid on the fuel consumed. This is exactly the same as the tax revenue that would be given to the CCEMF, calculated above, and would be approximately $150 million per year. This is a very large amount of money to be borne by the public sector, however, at current diesel prices, this amounts to only a 3.4% increase in the total fuel price, and so should not be unmanageable. Still, because this cost was higher than that of the other evaluated policy options, it was scored as **very low**.

Freedom of Choice

This policy does not limit people's choices or freedoms in any way, as it imposes no restrictions. Therefore, the Freedom of Choice for this policy was scored as **high**.

7.2. Option 2: require heavy trucks to use Auxiliary processing units

Effectiveness

GHG Reduction

The fuel and GHG savings achieved through the use of an APU will depend on the behaviour of the driver of the truck, as the more time the driver tends to idle the vehicle (purposefully), the greater the fuel and GHG savings that can be expected. Transport Canada commissioned a field test in 2006 to determine the typical fuel savings from the use of an APU, and estimate that annual fuel savings for a typical truck operating in Canada and the U.S. would be approximately 2400 L/year.

To estimate the number of trucks that would be required to install APUs with this policy, the size of Alberta's heavy truck fleet, which was approximately 84,700 vehicles in 2009 (Transport Canada, 2011), was multiplied by the proportion of the Canadian medium and heavy truck fleet estimated to be under 3 years of age in 2009 (20.6%; NRCan, 2011). This resulted in an estimate of approximately 17, 500 trucks being fitted with APUs, which is predicted to result in a 52 million L reduction in fuel, and a resulting reduction of approximately 130 kt of GHGs per year. This number would continue to increase, however, as new trucks are purchased each year. Assuming that 1/3 of the number of trucks under 3 years of age are new, this means that an additional 33% of GHG savings will be added each year as new trucks are purchased (approximately 40 kt increased savings each year). However, it should be noted that as the fuel efficiency of large trucks continues to increase, this will reduce the fuel savings somewhat. Overall, while the average GHGs savings are difficult to estimate on a yearly basis, this measure was scored as **high**.

Implementation speed

The implementation of the APU requirement will take a bit of time. After legislation (for both the regulation and the weight exemption), a fund would have to be set in order to provide financing for truck owners. In addition, there would need to be a reasonable grace period before the regulation comes into effect, to give truck drivers and companies time to apply for and receive financing, and organize the installation of APUs. It is hard to imagine implementation occurring much before 1-1.5 years after the announcement of the policy. Therefore, this measure received a score of **low**.

Government Affordability

Up-front Affordability

The up-front costs to government for this policy would be steep, as the GoA would have to provide funds to cover 50% of the installed APUs before the policy is even implemented. Using estimates from Transport Canada's (2011b) APU calculator, a typical APU costs $8500 to purchase and install. Assuming, as above, that approximately 17,500 trucks would qualify for rebates, this would cost the GoA almost $75 million during the first year of implementation. This measure is therefore rated as **very low**.

Long-term Affordability

There would be considerable upkeep costs for this policy, in addition to the up-front costs, as new trucks are purchased each year, and therefore require access to financing. Assuming, as above, that 1/3 of the 17,500 trucks under 3 years old were purchased new in 2009, this indicates that almost 6,000 trucks per year would require additional financing. This means the government would have to pay out approximately $25 million each year after the first.

However, this maintenance cost would be reduced over time, as previous loans are paid back. In the long term, the net costs to the government would balance out to approximately zero, assuming the policy continues in perpetuity (excluding the up-front cost). However, a net present value calculation of the cash flow using a 5% discount rate indicates the long-term cost to be approximately $2 million (Appendix H). Therefore, this measure was scored as **medium**.

Administrative Simplicity

There would be several administrative costs as a result to this policy. The government would need to negotiate or organize money to provide in loans. The bulk of the administrative costs would be for administration of loans, and making sure they were paid back, and ensuring that those who qualified for the rebates made the requisite purchases, etc. The administration costs would be highest in the first year, and decrease over time until stabilizing in the long term. However, there will always be administrative costs each year the policy is in operation in order to give out new loans and maintain them. Therefore, the administrative simplicity for this program was scored as **low**.

Political Acceptability

Public Affordability

The initial cost to truck owners of this policy would be quite substantial, and be approximately the same as the costs to the government, approximately $75 million. However, at the 2012 average price for diesel in Alberta of $1.10 per L, and a typical savings of 2400 L per year per truck, the savings on fuel would be expected to be approximately $45 million. After accounting for loan payments to the GoA ($15 million), this policy would cost freight truck owners in the province approximately $45 million during the first year of implementation.

However, the following year and for years after, truck owners (from the first year of installation) would continue to save $45 million per year on fuel, while only paying $15 million to the GoA in loan repayments. Therefore, after a few years, the costs to individual truck drivers would be negative, as after all loans were paid off, and initial capital loss was compensated through savings, they would still be saving money each year from reduced fuel consumption. A discounted cash flow analysis indicates that using a discount rate of 10%, and assuming an annual $500 maintenance cost per APU, it would take just over 4 years for a truck owner to pay off the cost of one APU (Appendix I). The un-discounted payback period would be slightly over 3 years. However, after payback, truck owners stand to realize substantial monetary gains of almost $2200 per year per truck (undiscounted).

