OFF TRACK TO 2050?: A STUDY OF PRESENT AND FUTURE INTERURBAN TRANSPORTATION EMISSIONS IN BRITISH COLUMBIA, CANADA, RELATIVE TO ITS GREENHOUSE GAS REDUCTION TARGETS ACT OF 2007

by

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
NATURAL RESOURCES AND ENVIRONMENTAL STUDIES

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

FEBRUARY 2016

ABSTRACT

Carbon dioxide (CO_2) emissions from transportation contribute to anthropogenic climate change and are expected to increase significantly in the future. CO_2 emission inventories exist for various transportation modes at the global scale, but are rare at the subnational scale and even rarer for interurban (versus urban) transportation. In this dissertation, I present a detailed analysis of CO_2 emissions and emission factors for interurban transportation for the province of British Columbia (BC), Canada, and an analysis of a wide variety of emission scenarios for BC's interurban transportation system, comparing modelled emissions to the 2020 and 2050 greenhouse gas reduction targets set by the province's 2007 *Greenhouse Gas Reduction Targets Act.* Nine modes of transportation were included: passenger (private vehicles, ferries, aviation, intercity buses, trains) and freight (trucking, marine, rail, aviation). Annual CO_2 emissions from BC interurban transportation were approximately 11.2 Mt CO_2 in 2013, of which freight trucking was the greatest contributor with 48.5% of total CO_2 emissions. The second largest contributor was private vehicles (17.1% of total CO_2 emissions), while the third largest contributor was marine freight (16.8% of total CO_2 emissions). Of 106 scenarios modelling future changes to the interurban transportation system, only 15 were able to meet BC's 2050 emission reduction target, and only two were able to meet both the 2020 and 2050 targets (assuming interurban transportation had to meet the same emission reductions as prescribed for the economy as a whole). Only scenarios with the highest reduction rates were able to meet the reduction targets, and with every passing year, meeting them becomes more challenging.

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GLOSSARY

AADT	Average Annual Daily Traffic
BAU	Business-as-usual
BC	British Columbia
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEFRA	United Kingdom Department for Environment, Food, and Rural Affairs
EF	emission factor
g	gram
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
L	litre
LF	load factor
Mt	megatonnes = 10^6 tonnes
pa	per annum
Tonnes	1000 kilograms (kg)

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisor, Dr. Ken Wilkening. Without his tireless support and editing, this dissertation would not have been possible. I would also like to acknowledge my committee members, Dr. Balbinder Deo, Dr. Bill McGill, and Dr. Ron Thring, as well as the external examiner, Dr. Amy M. Kim of the University of Alberta. Thank you all.

I would further like to acknowledge the generous funding provided by the Pacific Institute for Climate Solutions (PICS) and the University of Northern British Columbia (UNBC), both of which helped me greatly in pursuing my studies and completing this dissertation.

CHAPTER 1: INTRODUCTION

1.1 Overview

Transportation of people is an integral part of the social fabric of modern societies, and transportation of goods is an integral part of modern economies. However, while transportation's positive benefits for society and the economy are undeniable, they also contribute significantly to anthropogenic climate change, one of the most pressing issues of modern times. Climate was not negatively impacted by the movement of people and goods in a significant way until the invention, between approximately 1800 and 1900, of modern means of transportation such as self-propelled ships, trains, and finally automobiles and airplanes (Bellis 2015). The impact of a human activity, such as transportation, on the climate is often expressed quantitatively through the amount of greenhouse gas (GHG) emissions produced by the activity, usually expressed in terms of carbon dioxide (CO_2) emissions. In general, the higher the GHG emissions of a given activity, the higher the climate impact.

In 1900, global emissions of CO_2 from fossil fuels were approximately 2.5 billion tonnes; between 1900 and 2008, they grew to approximately 32.5 billion tonnes CO_2 (United States Environmental Protection Agency 2013). Transportation now accounts for approximately 23% of global and 30% of developed country GHG emissions from fossil fuel consumption (International Transport Forum 2010). Thus, transportation is a major contributor to anthropogenic climate change.

A common step in assessing the climate impact of an activity is to begin with a GHG emissions inventory; in other words, a record of the amount of GHGs emitted into the atmosphere. The inventory contains the emissions for a given pollutant or set of pollutants originating from sources in a defined category, such as transportation, in a given geographical area (for example, global or national or local) over a given time span (the typical time frame is one year). An inventory usually also contains data to calculate the emissions. In addition, an inventory can include other emissions-related information or calculations such as emission factors (the amount of the pollutant emitted per unit activity). The objective of the research in this dissertation was to develop an emissions inventory for the transportation sector in British Columbia (BC) that could be used to answer various policy-related questions about BC's present-day and future transportation emissions.

There are two distinct types of transportation emissions inventories: top-down and bottom-up. Top-down inventories are based on large-scale, overarching ('top level') data, such as total fuel sales for a given jurisdiction, that are used to calculate emissions which are then allocated to the lower levels in some manner within the jurisdiction. Bottom-up inventories work in the opposite direction, so to speak. They start with small-scale, on-the-ground ('bottom level') data, such as fuel sales at each sales outlet within a jurisdiction, that are used to calculate emissions which are then summed up in some manner for the jurisdiction. My original intent for my dissertation research was to develop an entirely bottom-up emissions inventory for BC; however, because of the lack of fine-scale data for some of the modes of transportation considered, a top-down approach was also used.

There is value in compiling detailed, bottom-up inventories at local levels, such as the province of BC. They can, for example, provide policymakers with comprehensive information for making decisions. Despite their seeming advantages, there seem to be few detailed, multi-modal, bottom-up GHG emissions inventories of transportation systems at the local level. This may be because bottom-up inventories are difficult to compile and because there are few direct negative impacts of the major greenhouse gas, CO_2, at the local level as there are for air pollutants such as nitrogen oxides. However, high resolution GHG inventories at the local level may be of distinct benefit to policymakers in making local decisions regarding GHG emission reductions; for example, in channeling money for infrastructure into light rail instead of road building. For this reason, I decided to construct (as nearly as possible) a 'pure' bottom-up transportation emissions inventory for BC that may prove beneficial to BC policymakers.

Transportation systems, especially for 'large' local regions such as BC, can be divided into urban and interurban components. Urban transportation refers to transportation within cities and communities, while interurban transportation refers to transportation between cities and communities. For the purposes of inventorying and policymaking, it is valuable to disaggregate these two components because the nature of transportation can differ significantly between them. For instance, commuting is often a large part of urban transportation but less so for interurban transportation. Also, certain modes, such as air travel, are generally not applicable *within* an urban area (i.e., one does not generally fly between two destinations within a city). In addition, some policy approaches that can be used to reduce urban transportation emissions, such as encouraging the use of public transit or the creation of bike lanes, are generally not applicable for interurban transportation. Thus, while both urban and interurban transportation are important components of the transportation system, they are distinct and often require distinct policy approaches for emission reductions.

My research focuses solely on interurban transportation. Analyzing interurban transportation GHG emissions by itself can facilitate policymaking that is tailored specifically to the unique challenges and requirements of this component of the transportation system. While scholarly work has been done on local transportation GHG emissions, stand-alone treatment of interurban transportation GHG emissions has so far received little attention.

The jurisdiction chosen for my research on interurban transportation was the subnational level, specifically, British Columbia, Canada. There were two main reasons for choosing this location. First, BC is a very large 'local' jurisdiction. Despite being only a province, it is several times larger than many countries, such as Great Britain and Japan (BCRobyn 2013). BC has a comparatively small population of approximately 4.5 million residents (BC Stats 2013), of which approximately three million live in the Greater Vancouver and southern Vancouver Island areas in the southwest of the province. The remaining population is spread over the rest of the province. This means that interurban transportation of passengers and freight within the province is significant and, based on distances that have to be covered, generates significant emissions.