Because the up-front costs are heavy, but long-term monetary savings on fuel are quite substantial after a relatively short period of time, this measure was scored as **medium**.

Freedom of Choice

This policy forces truck owners to make purchases that they otherwise may not have. Therefore, it definitely impacts the owners' ability to make decisions for themselves. However, the use of APUs is unlikely to affect people's behaviour significantly after they are installed, and so the impact is not long lasting. Regulatory requirements are common in many different economic sectors, often relating to safety, and are generally considered acceptable and/or necessary by society. Therefore, the impact on Freedom of Choice is scored as **medium**.

7.3. Option 3: require heavy trucks to use speed limiters

Effectiveness

GHG Reduction

GHG savings from speed limiters is based on the expected reduction in fuel consumption from being forced to drive at slower speeds. Exactly how much fuel is saved depends on the speed the truck would otherwise be travelling. Transport Canada (2007) reports province-specific estimates of the proportion of trucks weighing > 11,000 kg travelling at several different ranges of speed. Using these data, combined with Alberta Transport's highway traffic data for 2011, and savings calculations provided by

Transport Canada (2007), I calculated the expected fuel savings from restricting the maximum speed of heavy trucks to 105 km/h (see Appendix J for a list of assumptions). This worked out to a savings of approximately 16 million L of fuel per year, which translates to an annual reduction of over 40 kt of GHGs. This measure was therefore scored as **low**.

Implementation speed

Little time would be required to implement this law, as speed limiters should already be present in Alberta's heavy truck fleet. They simply need to be engaged, and if the GoA provided 2-3 months before enforcement to allow truck owners to have their vehicles serviced, this should be ample time. This measure is thus rated as **high**.

Government Affordability

Up-front Affordability

This policy requires would involve no up-front capital costs to the GoA, and so this measure was scored as **high**.

Long-term Affordability

Similarly, there would be no ongoing capital costs. This measure was scored as **high**.

Administrative Simplicity

While there are no capital costs to this policy, there would be some small administrative costs associated with enforcement. Vehicle inspection centres would need to be equipped with the electronic devices necessary to determine if heavy trucks have their speed limiters engaged, so that they could be checked during their yearly inspections. Additionally, some police officers may also need to be equipped with these devices so that heavy trucks pulled over for speeding could be checked. However, it is unlikely that additional inspection staff or police officers would be required to enforce this policy. Therefore, because total administrative costs are likely to be small, this measure received a score of **medium**.

Political Acceptability

Public Affordability

The public costs associated with this policy would be minimal. While truck owners would either have to purchase the equipment necessary to engage speed limiters, or have their vehicles serviced by a mechanic, they would also save money on fuel as a result of this policy, approximately $18 million per year. It therefore seems likely that the net cost to the public would be very low, if not negative, and in future years there would certainly be net savings as a result of this policy. Therefore, Public Affordability was deemed to be **high**.

Freedom of Choice

This policy would restrict the ability of drivers to drive at the speed they desire, and so this definitely limits the choices they can make while driving. Some members of the industry are of the opinion that limiting the maximum speed decreases safety for truck-drivers and those around them (Transport Canada, 2008b). Further, in July 2012, an Ontario Superior Court judge ruled that the speed limiter law was unconstitutional, as it limits the drivers' ability to ensure their own safety by restricting driving speeds. This ruling is being challenged by Ontario's Ministry of Transportation, who is hoping to have the issue cleared up by the Supreme Court.

Transport Canada (2008c), on the other hand, has concluded that in low-traffic scenarios, speed limiters actually increases safety. Since making speed limiters mandatory for large trucks, the UK has seen a 26% decrease in the number of accidents involving vehicles with trailers. Similarly, Ontario's Ministry of Transportation's (2010) Safety Report indicates the lowest number of fatal accidents where heavy trucks were involved in a decade, following the introduction of their speed limiter law.

So, because there are potential safety concerns surrounding this issue, and the fact that this policy would limit truck driver's behaviour, this measure was scored as a **low,** even though the effect on drivers' behaviour is likely to be fairly small.

7.4. Option 4: Require an annual average of 4% biodiesel in Alberta's diesel pool

Effectiveness

GHG Reduction

As discussed, biodiesel is able to reduce net GHGs throughout its lifecycle, rather than during combustion. Therefore, the net GHG reduction can thus vary heavily depending on how it is produced, and the type of organic material used. According to GenSolutions (2007), the most likely materials for manufacturing biodiesel in Alberta are canola, beef tallow, pork lard, and dairy waste. The International Energy Agency conducted a review of over 60 studies, and report that first-generation biodiesel made from rapeseed (or Canola) has emission reductions ranging from 20%-80% (IEA, 2011). As they do not report expected emissions reductions from animal fats, the average estimate of 50% for canola biodiesel was used to estimate GHG reductions.

In 2010, Alberta's GHGs that resulted directly from diesel fuel consumption in the transportation sector amounted to 12.8 Mt CO_2e. Alberta already requires, as of mid-2011, that biodiesel must compose at least 2% of the diesel pool. Therefore, the proposed regulations would require only an additional 2% biodiesel composition. As biodiesel costs more to produce than petroleum diesel, the increased proportion of biodiesel would drive fuel prices up, which would slightly reduce quantity demanded. With the assumption that 50% of the GHGs from this 2% are reduced, this suggests that the reduction in GHGs from this policy would amount to approximately 1% of the GHGs produced from diesel fuel. After including the reduced fuel consumption due to the higher price (see Public Affordability), the total GHG saving works out to approximately 190 kt CO_2e per year (Appendix K).

While this option is expected to reduce GHGs almost as well as Option 1 or 2, there is more uncertainty surrounding this estimation than the other measurements. This is because of the myriad of factors that could reduce the life-cycle GHG reductions of biodiesel fuel such as possible deforestation, imports of fuel and inputs to biodiesel, and possible emissions displacement. Assumptions for other estimations have been conservative, but determining whether the assumptions made for biofuel GHG savings are conservative is difficult, given the breadth of evidence, opinion and speculation in the literature. Therefore, I decided to estimate this measure as **medium** in order to reflect the high degree of uncertainty surrounding this measurement.

Implementation Speed

The increased biodiesel requirement may take considerable time to implement after the regulation is first proposed. If additional Canola oil needs to be produced, farmers will need time to increase production capabilities. Biodiesels producers in the province or other provinces will likewise need time to respond to the regulated increase in demand, and petroleum diesel manufacturers will need to secure a supply of biodiesel from the producers. Manufacturers will also need to determine optimal geographical and temporal distribution of diesel with different concentrations of biodiesel in order to minimize biodiesel inclusion during winter months.

When B.C.'s biodiesel mandate came into effect, it was phased in incrementally over a couple of years, in order to provide time for all these things to occur before the mandate was enforced. Given that it would make sense for Alberta to follow a similar timeline, this pushes the implementation time to at least two years, and would take considerably longer than any of the other measures to implement. Therefore, this measure was rated as **very low**.

Government Affordability

Up-front Affordability

This policy does not require up-front funding from the government. As no additional subsidy to biofuel manufacturers is being provided, there are no new capital costs introduced through this measure. It was therefore scored as **high**.

Long-term Affordability

As with the Up-front Affordability, there are no long-term capital costs to the GoA, therefore, this measure was also rated **high**.

Administrative Simplicity

The administrative costs related to this program would be fairly significant. Considerable government oversight would be required to make sure that the necessary amount of biodiesel was included in Alberta's annual diesel pool. While oversight must already be in place to enforce Alberta's 2011 biofuel requirement, it is likely that additional resources would need to be applied due to the increased complexity of having to manage which regions get higher or lower proportions of biodiesel and when. These administrative costs would be long-term, because management of fuel proportions would have to continually be re-optimized as Alberta's economic landscape continues to change. Therefore, this measure was scored as **low**.

Political Acceptability

Public Affordability

In general, biodiesel is more expensive to produce than petroleum diesel (Laan et al., 2011). Therefore, the increased biodiesel component of the diesel pool will result in a net cost to owners of diesel-powered vehicles, both passenger and freight. Similar to the variability in emission savings, the cost of production varies with the production method and input material. Laan et al. (2011) looked at subsidies received by Canadian biofuel producers between 2006-2008, and determined that in order to make biodiesel economically competitive with petroleum diesel, a subsidy of \$0.62-\$1.28 per L was required. This would indicate, that, on average, biodiesel costs about \$0.97 more per litre than petroleum diesel to produce. At this price, the 2% increase in biodiesel is estimated to increase the retail price of diesel at fueling stations by almost \$0.02/L (Appendix K). Estimated from the total diesel energy consumption reported by NRCan, Alberta's transportation sector (including both passenger and freight) consumed approximately 5 billion L of diesel in 2010. After adjusting this value for reduced quantity demanded due to the change in price, the increased cost to diesel-vehicle owners would be about \$90 million per year. Therefore, this measure was rated as **very low**.

Freedom of Choice

This policy would have a marginal effect on peoples' choice, because it forces people to use a higher proportion of biodiesel than they otherwise might have. While this may not seem like an issue for most people, it may well matter for some vehicle owners. Some studies have found that including biodiesel into the diesel fuel mix reduces engine performance in winter months. Additionally, biodiesel may wear on rubber engine parts faster than petroleum diesel. Therefore, there are valid reasons that people may wish to avoid consuming biodiesel. Given however that most diesel engines are warrantied to use up to 5% biodiesel, however, this issue is largely moot.

A final concern is that the environmental benefits from using biodiesel vary greatly among different production methods and inputs, with a possibility for a net *increase* in GHGs (IEA, 2011), and therefore some people may not support its inclusion in the diesel pool. Because of the relatively low, but non-negligible overall impact on choice, I scored this measure as **medium**.