A second justification for focusing my research on BC is that the province in 2007 passed the *Greenhouse Gas Reduction Targets Act*, legislating highly ambitious GHG reduction goals—reducing emissions 33% below 2007 levels by 2020, and reducing emissions 80% below 2007 levels by 2050 (Parliament of British Columbia 2007). To achieve this goal and to motivate societal change, the province implemented a carbon tax in 2008 (British Columbia Ministry of Finance 2008). Despite the ambitious GHG reduction targets set by the province, and despite the fact that transportation-related GHG emissions in BC are substantial, there has been little or no indication of what measures should or could be taken to allow transportation to significantly reduce its emissions. All components need to be examined both individually and collectively in order to determine what changes can be made to BC's transportation system to reduce emissions. My research is designed to provide policymakers with information on current BC interurban transportation emissions and on changes to interurban transportation that can be made to help the province to achieve its GHG reduction targets.

In Canada, total GHG emissions have increased from 613 Mt CO_2e[1] in 1990 to 726 Mt CO_2e in 2013 (Environment Canada 2015a), an increase of 18%. In the same timeframe, Canadian transportation emissions increased from 130 to 170 Mt CO_2e (Environment Canada 2015b), an increase of 31%, and thus almost twice the rate of overall emissions. In BC, total GHG emissions have increased from 51.9 Mt CO_2e in 1990 to 64.0 Mt CO_2e in 2013 (British Columbia Ministry of Environment 2012), an increase of 11%. Emissions from transportation increased from 18.6 Mt CO_2e in 1990 to 23.3 Mt CO_2e in 2012 (British Columbia Ministry of Environment 2012), an increase of 25% and thus more than twice as fast as overall emissions. Transportation in BC accounts for 38% of all fossil-fuel based GHG emissions (British Columbia Ministry of Environment 2012). They are 65% higher than the global average and 27% higher than the developed country average. Looking to the future, transportation is expected to be one of the fastest-growing sectors in BC (Vancouver Public Library 2015).

1.2 Research questions

The research contained in this dissertation was guided by the following two questions:

[1] CO_2e = CO_2 equivalent. The unit CO_2e is used to provide a common or equivalent unit of measure for the different warming effects of different GHGs. It represents the amount of CO_2 that would have the same relative warming effect as the GHGs actually emitted (CO2 Australia Limited 2009).

(1) What are the present-day total CO_2 emissions and emission factors of interurban passenger and freight transportation in BC?

In my research, the CO_2 emissions of individual transportation modes comprising the BC interurban transportation system were calculated, from which were derived the total emissions of the BC interurban transportation system. Calculations included only those emissions directly associated with the operation of the vehicle ("tail-pipe emissions"), and not those associated with the production of fuel, or other environmental impacts such as radiative forcing or the emission of other pollutants and GHGs. In addition, emission factors (EFs) were calculated for each mode of interurban transformation considered for the year 2013, the base year for this research. An emission factor expresses the emissions per unit activity; in this case, the emissions to transport one passenger or one unit of freight over one unit of distance. For my research, emissions and emission factors were calculated for CO_2, instead of CO_2e, because existing data for some modes did not allow calculating CO_2e emissions. Thus, this research analyzes not all GHG emissions associated with transportation but rather just the subcategory of CO_2, which, however, makes up the vast majority (~99%) of transportation GHG emissions. The nine transportation modes used in this research are as follows:

for passenger transportation:

- private vehicles
- ferries
- aviation
- intercity buses
- trains,

and for freight transportation:

- trucking freight
- marine freight
- rail freight
- aviation freight.

(2) What changes to BC interurban transportation can help the province to achieve its legislated 2020 and 2050 emission reduction targets, and how far above target values will projected values be if reduction rates are insufficient?

BC has set ambitious GHG reduction targets for 2020 and 2050. In order for these targets to be met, reducing emissions from interurban transportation will be crucial. To assist policymakers in this task (and to answer this research question) scenarios of possible future changes to the BC interurban transportation system were created and analyzed. Scenarios were created that achieved the emission reduction targets and that did not meet them. For scenarios that failed to meet the reduction targets, the cost of buying carbon offsets for excess emissions was used as one way of illustrating the 'price of failure'.

In my research, it was assumed that interurban transportation should, as is mandated for the BC economy in general, reduce its emissions 33% below 2007 levels by 2020 and 80% below 2007 levels by 2050. There is no such requirement in the legislation, however. Even if one sector fails to meet its target, another may exceeds its target, and thus the overall target could still be met.

1.3 Methodology

To answer the two research questions above, I developed an Excel-based model which I termed SMITE (Simulator for Multimodal Interurban Transportation Emissions). The model contains data for and calculates present-day emissions (which for this research was the time period between 2007 and 2013) and contains formulas for calculating future emissions for various scenarios, starting from the calculated present-day emissions.

The first element of SMITE, and the first step of my research, was to quantify the current CO_2 emissions of interurban passenger and freight transportation in BC. This provided answers to the first research question. As much as possible, a bottom-up approach to constructing an emissions inventory of interurban transportation emissions was pursued. The basic formula for calculating CO_2 emissions for each interurban transportation mode was as follows:

$$ET_M = EF_M \ x \ D_M$$

Where,
ET_M = BC emissions for transportation mode M (tonnes of CO_2)
EF_M = BC-specific emission factor for mode M (tonnes CO_2 emitted per unit distance)
D_M = Distance for activity of mode M (e.g., kilometres driven, flown, sailed)

My methodology consisted of compiling detailed usage data for each mode, calculating emissions, and computing BC-specific EFs. If BC-specific EFs could not be computed, they were obtained from alternate sources. All data and calculations were contained in Excel spreadsheets.

The second element of SMITE, and the second step of the research, was to devise and analyze scenarios of future emissions. This provided answers to the second question. The scenarios are characterized by rates of change; in other words, contain parameters representing annual increases or decreases in emissions between the present and 2050. The scenarios, with a few exceptions, cannot model specific changes to the transportation system, such as a modal shift in cars from gasoline to diesel or the effect of public awareness campaigns on public transit use, unless those changes can be translated into a rate-change parameter. Calculating future emission scenarios permitted analysis of which change rates allow BC to meet (or not meet) its legislated 2020 and 2050 emission reduction targets.

In addition to emissions, carbon offset costs were calculated in the SMITE model for each scenario as a way of illustrating monetary cost associated with the various scenarios. The carbon offset prices are input into the model and costs to offset the discrepancies between the scenario emissions and the 2020 and 2050 target values were calculated. Thus, the model determined either (1) the ‘income’ derived for those scenarios for which the legislated target values were exceeded and excess offsets could be sold by the province on the market or (2) the ‘expense’ incurred for those scenarios for which the legislated target values were not exceeded and thus offsets had to be purchased by the province on the market. For the purposes of this research, it was assumed a viable market existed for buying and selling these carbon offsets.

The rates of change incorporated into scenarios chosen for this research generally ranged from reducing emissions by approximately -5% per year to increasing them by up to +5% per year. The annual compound reduction rate to achieve an 80% reduction by 2050 over 2007 levels is approximately -4%, which is why modelling higher reduction rates is not necessary in order to meet the legislated reduction targets. While not meant to be exhaustive, the modelled scenarios bracket a spectrum of ‘plausible’ and ‘realistic’ scenarios; namely, with rates of change of generally -5% to +5%. In total, 106 scenarios were modelled.

1.4 Major research findings

In this section, major research findings are outlined. Relative to providing input into the policy process, the short, simple conclusion from my research is that for BC to be able to meet its target of reducing emissions 80% below 2007 levels by 2050—assuming that interurban transportation emissions must be reduced by this amount—the province will be required to introduce dramatic changes to interurban transportation sooner rather than later.

1.4.1 Introduction to answers to Research Question 1

Interurban transportation of passengers and freight produced approximately 11,194,000 tonnes of CO_2 in 2013, the base year for this study. Passenger transportation accounted for 22% of these emissions, while freight transportation accounted for the remaining 78%. Freight emissions were nearly four-fold those of passenger transportation.

According to provincial data, total BC GHG[2] emissions in 2013 were 64,000,000 tonnes CO_2e (British Columbia Ministry of Environment 2012). My calculated interurban transportation emissions were approximately 17.8% of this total. Table 1.1 lists individual interurban transportation modes analyzed in my research along with their contributions to the interurban total, their respective passenger or freight sector total, and their EFs.