7.5. Quantitative comparison of policies

In order to determine the post-evaluation ranking of policies, numerical scores were given to each measure. Measures that were deemed to be "very low" received a score of 1, "low" received a score of 2, "medium" received a score of 3, and "high" received a score of 4. Because the criteria had different numbers of measures, the score of each criterion was taken as a weighted average of the scores of each measure. All measures were given equal weight, except for Administrative Simplicity, which was given ¼ of the weight of the Government Affordability criterion. This measure was deemed less important than the other two, which each composed 3/8 of the total value of that criterion. For all criteria and measures, a high score is better than a low score.

Table 2 shows the weighted average scores for each criterion, as well as the overall scores for each policy. A table showing the component scores of each measure can be viewed in Appendix L.

Table 2. Average scores for each criterion and overall score for all policy options

Criterion	Option 1: fuel tax increase	Option 2: APU regulations	Option 3: Speed limiter regulations	Option 4: biodiesel increase
Effectiveness	4.00	3.00	3.00	2.00
Government Affordability	3.63	2.00	3.75	3.50
Political Acceptability	2.50	3.00	3.00	2.00
Overall Score	10.13	8.00	9.75	7.50

8. Recommendations and conclusions: What next?

8.1. Option evaluation comparisons

From Table 2 we can see that two policy options are nearly tied for the highest score: Option 1, the heavy truck fuel tax, and Option 3, the speed limiter requirements. Both scored substantially better than either of the other two options. Option 2, the APU requirement, scored particularly poorly on the Government Affordability criterion. Its high up-front costs and administrative complexity made it the most expensive option by a wide margin. Option 4, increased biodiesel, scored poorly in both effectiveness and political acceptability. Effectiveness scored very low because of the uncertainty of the net GHG reduction that would result and because of the long implementation time. Political acceptability scored low because of the substantial costs to owners of diesel-powered vehicles.

Options 1 and 3 had very similar scores, but for different reasons. Option 1 scored very highly for effectiveness, but rather low on political acceptability. Option 3 was more in between, scoring reasonably well for both effectiveness and political acceptability. Thinking outside of the measures used in the analysis, Option 3 should be readily politically acceptable as this policy reduces both private costs and GHGs, creating a “win-win” solution. All other things equal, such win-win solutions are likely to be more politically acceptable than other policies.

Several other weighting schemes were tested, and these were not observed to change the rankings of policy options. Only large changes to the weighting of criteria (rather than measures), such as double-counting political acceptability or effectiveness were found to provide reasonable distinction between the scores of Options 1 and 3, and no change in weighting was found to make Options 2 or 4 increase in ranking. Therefore, I concluded that, while Option 1 scored slightly higher, the difference in score between Options 1 and 3 was small enough to give equal consideration to both options, while rejecting Options 2 and 4.

8.2. Short-term recommendations

Because Options 1 and 3 cannot be easily distinguished using the multi-criteria analysis conducted, both should be considered for near-term implementation. Each of these options could be implemented quickly, as neither requires new bureaucratic infrastructure or significant monetary investment by the government. Additionally, these policies could both be implemented simultaneously, and may even work to complement each other. While the increased fuel tax would inevitably be a financial burden on drivers of heavy trucks, the mandatory use of the speed limiters will reduce the burden somewhat. Some drivers, who may have otherwise driven at speeds that did not maximize fuel efficiency, are forced to slow down, and in the process, save some money that they otherwise would have spent on fuel. Obviously there are distributional issues, as the tax would affect all truck drivers while the speed limiter regulations would only reduce costs for those who regularly travel above 105 km/h, but the net cost to truck drivers would be considerably less than if the tax was implemented by itself.

As well as any other short-term policies that may be implemented, I would also recommend putting in place a program to collect more data on road freight transportation in Alberta. Currently, Alberta does not record the number of trucks each industry uses, or the mass of freight transported by different industries. Without such information, it is difficult to target emission-reduction strategies within the road freight transportation industry. While estimating the mass of freight transported by each industry may take a considerable amount of resources, it would be much easier to figure out the number of trucks operating in each industry. If, for instance, Alberta were to require that commercial vehicles register the industry (or industries) which they primarily transport goods for, this would allow some simple estimations of the amount of freight transported for each industry. This would also be aided by requiring registered commercial vehicles to report an estimate of the vehicle km travelled in the province in the preceding year. Collecting data during the annual vehicle registration would minimize associated administration costs and simplify requirements for vehicle owners. Regardless of the specific implementation, more effort should be put towards collecting data on freight transportation so that future policies can be better informed about the underlying freight transportation demand within the province.

The final short-term recommendation also pertains to data collection. A surprising result from my analyses was that public transit buses emit nearly as many GHGs per passenger-km as cars (60-90%), across all provinces. In order to figure out why this is the case, I would recommend exploring additional data collection mechanisms for public transit in Alberta, or at least attempting to disaggregate the data to a sub-provincial level. It would be interesting to compare data between large and small cities (which likely have fewer passengers per transit vehicle) to see if there was a big difference in per passenger-km GHGs. It is possible that in smaller cities where ridership is low, the per passenger-km GHGs are actually higher than those of cars, and if so, then this may lead policymakers in future to re-evaluate where and to what extent public transit is beneficial for GHG reductions[6].