Table 1.1: Summary of BC transportation mode emissions and emission factors

Transportation mode	**Emissions by mode (tonnes CO_2)**	**Percentage of *total* interurban trans-portation emissions**	**Percentage of *passenger* interurban trans-portation emissions**	**Percentage of *freight* interurban trans-portation emissions**	**EF (g CO_2/pkm for passengers; g CO_2/tkm for freight) (range where available or average)**
Passenger transportation					
Private vehicles	1,916,000	17.1	78.4		202
Ferry	342,000	3.1	14.0		260 – 1,781
Passenger aviation	167,000	1.5	6.8		75 - 386
Intercity buses	13,000	0.1	0.5		57* - 137*
Passenger trains	5,000	<0.1	0.2		117*
Freight transportation					
Trucking freight	5,431,000	48.5		62.1	196
Marine freight	1,883,000	16.8		21.5	n/a
Rail freight	1,428,000	12.8		16.3	15
Aviation freight	9,000	0.1		0.1	940 – 6,810
Total	11,194,000	100%	100%	100%	

[2] While the province accounts for all GHGs (CO_2e), rather than just the CO_2 considered in this research, the CO_2e value for transportation is generally only approximately 1% larger than the CO_2 value.

Table 1.1 Legend:
pkm = Passenger-kilometre
tkm = Tonne-kilometre
* = Value could not be calculated independently and was taken from the literature.

1.4.2 Introduction to answers to Research Question 2

Modelled scenarios fall into two categories, those that meet the GHG reduction targets, and those that do not. To meet the reduction targets, it was assumed that interurban transportation should have to reduce its emissions by the same percentages as the economy in general, namely 33% below 2007 levels by 2020 and 80% below 2007 levels by 2050, although the BC legislation does not mandate that specific sectors reduce their emissions by specific percentages.

Four types of scenarios were generally unable to meet either the 2020 or 2050 emission reduction targets. These modelled situations in which (1) emissions increase at any point between 2007 and 2050, (2) a business-as-usual approach is followed for a given period of time before applying sustained emission reductions (in other words, emission increases or decreases continue the trajectory set by the 2007-2013 rate of change), (3) emissions remain unchanged for a given period of time before applying sustained emissions reductions, or (4) reduction rates are too small (less than 3% per annum). The scenario with the least favourable conditions modelled—an increase of 5% per year for all modes— resulted in projected 2020 emissions of 15.66 million tonnes CO_2 (over 100% above the target value of 7.6 million tonnes CO_2), and projected 2050 emissions of 67.4 million tonnes CO_2 (almost 3,000% above the target value of 2.3 million tonnes CO_2). This scenario would result in total offset costs to the province of nearly $98 billion by 2050.

Only two scenarios, of the 106 used in my research, were able to meet both the 2020 and 2050 emission reduction targets. One, Scenario 6, which is described in detail in Chapter

5, used backcasting, which involved every mode changing its emissions by the exact percentage rates to meet a 33% reduction by 2020, and then using a reduction rate of -3.83% to meet the 80% reduction target for 2050), while the other, Scenario 96, which is also described in detail in Chapter 5, used each modes' rate of change from 2007 to 2013, minus 5%. (Again, these scenarios use only percentage change of emissions and do not incorporate specific changes to BC's interurban transportation system.) However, such scenarios could represent significant technological advances or infrastructure investments such as upgrading to an extensive, electrified, and hence zero emission, railway system. Meeting only the 2050 target requires somewhat less stringent changes because there is more time to accomplish technological and societal changes.

No scenario that achieves either the 2020 or 2050 targets, or both, would likely be easy to implement. My scenarios only model rates of change, not actual, concrete changes; however, the high rates of change needed to hit the targets implies that major transformations in technology, public policy, demographics, and/or social behaviour will have to take place to have a chance of meeting either target. However, on the positive side, if one assumes a viable offset market in which the province could sell its excess carbon credits, several of the scenarios modelled that encompassed reduction rates of up to 5% per year resulted in savings for the province of upwards of $6 billion.

1.5 Value of Research

There are three main benefits of the research contained in this dissertation: (1) development of the SMITE model, (2) application of this model to BC, and (3), policy perspective gained from model results to assist BC policymakers in making decisions on

BC's transportation system as it relates to the issue of climate change. Each is discussed in turn.

Because the level of study chosen for this research was interurban transportation at the sub-national level, and because there is a paucity of existing studies at this level, and consequently methodologies to use at this level, it was necessary for me to devise my own inventorying and modelling approach. The methodological approach developed for calculating both present-day and future emissions is independent of geographical scale. While I applied it to BC, it can serve as a template both for other jurisdictions and on different scales.

Using the SMITE model, an in-depth, bottom-up inventory of passenger and freight interurban transportation in BC was created. To my knowledge, there are no existing studies that include the total emissions and area-specific EFs of each mode considered in my research, or their geographic distribution, in BC or any other jurisdiction. I was able calculate or estimate CO_2 emissions for nine interurban transportation modes, and to calculate or estimate specific EFs for all but one mode (marine freight).

On a practical level, the SMITE results can assist BC scholars, policymakers, and practitioners in the transportation field in making climate change related decisions. My research indicates that rapid reductions in interurban transportation emissions will be crucial for achieving the province's legislated emission reduction target values.

1.6 Introduction to Chapters

Following this introductory chapter, the second chapter is a literature review; it contains reviews of the literature on transportation GHG modelling and the literature on BC transportation GHG emissions. The third chapter discusses the methodology adopted for my dissertation research, while the fourth chapter contains the detailed, bottom-up inventory of present-day (around the year 2013) interurban transportation CO_2 emissions in BC. The fifth chapter contains the results from having modelled 106 scenarios of changes to BC interurban transportation and their impact on transportation CO_2 emissions and the 2020 and 2050 emission reduction targets, along with associated carbon offset costs. The sixth and final chapter contains a summary of results, a discussion of examples of changes that may help BC achieve sustained transportation emission reductions, a review of the contribution of this research, a discussion of the limitations of this research, suggestions for further research, and final thoughts regarding this research project.

CHAPTER 2: TRANSPORTATION GREENHOUSE GAS MODELLING: A LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of the literature on climate change-related transportation modelling. The gaps in the literature and the research needs addressed by my research are identified, which provide justification for constructing an independent calculation model.

There are a myriad of types of transportation models with a myriad of applications. There are cost/benefit models, network analysis models, probabilistic models, supply/demand models, etc. that are applied to tasks such as air pollution emissions calculations, land use coordination and infrastructure provision, safety measure recommendations, toll pricing, and travel demand analysis for congestion reduction (Beimborn 2006, Wikibooks n.d.). The focus of my research is emissions types of models, specifically GHG emission models, and more specifically GHG emission models for interurban passenger and freight transportation. Relative to these models, two literatures are reviewed in this chapter to situate the research and highlight the knowledge gaps that the research fills: (1) the literature on transportation modelling related to GHG emissions and to mitigation costs, and (2) the literature related to transportation and climate change in BC. The first literature situates my work in the overall climate change-related transportation modelling field, and the second in the realm of research on transportation and climate change in BC.

2.2 Review of the literature on transportation GHG modelling

2.2.1 Types of transportation GHG models

The existing literature on transportation modelling of GHG emissions can be distinguished by two main criteria: the scale of the model's application, and the transportation modes covered. The scale of a model's application can range from global to national to local, while models can cover any range of transportation modes from a single mode to the totality of a transportation system in a given area. In total, I found about 30 studies related to modelling GHG emissions from the transportation sector, all of which are discussed to one degree or another in this chapter. In each section, those studies which were of more influence or relevance to my research are discussed first and in more detail, while those that were of tangential relevance are discussed second and only briefly.

Within the body of transportation-related GHG emission modelling literature, there are two main types of GHG emission models: (1) top-down and (2) bottom-up. Top-down models use 'overarching' input data, usually aggregated fuel usage, to calculate emissions; for instance, of all road transportation in a given region. Such models usually allocate the aggregate fuel use or emissions to transportation subsectors or to smaller scales (hence, top down). Bottom-up models generally use spreadsheets or other accounting software to inventory data such as fuel usage or emissions (by vehicle type, for example), and from this work 'bottom up' to calculate aggregated emissions. Bottom-up inventories allow for great detail on energy use or emissions but are generally very labour intensive, whereas top-down models are less detailed and less labour intensive—and are often more suited for large-scale comparisons, for example between economic sectors (Becken and Patterson 2006). There is a small 'meta-literature' of about a half dozen studies that analyzes and/or synthesizes results from existing studies based on the above two model types.

Besides top-down and bottom-up model types, there are two approaches to addressing future emissions: forecasting and backcasting. Forecasting is used to estimate future emissions by starting from a given 'present-day' emissions value and, employing various assumptions, attempting to derive a best-guess for emissions at a future date. Backcasting is an opposite approach. It rests on the assumption that future targets have been met and proceeds to work backwards to describe the means by which those targets can be achieved. In the model developed for my research, both forecasting and backcasting approaches are used.

2.2.2 Scale of transportation GHG model application and modes covered

Global/regional scale

There is a limited body of literature on transportation GHG modelling at the global/regional scale that directly or indirectly addresses interurban transportation. In this section, the literature related to passenger transportation is discussed first, and then the literature related to freight transportation. Both sections are further separated by the transportation mode modelled. A total of 10 studies are discussed. Four out of the five pieces of literature at the global/regional scale that address only one transportation mode analyze aviation; the fifth analyzes freight ship emissions. The other five global level studies all address freight transportation involving more than one mode, either in a comparative fashion or as part of an integrated transportation system. Of the modes address in my research, I was unable to find studies at the global/regional level for passenger bus transportation, passenger and freight rail transportation, and passenger ship transportation.

Global passenger transportation: Aviation

There are a number of large-scale, top-down future emission projections for interurban aviation transportation. (Note: Virtually all passenger aviation transportation is interurban; only a very small fraction is intraurban, primarily helicopter travel within a city.)

One of the governing bodies of civil aviation, the International Civil Aviation Organization (ICAO), published an Environmental Report in 2010 which reflects and promotes cooperation among governments, industry and members of civil society and showcases ideas and best practices that can accelerate efforts towards the goal of a sustainable air transport industry (International Civil Aviation Organization 2010). The report primarily covers the impacts of aviation emissions on the climate in a qualitative manner rather than estimating their quantities; however, for the quantitative estimates included in the report, a bottom-up approach recommended by the Intergovernmental Panel on Climate Change (IPCC) was followed which includes surveying airline companies or estimating aircraft movement data and standardized fuel consumption. The report highlights that aviation currently accounts for less than 2% of global CO_2 emissions, and that passenger traffic is expected to grow at an average rate of 4.8% per year through the year 2036 but that emissions are expected to grow at a smaller rate because of increased engine efficiencies. It also provides projections for global aircraft fuel burn to the year 2050. The maximum fuel burn in 2050 is estimated to be 4.5 times that of 2006. The most relevant aspect of this report to my research was that it advocates establishing bottom-up inventories over top-down inventories, which was the approach followed in my research, and that it provides growth projections for aviation that I used to inform my construction of emissions scenarios for BC.

The IPCC published its *Special Report: Aviation and the Global Atmosphere* in 1999, which contains national top-down emission inventories aggregated at the global level (Intergovernmental Panel on Climate Change 1999). The report analyzes how subsonic and supersonic aircraft affect climate-related properties of the atmosphere, how aviation emissions are projected to grow in the future, and what options exist to reduce emissions and impacts in the future. The report acknowledges that while emission growth projections can be made with a fair amount of certainty for one to two decades based on projected passenger growth and efficiency improvements, projections that reach beyond two decades are more uncertain because of variables such as technological development (Intergovernmental Panel on Climate Change 1999). The various growth scenarios up to the year 2050 contain ratios of fuel burn between 2050 and 1990 of between 1.6 and 9.4 (Intergovernmental Panel on Climate Change 1999, 5), meaning that emissions were expected to be between 1.6-fold and 9.4-fold those of 1990 values. The report had two main influences on my research. First, while I did not use the emission growth ratios in my future scenario calculations, the ratios gave me general guidelines as to what growth rates experts were projecting in the late 1990s. Second, the large range of growth ratios indicated that future scenario calculations, especially as we go further into the future, are subject to significant levels of uncertainty. This reinforced my approach of modelling a comparatively large range of growth and/or reduction rates for my future emission scenarios.

Akerman (2005) examines three ‘images’ of how air travel could achieve sustainability by the year 2050, with sustainability defined as a stabilization of atmospheric CO_2 at a concentration of 450 parts per million. His study uses backcasting. The author concludes that radical changes are not only more likely to bring significant emission reductions but also entail more risks, and that changes in people's lifestyles and travel patterns could significantly contribute to reducing aviation emissions. Akerman's study highlights the importance of people's travel behaviours and the difficulty in changing them. In contrast to Akerman, Lee et al. (2009) emphasize the importance of technological change. In their study, they quantified the contribution of aviation emissions to the radiative forcing of climate, which while not an emission model per se directly relates to aviation CO_2 emissions. The authors project that fuel usage could increase by a factor of between 2.7 and 3.9 and radiative forcing by a factor of between 3.0 and 4.0 between 2000 and 2050, and that significant changes in fuel usage and emissions will only be possible through the introduction of radically different aircraft technologies or the incorporation of aviation into an emissions trading system. Lee et al. (2010) provide an update to the 1999 IPCC report on aviation's impact on the atmosphere. They state that aviation's contribution to radiative forcing may increase by a factor of 3.0 to 4.0 by the year 2050 over the year 2000, and that while liquid hydrogen and biofuels represent options for the aviation industry to reduce its emissions, both fuel types face obstacles such as development funding and safety certifications. The Akerman and two Lee studies were only tangentially relevant to my research; however, they gave me insight into aviation growth rates and types of changes that could affect future aviation emissions. The discussions of types of changes informed my discussion of examples of how various transportation modes can achieve required annual reduction rates in the various scenarios modelled.

Global road (passenger and freight) transportation

For road transportation, I found only one pertinent study at the global level. Borken et al. (2007) constructed a global bottom-up inventory of road passenger and freight transportation based on EFs, fuel usage, and distance driven in individual countries for eight pollutant types (one of which was CO_2) which were then aggregated into regional/continental groups. The authors found that in the year 2000, the Organization for Economic Cooperation and Development (OECD) countries (i.e., the main industrialized countries) accounted for almost two-thirds of fuel consumption and CO_2 emissions, and that North American road transportation in the year 2000 emitted 1,639 Mt CO_2 (out of a global total of 4,280 Mt CO_2). Unfortunately, while data for North America (United States and Canada) in aggregate is presented, disaggregated data for Canada are not presented. The relevance of this study to my research was that it advocates using a bottom-up approach using information similar to what I used; namely, EFs, fuel consumption, and distances. However, the EFs used for this study were likely, because of its broad geographic scope, generic, unlike the Canada-specific private vehicle EF calculated for this research.

Global freight transportation

For freight transportation, research at the global level is sparse. Endresen et al. (2003) compiled a bottom-up inventory of marine transport, while Cristea et al. (2013) studied trade and GHG emissions from international freight transport using a bottom-up database to quantify the contribution of international transport to total global CO_2 emissions. Neither study was particularly informative for my research, but both studies reinforced the approach of compiling a bottom-up transportation emission inventory using EFs.

Regional freight transportation

Kim and Van Wee (2009) tested the hypothesis that truck and rail intermodal freight systems are more environmentally friendly than truck-only freight systems. The authors state that truck and rail intermodal systems are indeed more environmentally friendly than truck-only systems but that the environmental benefit of rail transportation can vary significantly depending on the type of locomotive used and the way in which the locomotive's fuel is produced. This influenced my research because the interaction of rail and trucks through the concept of modal shift in freight transportation was one of the main aspects I considered in my discussion of how large annual emission reductions from the trucking sector in BC may be able to be achieved.

Mattila and Antikainen (2011) studied how a sustainable freight system for Europe can be achieved by the year 2050. Their study involved backcasting and using several 'futures of transportation' scenarios to achieve an 80% reduction in GHG emissions over 2005 values (nearly the same timeframe and percentage as BC's overall emissions reduction target). The authors conclude that there are several possible scenarios that can achieve the targeted reductions if significant changes in transport efficiency and energy mix are utilized. The study informed my work because it studied a very similar timeframe and emission reduction percentage as is the case in BC. Its emphasis on efficiency improvements guided my discussion of ways in which sustained annual emission reductions for various modes may be able to be achieved.