8.3. Long-term recommendations

All solutions presented here are short-term, stop-gap solutions that barely scratch the surface of the issue of GHG emissions from Alberta's transportation sector. For example, the fuel tax, one of the two options determined to be the most effective at reducing GHGs, is expected to reduce emissions by approximately 270 kt per year. While this may seem large, such a reduction represents only a small fraction of total emissions: in 2010, Alberta's road transportation sector emitted almost 25 Mt of GHGs, meaning that the most effective measure proposed here would reduce the transportation sector's emissions by only ~1%. And when one considers that transportation emissions compose only 16% of Alberta's total annual GHGs, the reduction achieved by this policy appears small indeed. While this would be a good start, it is hardly enough to make a difference to any of the problems, local or global, caused by GHGs.

[6] Public transit indeed serves other purposes, such as providing transportation for those who cannot afford vehicles, reducing congestion etc. The relative decrease in per passenger-km GHGs will also depend on the fuel mix of public transit, which could be altered to further reduce GHGs.

Similarly, the upcoming federal regulations will complement my proposed policies, but not at the scale necessary for significant reductions. Although no province-specific estimates for emission reductions are available, the federal government has estimated that these regulations will reduce emissions by 19 Mt over the lifetime of vehicles purchased between 2014-2018 in Canada (Canada Gazette, 2012). Spread across 10 provinces, 3 territories, and an expected 30-year life-span for the effected vehicles, these regulations will also have only a minor impact on transportation emissions.

Despite the relatively small impact of the policies proposed in this paper, they would be an important contributor to long-term reduction in transportation GHGs. They are pragmatic, short-term solutions that are stepping stones on the way to stronger policies, and they would help to distribute GHG reductions to a sector of Alberta's economy that is not usually in the spotlight. Without taking small steps, the public is unlikely to accept the larger measures necessary to effectively deal with climate change in the future.

In order to make a major reduction in road transportation GHGs, the focus of Alberta's future policies needs to be on two things: curbing emissions from the freight sector, and reducing GHG intensity of the electricity generation sector. Alberta has more road freight transportation emissions per capita and per GDP than any other province than Saskatchewan. This is clearly a huge driver behind the high emissions from the aggregate road transportation sector. It therefore seems likely that in order to make significant reductions in this sector, the proposed fuel tax will have to be increased in size and scope. This policy, unlike the others suggested, affects all parts of the decomposition equation (activity, structure, fuel efficiency, fuel mix, and greenhouse gas intensity), and so is more likely to be effective than the other policies in the long run. As a short-term policy option it was designed to be intentionally narrow in order to target the worst GHG emitters in the transportation sector and to minimize political opposition. However, the proposed tax is low compared to other jurisdictions (such as B.C., which has a carbon tax that is currently double the rate proposed here) and so should be increased in size in future, in order to increase its effects. Additionally, increasing its breadth, perhaps making it generally applicable to all forms of transportation instead of just heavy trucks, would also help to increase its efficacy. The issue is to get the tax in place without causing large public outcry. Hence, I would suggest phasing it in over time, and use the above recommended fuel tax as a spring-board for a more broadly applicable tax.

A final long-term recommendation is a shift away from coal-powered electricity production. Hydrogen fuel cell vehicles and electric vehicles are recognized as the most viable long-term solutions for reducing transportation emissions (Hill et al., 2009), but neither is currently a viable option for Alberta because of how electricity is generated in the province. Neither will reduce Alberta's transportation emissions while electricity generated at a coal plant generates more GHGs on a per joule basis than the combustion of gasoline. While other solutions suggested in this paper will help to reduce emissions, they simply are not scalable to the point of reducing emissions by half (for example) or more. In the long run, Alberta (and other jurisdictions) will need to adopt technologies that dramatically reduce emissions without relying on unrealistic behavioural changes that would significantly reduce material well-being. Demand for transportation increases with population size, and it is unlikely that behavioural and simple efficiency modifications will be enough to substantially reduce emissions. Therefore, given the technology currently available, it will be extremely difficult to eliminate a substantial portion of the emissions produced by Alberta's transportation sector without first addressing the issue of electricity generation.

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Appendices

Appendix A.

GHG intensity of fuels used in passenger transportation from 1990-2010 in Alberta. Measured in Kt CO2e per PJ of fuel consumed. Values are very similar to B.C. + Territories and Quebec.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Electricity	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	65.2	64.6	64.4	64.0	62.0	65.7	65.2	63.0	61.6	62.5	62.6
Motor Gasoline	69.3	69.7	69.8	70.3	70.5	70.6	70.8	70.9	70.2	70.2	70.1
Diesel Fuel Oil	69.7	69.7	69.8	69.8	69.8	69.8	69.9	70.0	70.7	70.8	70.8
Ethanol											
Biodiesel Fuel	60.0	60.0	60.0	60.0							
Propane	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.5	60.5	60.5

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electricity	0	0	0	0	0	0	0	0	0	0
Natural Gas	59.3	57.1	60.2	60.4	55.8	58.9	60.7	56.9	59.1	58.9
Motor Gasoline	70.2	70.2	70.2	69.7	69.3	68.9	68.5	68.2	67.8	67.6
Diesel Fuel Oil	70.8	70.8	70.8	70.8	70.9	70.8	70.8	70.8	70.8	70.9
Ethanol										
Biodiesel Fuel										
Propane	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5	60.5

Appendix B.