Magelli et al. (2009) studied the environmental impact of exporting wood pellets from Canada to Europe using a bottom-up approach. The limited relevance of this study for my work lay in its methodological approach of using distances and EFs, which was also used in my calculations where the pertinent base data were obtainable.

Global/Regional analysis of total transportation systems

Banister et al. (2011) discuss the recent history of transportation emissions and the necessity of reducing them, along with challenges in doing so such as embedded infrastructure investments, dependency on private vehicles, a lack of agreement on the global level to which countries should reduce their emissions, and technological developments that have not occurred as quickly as expected. The authors then discuss measures that can be used to reduce transportation emissions (such as shifting modes, improving infrastructure, using financial instruments, and restructuring transport governance), which generally fall in either demand or supply management categories, but caution that demand side measures are often neglected as they are complex. The importance of this article for my research lay in its discussion of some of the difficulties associated with reducing transportation emissions, which played a role in my discussion of possible examples of changes that can help various BC transportation modes achieve sustained emission reductions.

The European Commission (2009) published a report on its version of a sustainable future for transportation (for both passengers and freight), addressing trends such as developing technology and changing citizens' travel behaviour. Its relevance to my work lay in its advocacy for a multifaceted approach that pursues not only more efficient transportation technologies but also changes in people's travel behaviour, which could include measures such as modal shift.

National/subnational scale

The majority of the work at the national level is multimodal and addresses surface transport. Of the 14 inventories I found, six address multimodal passenger road transport emissions, and four address multimodal freight road transport emissions. One study addresses all transportation options at the national level, another all transportation options at the subnational level, and three studies address freight trucking only. I was unable to find studies at the national level that solely or extensively address passenger bus travel, passenger or aviation freight, passenger or marine freight, or passenger rail transportation.

Many governments have compiled emission or fuel usage inventories at the national or sub-national level. In Canada, there are inventories at the federal level (e.g., Environment Canada 2013), and also at the provincial level (e.g., British Columbia Ministry of Environment 2010). The inventory at the federal level is top-down and generally based on fuel sales data. The provincial inventory utilizes the values from the national inventory without performing independent calculations.

National (passenger and freight) road transportation

Burón et al. (2004) present a top-down model studying Spanish national road transport emissions without an urban/interurban distinction and using Spain-specific EFs (such as emissions per quantity of fuel consumed at a given speed and temperature). The authors used the COPERT model ((COmputer Programme to calculate Emissions from Road Transport), originally released as COPERT III, but since updated to COPERT 4), a software program used primarily in Europe to calculate emissions from the road transport sector (Kouridis and Ntziachristos 2000). Burón et al. (2004) acknowledge the importance (and initial absence in their study) of disaggregated data, and conclude that while local (air pollution) emissions have decreased because of increased environmental regulations, CO_2 emissions continue to follow an increasing, albeit slowing, trend. The relevance of this article to my research lay in recommending to calculate EFs specific to the transportation system being studied, which is the approach taken in my research, and also in stating that CO_2 emissions are continuing to increase, which is reflected in my research by including emission increase scenarios.

Kioutsioukis et al. (2004) studied the uncertainty and sensitivity of road transport emission estimates to changes in input parameters using Italy as a case study. In reference to

CO_2 emissions, the authors find that emission uncertainties relate to uncertainties in passenger car data, such as annual mileage and average trip length. Since annual mileage and and average trip length were among the main factors in my passenger vehicle and trucking calculations, this study's relevance was to emphasize the possible uncertainties associated with this approach.

Yeh et al. (2008) studied US national road transportation emissions by modelling vehicle fuel use and corresponding emissions using the U.S. EPA's national MARKet ALlocation (MARKAL) model technology database. The authors state that strict and system-wide CO_2 reduction targets will be required to achieve significant emission reductions from the transportation sector and suggest that policies should be informed by the transitional nature of technology adoptions and interaction between mitigation strategies. This influenced my research by highlighting the varied paces and successes of technology adaption and that changes to one mitigation strategy can have impacts on other mitigation strategies, which was tangentially relevant for my discussion of examples that may help BC achieve transportation reductions.

Cortes, Vargas, and Corvalan (2008) studied the transportation and energy sectors in Chile with a time horizon of ten years. While the model did not calculate CO_2 emissions, it did calculate fuel usage, which can be converted into CO_2 emissions. The study's methodology diverged from most other transportation studies in that it did not use EFs and operational parameters for calculations but instead used activity data (vehicle-kilometres per year) combined with changes in demographic and socio-economic factors. The relevance of this study to my research was that it validated my approach of using activity data for passenger vehicle and trucking calculations rather than using fuel sales data.

National freight transportation

For freight transportation, more studies exist at the national level than at the global/regional level. Perez-Martinez (2010) studied freight transportation and emissions in Spain using transportation statistics data and calculated emissions factors (amount of CO_2 per quantity of fuel burned) in a top-down inventory model. The author states that emissions have increased 68% between 1990 and 2007, and that by 2025 Spain could be up to 167% above the emission levels it has committed to under the Kyoto Protocol, noting also that emissions could be reduced 3.3% by 2025 compared to 2007 if the average performance of diesel vehicles in 2025 showed a 55% increase in efficiency. The emphasis on more efficient vehicles was relevant to my research because it indicated emission reduction potential, which reinforced my discussion of switching to more efficient vehicles as one way to reduce private vehicle emissions.

Ang-Olson and Schroeer (2002) analyzed eight energy efficiency strategies for freight trucking in the United States, and estimated that if 50% of trucks participated in these measures, the maximum benefit of implementing these strategies would, by 2010, result in a fuel usage reduction of 3.0 billion gallons and an 8.3 million metric tonne reduction (9%) of CO_2e emissions. This study was only marginally relevant for my research, but it influenced my discussion of trucking emission reductions by highlighting that not only revolutionary changes can help to reduce emissions but also that small, currently implementable measures can result in cumulative reductions.

Steenhof, Woudsma, and Sparling (2006) studied GHG emissions of surface freight transport in Canada, finding that increasing cross-border trade and concurrent modal shift towards trucks were largely responsible for increasing freight emissions. This influenced my creation of scenarios in which trucking emissions are substantially and 'suddenly' reduced, which may happen through measures such as modal shift back from trucks to trains.

Garcia-Alvarez, Perez-Martinez, and Gonzales-Franco (2012) studied fuel consumption and CO_2 emissions in an 'intelligent' freight transportation system. A bottom-up energy consumption model was used and explicitly recommended over a top-down model because a top-down model can lead to significant errors when incorrectly applied, e.g. when underlying assumptions are not met in a given scenario. The relevance of this article to my research was that it highlighted risks of using a top-down approach, which reinforced the value of my bottom-up approach.

McKinnon and Piecyk (2009) investigated and compared various methods of collecting data to be able to calculate CO_2 emissions from road freight transportation in the United Kingdom, including government road usage inventories and surveys of transportation providers, both of which are also used in my study. The authors' conclusion that data for one activity can vary significantly if published by various sources, or even that various government departments sometimes publish divergent data on the same activity, influenced my research by leading me to calculate values based on traffic statistics wherever possible rather than using 'processed' data, such as fuel consumption or annual emissions.

The following studies form part of the literature but were of minimal relevance to my work. Kissinger (2012) and Weber and Matthews (2008) studied the emissions associated with food imports – Kissinger for Canada, and Weber and Matthews for the United States. Winebrake et al. (2008) studied energy, environmental, and economic tradeoffs in intermodal freight transportation. Three case studies for the US Eastern Seaboard revealed that while trucking generally has a time advantage over other modes, this advantage is achieved at a cost and emissions penalty. Bauer, Bektaş and Crainic (2010) presented an approach to intermodal transportation planning that incorporates environment-related costs into freight transportation planning, finding that there are often trade-offs in transportation systems between environmental costs and time costs. Demir, Bektaş and Laporte (2011) reviewed and numerically compared several available freight transportation vehicle emission models and compared their outputs to data collected in the field. The models produced somewhat different results in simulations using broadly realistic assumptions but overall were consistent with expectations, such as fuel consumption varying with size of vehicle and speed.

National analysis of total transportation systems

I found only two studies that, like my study, include all transportation modes (passenger and freight road transportation, rail transportation, marine transportation, and aviation) in a single jurisdiction, though one is a country (Sweden) rather than a province as in my research.

Akerman and Hojer (2006) utilized fuel usage data and backcasting to explore how "sustainable transportation" could be achieved in Sweden by 2050. Sustainability is assumed to be stabilization of atmospheric CO_2 at 450 parts per million, to which end Sweden would have to reduce its transportation emissions by 63% compared to 2000 levels as its national contribution from this sector. The study considered a wide range of approaches to sustainable transportation futures, including changes in how society views and makes use of transportation in general, and areas of high inertia, such as replacing existing infrastructure. It informed my examples of changes that may help BC achieve transportation emission reductions because it had the same broad approach that includes road, rail, marine and air transportation modes, acknowledged the importance of societal attitudes, and highlighted that some aspects of the transportation system are difficult to change.

Yang et al. (2009) used a spreadsheet model to study how California could reduce transportation emissions (including sectors not covered by my work, such as agriculture) 80% below 1990 levels by 2050 and studied each transportation subsector without making an urban/interurban distinction. The authors state that while no single strategy seems promising for the reduction, a combined portfolio approach, including advanced vehicles and fuel as well as travel demand reductions, could potentially yield success. The relevance of this article was not only that it is similar in scale and scope to my work and also used a spreadsheet-based model, but also that it advocates a multifaceted reduction strategy, which informed my discussion of examples of how emission reductions in BC may be able to be achieved.

Local scale

At the local (urban) level, bottom-up models seem to dominate the existing scholarly research. All studies I found at the local level address road transportation, either for passenger and freight transportation or just for freight transportation. I have been unable to find any studies about urban passenger or freight transportation exclusively for the rail, marine, and air modes. For rail, this may be a more prominent field of study in Europe or Asia, which tend to have greater urban rail usage than North America. For marine, this is likely because in most settings, transportation in the marine mode is either not applicable or accounts for only limited emissions. For aviation, likely the only aspect that falls under the urban scope would be helicopter travel, which in all probability accounts for only a very small share of overall transportation emissions.

Local passenger road transportation

Borrego et al. (2003) analyzed transportation air pollution and CO_2 emissions in Lisbon, Portugal through a bottom-up inventory utilizing speed-dependent EFs specifically calculated for the research (amount of pollutant per distance driven at given speed on given road segment), while Lyons et al. (2003) analyzed vehicle-kilometres in several cities across the globe as a surrogate for vehicular emissions to estimate urban vehicle pollution. The former article reinforced my approach of utilizing a bottom-up inventory with EFs calculated specifically for my research, while the latter article reinforced my approach of using vehicle-kilometres as a surrogate for direct emission data collection.

Local freight road transportation

For freight, I found only one urban model. Zanni and Bristow (2010) studied emissions of CO_2 from road freight transport in London through a bottom-up inventory using traffic data and generic EFs because data to calculate specific EFs were unavailable. The model also included projections up to the year 2050 which were carried out by calculating average growth rates for the years for which traffic statistics were available and extrapolating future growth rates from this and consequently basing emission projections on these values. The authors state that there are several policies with potential to reduce emissions in the period up to 2050 (such as low-carbon or zero carbon vehicles or packages of technological, logistical and behavioural policy changes), but that even with optimistic policy interventions they cannot deliver absolute reductions from 2005 levels, and instead only slow the rate of growth. The relevance of this article lay in its approach of using various growth and reduction rates to estimate future emissions, which was similar to mine, and in its conclusion that absolute reductions may not be achieved even with emission reduction measures, which influenced my scenario division process to also include emission growth scenarios.

Existing comparative research and analysis at the local level is sparse. I have found only one study (Nagurney 2000), which addressed paradoxes in emission reduction strategies where perceived improvements to the transportation system can actually increase overall emissions. This article provided impetus for me to also include emission growth scenarios in my collection of future emission scenarios.

2.2.3 Literature on costing of transportation emission reductions

The literature on the cost of achieving transportation emission reductions that is relevant to my research (for example, costing of measures that may reduce BC transportation emissions, such as modal shift) is small (about half a dozen studies). None of the modelling studies cited above include cost analyses (Yang et al. (2009), for example, explicitly state that they excluded cost analysis because of its complexity). Most emission forecasts simply aim to provide emission values under varying transportation scenarios. A common theme in the studies discussed in this section is the complexity of calculating transportation GHG reduction costs.

The International Transport Forum (2009), in a review of existing literature, studied opportunities and costs for reducing transportation GHG emissions (without an interurban/urban distinction). It found that GHG mitigation should be planned on the basis of marginal abatement costs, should focus on the most cost-effective actions, and that success will depend on action across several fronts, such as technology and travel behaviour. In addition, it was highlighted that regional context will play an important role in affecting emission reductions, especially the extent to which each region’s (country’s) geography necessitates transportation and regionally varying policy approaches to both emission standard implementation and travel behaviour. The emphasis on regional context reinforced my focus on the sub-national level.

Azar, Lindgren and Andersson (2003) used a top-down global energy systems model to analyze fuel choices in the transportation sector under stringent global carbon emission constraints, specifically when it is cost-effective to carry out the transition away from gasoline and diesel, to which fuels (including biomass, hydrogen, or solar electricity) it is cost-effective to shift, and in which sector biomass is most cost-effectively used. They found that oil-based fuels remain dominant in the transportation sector until approximately 2050, that once the transition towards alternative fuels takes place, the preferred fuel is hydrogen, and that biomass is most cost-effectively used in the heat and process heat sectors. The relevance of this study to my research was that it deemphasizes alternative fuels as a means of achieving significant emission reductions until after the year 2050, which is the end of the time horizon of my study. As such, my discussion of ways of BC achieving transportation emission reductions did not strongly emphasize alternative fuels.

Cost-related work has also been conducted in the United States using the Energy Information Administration's National Energy Modeling System (NEMS) (Morrow et al. 2010). All of the policy scenarios that were modelled in this study failed to achieve a targeted reduction of transportation GHG emissions of 14% over 2005 levels by 2020. This was relevant for my work by leading me to emphasize technological developments or optimizations such as modal shift over policy approaches in my discussion of ways in which BC may be able to achieve transportation emission reductions.

The following two studies were of minimal influence on my work. On the national scale, work studying the cost of reducing transportation GHG emissions (without an interurban/urban distinction) has been conducted in Canada using a subjective evaluation framework containing nine planning objectives that included energy conservation and congestion reduction (Litman 2005) and highlighted that a comprehensive analysis is critical so that improvements to one problem do not result in exacerbating another problem. In another Canadian study, McKitrick (2012) analyzed the benefits and costs of GHG abatement in the transportation sector using marginal abatement cost functions, finding that the convenience and availability of the private car is a main reason why people avoid alternatives, and that achieving a 30% reduction in GHG emissions from motor vehicles in Canada would require taxation of about $975 per tonne of CO_2 (or a gasoline tax of about $2.30 per litre), and would still result in economic deadweight losses (economic losses after environmental benefits are accounted for) of $9.6 billion in the short-run and $2.9 billion in the long-run.

2.2.4 Summary of literature on transportation GHG emissions and cost modelling

The body of work on modelling GHG emissions from transportation is modest, and, relative to the research I conducted, was deficient in multiple respects. First, models typically calculate emissions without distinguishing what activities (apart from distinguishing modes) generate the emissions or where they are generated geographically. This is the method often found in national emission inventories compiled by governments. Second, not all transportation models address all transportation modes, most focus only on road transportation. Global models generally focus on one transportation mode (e.g., aviation). Even when models contain multiple transportation modes, not all compare the modes. Third, detailed work on interurban passenger transportation GHG emissions is sparse for all model types at all scales. Fourth, studies that calculate the cost of achieving transportation GHG reductions are few and far between.