Fuel mix of passenger transportation fuels in Alberta from 1990-2010, measured as a percentage of total fuel consumption for each year by passenger vehicles. B.C. + Territories show similar trends.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Electricity	0.2%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Natural Gas	0.8%	0.7%	0.6%	0.5%	0.3%	0.7%	0.5%	0.6%	0.5%	0.3%	0.3%
Motor Gasoline	89.0%	88.0%	88.1%	90.9%	90.1%	90.1%	89.6%	90.4%	91.2%	92.0%	92.3%
Diesel Fuel Oil	5.8%	6.6%	6.2%	6.0%	6.1%	5.6%	5.8%	5.8%	5.5%	5.4%	5.4%
Ethanol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel Fuel	0.7%	0.7%	0.6%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propane	3.6%	4.0%	4.4%	2.0%	3.4%	3.5%	3.8%	3.0%	2.6%	2.2%	1.7%

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electricity	0.2%	0.3%	0.4%	0.4%	0.4%	0.3%	0.3%	0.2%	0.3%	0.3%
Natural Gas	0.1%	0.1%	0.2%	0.2%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%
Motor Gasoline	93.1%	93.2%	93.1%	92.9%	93.3%	94.2%	94.1%	93.9%	93.9%	93.5%
Diesel Fuel Oil	5.0%	5.1%	5.1%	5.3%	5.3%	4.5%	4.8%	5.2%	5.1%	5.6%
Ethanol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel Fuel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propane	1.6%	1.3%	1.2%	1.2%	0.9%	0.8%	0.6%	0.5%	0.6%	0.4%

Appendix C.

Passenger transportation activity mix in Alberta from 1990-2010 for each mode of passenger transportation. Measured as a proportion of the total passenger activity reported for each year (measured in passenger-km).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Car	62.7%	62.5%	62.0%	62.2%	60.8%	59.2%	58.8%	57.0%	55.7%	54.7%	53.6%
School Bus	6.8%	6.6%	7.0%	5.8%	5.9%	7.0%	6.3%	6.0%	6.3%	6.4%	6.9%
Urban Transit Bus	5.1%	5.2%	4.5%	4.6%	4.5%	4.2%	4.0%	3.9%	3.5%	3.7%	3.8%
Inter-City Bus	3.3%	3.2%	2.9%	2.8%	2.9%	3.3%	2.8%	3.1%	2.8%	2.6%	2.6%
Motorcycle	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Light Truck	21.6%	22.1%	23.2%	24.2%	25.4%	26.0%	27.7%	29.6%	31.3%	32.3%	32.7%

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Car	54.2%	53.2%	51.9%	51.4%	50.3%	50.2%	50.5%	49.4%	48.3%	46.5%
School Bus	5.7%	5.7%	6.8%	6.3%	6.6%	8.0%	6.4%	7.0%	8.0%	8.7%
Urban Transit Bus	4.0%	4.3%	4.5%	5.0%	5.1%	5.0%	4.3%	4.6%	5.0%	5.4%
Inter-City Bus	2.4%	2.5%	2.3%	2.2%	2.4%	1.9%	2.2%	2.2%	1.9%	1.7%
Motorcycle	0.5%	0.6%	0.7%	0.7%	0.8%	0.8%	0.9%	0.9%	0.8%	0.8%
Light Truck	33.2%	33.6%	33.8%	34.3%	34.8%	34.1%	35.8%	35.9%	36.1%	36.9%

Appendix D.

GHG intensity of different modes of passenger transportation in Alberta from 1990-2010. Measured in kg of CO_2e per passenger-km travelled.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Car	0.173	0.169	0.163	0.161	0.159	0.157	0.154	0.150	0.148	0.147	0.146
School Bus	0.059	0.060	0.057	0.055	0.054	0.051	0.049	0.048	0.046	0.045	0.043
Urban Transit Bus	0.125	0.135	0.139	0.127	0.127	0.133	0.125	0.119	0.129	0.121	0.125
Inter-City Bus	0.070	0.075	0.070	0.067	0.063	0.060	0.061	0.062	0.061	0.057	0.056
Motorcycle	0.101	0.101	0.101	0.101	0.101	0.101	0.100	0.100	0.100	0.100	0.100
Light Truck	0.243	0.230	0.220	0.217	0.215	0.214	0.212	0.211	0.209	0.208	0.207

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Car	0.144	0.142	0.138	0.137	0.135	0.133	0.131	0.130	0.129	0.127
School Bus	0.042	0.040	0.039	0.037	0.035	0.030	0.036	0.038	0.032	0.030
Urban Transit Bus	0.114	0.113	0.112	0.108	0.105	0.092	0.117	0.117	0.110	0.109
Inter-City Bus	0.057	0.055	0.055	0.054	0.053	0.060	0.054	0.058	0.049	0.054
Motorcycle	0.090	0.086	0.086	0.086	0.079	0.079	0.077	0.077	0.116	0.116
Light Truck	0.205	0.204	0.202	0.201	0.198	0.195	0.192	0.189	0.186	0.184

Appendix E.

Fuel mix of freight transportation fuels in Alberta from 1990-2010, measured as a percentage of total fuel consumption for each year by freight vehicles.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Motor Gasoline	42.9%	43.2%	46.3%	43.8%	40.5%	37.5%	39.0%	35.4%	35.0%	36.9%	33.9%
Diesel Fuel Oil	50.4%	49.4%	45.3%	52.6%	54.5%	57.9%	56.6%	60.9%	61.8%	60.7%	64.3%
Ethanol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel Fuel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propane	6.7%	7.4%	8.4%	3.6%	5.0%	4.6%	4.5%	3.7%	3.1%	2.3%	1.8%

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Natural Gas	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Motor Gasoline	32.2%	31.6%	30.4%	31.7%	30.6%	30.1%	28.4%	27.9%	26.0%	24.2%
Diesel Fuel Oil	66.1%	67.1%	68.5%	67.4%	69.0%	69.1%	71.0%	71.5%	73.5%	75.4%
Ethanol	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biodiesel Fuel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Propane	1.7%	1.3%	1.1%	0.9%	0.4%	0.8%	0.5%	0.5%	0.5%	0.3%

Appendix F.

Freight transportation activity mix in Alberta from 1990-2010 for each mode of freight transportation. Measured as a proportion of the total freight activity reported for each year (measured in tonne-km).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Light Truck	13.6%	14.5%	17.0%	12.7%	11.2%	10.7%	9.6%	10.3%	9.9%	8.6%	8.0%
Medium Truck	16.2%	17.2%	20.0%	16.5%	14.5%	14.8%	14.2%	11.5%	11.2%	12.4%	9.7%
Heavy Truck	70.2%	68.3%	63.1%	70.8%	74.3%	74.5%	76.2%	78.2%	79.0%	79.0%	82.3%

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Light Truck	8.0%	8.1%	7.7%	6.5%	6.7%	6.4%	6.7%	7.0%	7.0%	6.1%
Medium Truck	8.6%	7.7%	8.8%	10.2%	8.9%	10.5%	9.4%	9.2%	8.3%	8.8%
Heavy Truck	83.4%	84.2%	83.5%	83.2%	84.4%	83.1%	83.8%	83.9%	84.7%	85.1%

Appendix G.

Assumptions and calculations used to estimate costs and GHG savings achieved through a fuel tax for heavy trucks.

$1.11/L	2012 Avg. Alberta diesel price
150.5	PJ consumed in 2010 by heavy trucks
150,537,396,000	MJ consumed
4,197,919,576	L consumed
38.68	MJ/L energy density of diesel fuel
$4,678,772,182	2012 estimated fuel costs
10.7	Mt GHGs produced by heavy trucks

$0.04106	Carbon tax (per L)
3.68%	Proportional price increase of new tax
-0.3	Elasticity of freight fuel demand
-1.11%	% change in fuel consumption

148.8735424	PJ - New fuel consumption
3,848,850,631	L - New fuel consumption

1.664	PJ - Fuel reduction
46,398,594	L - Fuel reduction

0.117756429	Mt GHG reduction

118	**kt GHG reduction from reduced fuel consumption**

$158,044,103.57	Taxes collected

158	**kt GHGs abated through CCEMF, assuming $1000/tonne of abatement**

Appendix H.

Example cash flow calculations for the GoA for the proposed APU policy. Cash flow for years 8+ are not shown, as additional annual costs remain at zero extending indefinitely. NPV for several discount rates is reported.

Discount rate		5%		
Year	0	1	2	3
Discount factor	1	0.9524	0.9070	0.8638
Loans paid out	$74,154,850	$24,718,283	$24,718,283	$24,718,283
Loans paid back	$0	$14,830,970	$19,774,627	$24,718,283
Undiscounted cost	$74,154,850	$9,887,313	$4,943,657	$0
Discounted cost	$74,154,850	$9,416,489	$4,484,042	$0
Year	4	5	6	7
Discount factor	0.8227	0.7835	0.7462154	0.7107
Loans paid out	$24,718,283	$24,718,283	$24,718,283	$24,718,283
Loans paid back	$29,661,940	$34,605,597	$24,718,283	$24,718,283
Undiscounted cost	-$4,943,657	-$9,887,313	$0	$0
Discounted cost	-$4,067,159	-$7,746,969	$0	$0
Undiscounted NPV after 10 years (excluding year 1)	**$0.00**			
Discounted NPV after 10 years (excluding year 1)	**-$2,086,404**			
2009 Heavy Truck count	84700			
Proportion of trucks < 3 years old	21%			
Initial trucks requiring loans	17448			
Annual additional trucks requiring loans	5816			
APU Cost	$8,500			
Loan Value per truck	$4,250			
Loan payback period (years)	5			

NPV after 10 years

Discount rate	NPV
0%	$0
3%	-$1,337,946
5%	-$2,086,404

Appendix I.