I concluded from the literature summarized above that there did not appear to be any existing models that directly calculate emissions and EFs of different interurban transportation modes in a geographically-defined area at the sub-national level. One consequence of this is that there did not seem to exist an 'off-the-shelf' model to use for my research. I had to create my own model that would be able to address:

1. distinguish activities and geographical distribution of regional (i.e., BC) transportation emissions
2. include all regional (i.e., BC) transportation modes
3. focus solely on interurban transportation
4. nominally include cost.

2.3 Review of the literature on BC transportation GHG emissions

In my review of the literature on transportation GHG modelling, I found only two academic studies at the national level that address Canada. Similarly, research on BC transportation GHG emissions is also limited. There seem to be only about a half dozen such studies. This section contains first a review of the literature on passenger transportation emissions in BC and then of the literature on freight transportation emissions in BC.

Kelly and Williams (2007) constructed a bottom-up inventory for studying tourism GHG emissions to Whistler, which assessed the relative effects of various destination planning strategies on energy use and GHG emissions. Their study includes all GHG emissions associated with tourism, not just transportation. It estimates transportation emissions through a formula multiplying visitors by return distance by modal split, and then using generic fuel efficiency and EFs (amount of CO_2e per amount of energy used). This article was relevant to my work for its BC focus and for reinforcing the approach of a detailed bottom-up inventory in the province.

Poudenx and Merida (2007) compared the urban energy demand and GHG emissions in the Fraser Valley from fossil fuel-based private vehicles versus electric buses and light-rail by analyzing the modes' respective travel and emissions statistics from previously-collected inventories. The authors state that electric trolley buses and the automated rapid transit SkyTrain were eight times as energy efficient as private vehicles, and 100 times as emission efficient as private vehicles in terms of GHGs emitted per passenger-kilometre. While this study focused on urban travel, its results were significant for my work because of the implications for the environmental feasibility of modal shift on short-distance interurban routes. In my research, this influenced the discussion of how transportation emissions may be reduced on some of the shortest interurban routes in the Lower Mainland and on Vancouver Island that have very high traffic volumes.

I was unable to find any academic studies on BC-specific freight GHG emissions. While estimates of aggregate BC freight transportation emissions at the provincial level have been published by the province (British Columbia Ministry of Environment 2010) (with values that are, as discussed above, taken from the national inventory), there do not appear to be any BC-specific studies similar to my research. These estimates list total emissions by different vehicle types (e.g., light-duty gasoline vehicles, heavy-duty diesel vehicles), but do not distinguish between interurban and urban emissions. There are also no BC studies that make detailed future emission forecasts.

In summary, the existing scholarly research on BC transportation GHG emissions is sparse. To date, it has focused almost exclusively on urban transportation emissions, generally in Vancouver and surrounding areas, through bottom-up inventories. There are no interurban studies for the entire province. Emissions data published by the province are aggregate and top-down, using fuel usage. Interurban and urban are not distinguished, the spatial distribution of emissions is not calculated, nor are transportation modes compared (even though data is provided separately for different modes). My research is thus the first extensive study of the distribution of present and future transportation GHG emissions in BC that explicitly compares emissions between available transportation modes.

2.4 Meeting research needs and filling knowledge gaps

Much of the literature reviewed in this chapter has been relevant to my research by (1) reinforcing the value of utilizing a bottom-up approach for the scale and scope of my research, (2) providing insights into making emission calculations at a local level, and (3) offering suggestions applicable to achieving emission reductions for various BC interurban transportation modes. Four pieces were particularly relevant to guiding my research: Yang et al. (2009), Akerman and Hojer (2006), Perez-Martinez (2010), and Steenhof, Woudsma and Sparling (2006).

The study conducted by Yang et al. (2009) on California transportation emission reductions is perhaps closest to my research in scope and timeframe, although significant differences remain between the two geographic areas of study, such as the population density and distances between urban areas in BC and California. Akerman and Hojer's (2006) study on Swedish emissions is also closely related to my study because it examines all transportation modes in a single country (although BC, at the subnational level, is still more than twice as large as Sweden). In terms of mitigation measures, Perez-Martinez's (2010) assessment of potential improvements in diesel technology is an important guideline for my study of modal shift or mode efficiency improvements that provided impetus for my creation of various scenarios in which there are 'sudden' drops in private car emissions, which may, for example, be caused by large-scale switching to more efficient diesel vehicles (but could also apply to other more efficient vehicles, such as hybrid cars). The study of surface freight transportation in Canada by Steenhof, Woudsma and Sparling (2006) is directly relevant to my research where modal shift between rail and truck may be one of the mitigation options, especially because this study also addresses Canada. This reinforced my approach of devising several scenarios in which there would be varying degrees of 'sudden' reductions of trucking emissions, which may be caused, for example, by large-scale modal shift from trucks to freight trains.

Based on my literature reviews, there are three gaps in the existing literature on GHG transportation modelling that dictated the need to construct an independent GHG emissions model for the specific approach and scope chosen for my research. These gaps are: (1) the paucity of detailed transportation emission inventories at the sub-national scale (both in general and in BC), (2) the lack of detailed comparisons between emissions from different transportation modes and vehicle models, and (3) the absence of detailed future transportation emission forecasts based on various scenarios of interurban transportation or how targeted GHG reductions can be achieved.

While there are numerous transportation emission inventories as discussed in the previous sections, none has the exact scope of my research, namely an exclusive focus on interurban emissions of the entire passenger and freight transportation system. Existing studies either focus on just one mode, or if they include all modes, they do not distinguish between urban and interurban transportation except when the distinction is made by default, for example in studies at the local (urban) level. The majority of transportation emission inventories are bottom-up inventories because they can analyze the transportation sector in more detail. Their drawback, though, is that the required level of statistical information must be available.

The above observations provide the rationale as to why, for my research, I constructed a spreadsheet-based, bottom-up GHG emission model and applied it to BC interurban transportation. A bottom-up model also provided the greatest flexibility to estimate the emission effects of future changes to BC interurban transportation (i.e., to test various scenarios) in order to inform policy decisions. The cost of implementing emission reduction scenarios is not included in the model. The literature review on the costing of GHG emission reductions validates this decision because it is extremely complex and subject to too many uncertainties, especially when long time horizons are involved. However, estimates for offsetting excess emissions for scenarios that do not meet the targets, and the credit value of excess reductions that exceed the targets, are included and are based on current and projected carbon offset prices. The methodologies used to calculate current emissions and EFs of interurban passenger and freight transportation in BC, as well as the future emission scenario methodology, are discussed in the following chapter.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The survey of the literature on modelling of transportation GHG emissions revealed no studies identical to what is contained in this dissertation. Thus, there was also no established methodology to follow for conducting my research, which compelled me to devise my own methodological approach for calculating interurban transportation emissions on a local scale. In this chapter, this approach is explained. I developed an Excel-based model that I call SMITE (Simulator for Multimodal Interurban Transportation Emissions). SMITE was used to calculate current and future emissions for BC's interurban transportation sector. Current emissions were calculated for the year circa 2013 and future emissions for a wide variety of scenarios up to the year 2050. The chapter is divided into two sections: the first explains the approach for calculating current transportation emissions (which was used to answer Research Question One), broken down by passenger and freight transportation modes; and the second explains the approach for constructing future emission reduction scenarios (which was used to answer Research Question Two).

3.2 Present-day emissions of passenger transportation methodology

In this section, the methodologies employed for calculating present-day passenger transportation emissions are explained. They are discussed in order of the transportation mode's aggregate contribution to BC's interurban transportation emissions as determined by SMITE model calculations, thus, in the following order: private vehicles, ferries, aviation, interurban bus, and train.

3.2.1 Private vehicle methodology

For private vehicles, my method consisted of collecting private vehicle usage data, calculating the percentage of vehicles at counting sites that were cars, and then performing calculations in the following order: annual kilometres driven, changes in kilometres driven between 2007 and 2013, calculating a Canada-specific highway EF, annual emissions, and changes in emissions between 2007 and 2013.