Example cash flow analysis for a truck owner for the first five years following an APU purchase. Following the example cash flow is a table that shows the payback periods for several different discount rates and maintenance costs for APUs.

Discount rate	10%					
Annual maintenance costs	$500					
Year	0	1	2	3	4	5
Discount factor	1	0.9091	0.8264	0.7513	0.6830	0.6209
Cost of APUs	$8,500	$0	$1	$2	$3	$4
Loans paid back	$0	$850	$850	$850	$850	$850
Maintenance costs	$0	$500	$500	$500	$500	$500
Money received from gov't	$4,250	$0	$1	$2	$3	$4
$ saved on fuel	$0	$2,675	$2,675	$2,675	$2,675	$2,675
Undiscounted cash flow	-$4,250	$1,325	$1,325	$1,325	$1,325	$1,325
Cumulative undiscounted cash flow	-$4,250	-$2,925	-$1,600	-$275	$1,050	$2,375
Discounted cash flow	-$4,250	$1,204	$1,095	$995	$905	$823
Cumulative Discounted cash flow	-$4,250	-$3,046	-$1,951	-$955	-$50	$772
Undiscounted NPV (10 years)	**$13,249.09**					
Discounted NPV (10 years)	**$5,891.71**					
Undiscounted NPV (5 years)	**$2,374.55**					
Discounted NPV (5 years)	**$772.45**					

Payback period (in years) for a variety of discount rates and annual maintenance costs

	Annual maintenance costs		
Discount rate	$0	$500	$1,000
0%	2.3	3.2	5.1
5%	2.5	3.6	5.5
8%	2.7	3.9	5.9
10%	2.8	4.1	6.2
15%	3.1	4.7	7.2

Appendix J.

Assumptions used to estimate fuel savings from the introduction of a speed limiter use requirement in Alberta, reducing maximum speed of heavy trucks to 105 km/h.

Average heavy truck fuel consumption	33.1	L/100km

Transport Canada's (2007) estimates of the proportion of trucks traveling at various speeds on Alberta's highways

Speed (km/h)	100 km/h highways	110 km/h highways
< 105	69.7%	44.4%
< 110	22.5%	26.5%
< 115	6.0%	18.9%
< 120	1.3%	7.3%
120+	0.5%	2.9%

Total vehicle km travelled by heavy trucks in 2011 (Alberta Transportation, 2012)	2,405,517,334
Assumed proportion of travel on 100 km/h highways	90%
Assumed proportion of travel on 110 km/h highways	10%

Fuel Savings Assumptions from Transport Canada (2007)

Speed (km/h)	Assumed speed	Extra fuel consumption
< 105	105	0.0%
< 110	107.50	2.5%
< 115	112.5	11.0%
< 120	117.5	22.5%
120+	122.5	40.0%

Appendix K.

Assumptions and calculations used to estimate GHG savings and monetary costs of the increased biodiesel policy.

Assumptions

Biodiesel price increase relative to petroleum diesel (per L of diesel)	$0.97	/L
Original retail price of diesel	$1.11	/L
Fuel consumption price elasticity	-0.3	
Alberta Diesel Emissions (2010)	12.84	Mt
Additional biodiesel component	2%	
Emissions savings %	50%	
Total 2010 diesel consumption	181.4	PJ
J to L conversion for Diesel	38.68	MJ/L

Calculations

Proportional price increase	1.74%
Change in fuel consumption based on elasticity	-0.52%
Price-adjusted demand emissions	12.77

GHG reductions from use of biodiesel	0.13	Mt
GHG reductions from reduced demand	0.07	Mt
Total GHG reductions	194.81	kt

New retail price of diesel = 0.02 * ($0.97 + $1.11) + 0.98 * ($1.11)	$1.13

Total 2010 diesel consumption	4,690,775,698	L
Elasticity-adjusted consumption	4,666,281,125	L
Extra $ paid from higher cost	$90,525,854	

Appendix L.

Detailed scoring matrix showing the component scores and average scores of each measure for each policy.

Criterion	Measure	Option 1: fuel tax increase	Option 2: APU regulations	Option 3: Speed limiter regulations	Option 4: biodiesel increase
Effectiveness	**Average Score**	4.00	3.00	3.00	2.00
	GHG Reduction	4	4	2	3
	Implementation Speed	4	2	4	1
Government Affordability	**Weighted Average Score**	3.63	2.00	3.75	3.50
	Up-front Affordability	3	1	4	4
	Long-term Affordability	4	3	4	4
	Administrative Simplicity	4	2	3	2
Political Acceptability	**Average Score**	2.50	3.00	3.00	2.00
	Public Affordability	1	3	4	1
	Freedom of Choice	4	3	2	3

Overall Score		10.13	8.00	9.75	7.50