Initially, I had planned on calculating interurban private vehicle emissions by subtracting urban transportation emissions from total provincial road transportation emissions, where these data would come from two different data bases. However, it turned out that emission results using these data bases were incompatible. Urban vehicle emissions were higher than total vehicle emissions, which is an impossibility since total road transportation emissions are the sum of urban and interurban road transportation emissions. The Province of BC publishes BC-wide road transportation emissions (British Columbia Ministry of Environment 2012), and, for select years, the Community Energy and Emissions Inventory (CEEI) (British Columbia Ministry of Environment 2014), which contains local emission data including road transportation emissions. My plan was to subtract the CEEI value from the overall road transportation value provided by the Province. However, as stated above, the urban value was higher than the total value. Determining which of the two values was correct proved impossible; they were derived using different and incompatible methodologies. Therefore, I created an emissions inventory using a bottom-up method for calculating emissions based on private vehicle usage. The steps to compile this inventory are discussed in the following sections.

Collecting BC data for private vehicle emissions calculations

To calculate the emissions associated with interurban private vehicle transportation in BC, the first step was to derive interurban road use statistics. The British Columbia Ministry of Transportation counts vehicle movements at approximately 120 Permanent Count Sites as well as more than 500 short-count (temporary) sites throughout the province.[3] Of these, 66 Permanent Count Sites as well as 13 short-count sites were chosen for my usage compilation that cover the vast majority of primary BC interurban transportation routes as well as a small number of secondary routes; the remaining Permanent Count Sites were excluded because they are located within urban centres and thus likely contain a high number of urban rather than interurban traffic, while the remaining short-count sites were excluded either because they are also located within urban areas or because they are located on routes on which Permanent Count Sites provide more detailed information. The vast majority of the 79 sites chosen are located between urban areas. Data from these counting sites were input into an Excel spreadsheet along with the route along which they are located and the distance between the two urban areas the route connects.

The Ministry of Transportation provides various outputs for its counting sites. For my compilation, the output called Average Annual Daily Traffic (AADT) was used for the years 2007 and 2013, the latest year for which data was available at the time of my research. This daily value was multiplied by 365 to obtain the number of vehicles travelling past the counting site in a given year.

Not all vehicles travel the entire distance between two urban areas. I had intended to use a multiplier (with a value of between 0% and 100%) to reduce the AADT value so as to account for vehicles driving only part of a route. This multiplier would have been influenced,

[3] The main page for these statistics can be found at https://pub-apps.th.gov.bc.ca/tsg/.

for example, by the presence of towns along a route between urban areas, which may indicate that some people only drive part of the route. However, no statistics are available that would have allowed me to determine this multiplier in a quantitative manner. Rather than assigning a multiplier based on a best estimate of the percentage of vehicles that would drive the entire distance of a route, for simplicity sake, I abandoned this approach and assumed that 100% of vehicles counted by a counting site would drive the entire distance of a given route.

Percentage of vehicles that are private vehicles (cars)

The AADT values comprise all types of vehicles that travel past a given counting site, including private vehicles, trucks, buses, etc. Consequently, it is necessary to assign a percentage for what number of the vehicles at a given site are cars. For 49 of the 79 counting sites, this percentage was contained in the traffic statistics, and ranged from 35% to 94% of vehicles counted. For the remaining sites, I calculated an average vehicle percentage using the following formula:

$$APPV = \frac{\sum_{S=1}^{49} S_S}{49}$$

Where,

APPV	=	Average percentage of vehicles counted that are private vehicles (cars)
S_S	=	Percentages of vehicles counted that are private vehicles at site S (there are 49 sites)

The average percentage value obtained using this method was 74%.

Private vehicle emissions calculations

The annual kilometres driven between origin and destination of a given route were calculated using the following formula:

$$D_{RA} = T_{RA} \, x \, P_R \, x \, D_R$$

Where,

D_{RA} = Annual distance driven on a given route R (km)

T_{RA} = Annual traffic on route R obtained from Ministry of Transportation's AADT (number of vehicles)

P_R = Proportion of vehicles captured by counting site that are private vehicles for route R (= percentage on route R / 100)

D_R = One way distance of route R between origin and destination (km), from Google Maps

The D_{RA} values were determined for the years 2007 and 2013. The change in kilometres driven on route R between 2007 and 2013 was calculated using the below formula. The percentage change values were used in the future scenario emission calculations.

$$Percentage\ change_{DR} = \frac{D_{R\,2013} - D_{R\,2007}}{D_{R\,2007}} \, x \, 100$$

Where,

$D_{R\,2013}$ = D_{RA} kilometres driven in 2013 on route R

$D_{R\,2007}$ = D_{RA} kilometres driven in 2007 on route R

Canada average highway private vehicle emission factor

Natural Resources Canada provides fuel consumption information and highway and urban EFs for all vehicles for sale in Canada. At the time of my research, this information was available for model years 1995 to 2013, and comprised 16,972 models (this includes differentiations for different trim/engine options as well as manual and automatic models). All models and emission factors from 1995 to 2013 were compiled in an Excel spreadsheet. Next, a Canada-specific average highway private vehicle EF was calculated using the following formula:

$$ACHEFPV = \frac{\sum_{M=1}^{16792} EFHPV_M}{16{,}792}$$

Where,

ACHEFPV = Average Canadian highway EF for private vehicles (g CO_2/km)

$EFHPV_M$ = Highway EF of each of 16,792 private vehicle models M for sale between 1995 and 2013, as determined from Natural Resources Canada data

This yielded a value of 202.0 g CO_2/km. For comparison, the Department for Environment, Food, and Rural Affairs (DEFRA) in the United Kingdom (UK) provides an average vehicle EF of 201.9 g CO_2/km (DEFRA 2011). While this value is virtually identical to my value, it includes both highway as well as less efficient urban driving, meaning that the DEFRA value would be somewhat smaller than my value if it included only highway driving. This is in line with my expectations given that the average vehicle in the UK is smaller than the average vehicle in Canada and thus should have somewhat lower emissions.

Inability to calculate British Columbia average highway private vehicle emission factor

I had originally intended to calculate a BC-specific average highway private vehicle EF that would be reflective of the BC vehicle fleet. The following section outlines the methodology that was intended for these calculations as well as why this approach ultimately had to be abandoned.

Natural Resources Canada provides fuel consumption ratings for all vehicles available for purchase in Canada. According to this information, in 2013 there were 1053 different car models available for sale in Canada (Natural Resources Canada 2014). This number includes not only the different models by all manufacturers but also three subtypes for these models—different trim levels, different engine sizes, and automatic or manual transmissions. Natural Resources Canada includes annual emission values for each vehicle model that are based on travelling an average 20,000 km per year with a mix of 55% city driving and 45% highway driving. Since my research focuses only on interurban transportation, interurban-specific EFs for each of the 1053 car models and subtypes, which are for 100% highway driving, were calculated using the following formula:

$$EFH = FCH \ x \ EF_F$$

Where,

EFH = EF highway (g CO_2/km)

FCH = Fuel consumption highway (L/km) derived from Natural Resources Canada (2014)

EF_F = EF fuel (2.3 kg CO_2 per L of gasoline; 2.7 kg CO_2 per L of diesel) derived from Natural Resources Canada (2013) x 1000 g per kg

While the Natural Resources Canada information provided the kinds of vehicles available for sale in Canada, it did not indicate how many of each vehicle are licensed in BC. For this information, I contacted the Insurance Corporation of British Columbia (ICBC), which is in charge of insuring and registering all vehicles in BC. ICBC provided an Excel file of registered vehicles in 2014 that contained more than 13,000 rows of data and contained all models for which more than 10 vehicles are insured (Lee 2014). These data, however, were not disaggregated by model year. Thus, while the spreadsheet lists all insured models of a particular type, it was impossible to determine the model year. Since ICBC could not provide this information, I developed a method for determining model-specific EFs.

Models that were available in 2013 were matched with ICBC data on model types insured. Some models could not be matched because they are no longer sold in Canada (thus, ICBC was insuring model types that did not appear in the Natural Resources Canada (2014) data set). Moreover, the ICBC data did not include pickup trucks, only cars and SUVs. Of the total of 2,050,000 cars insured in BC in 2014, 1,377,000 could be allocated to Natural Resources Canada models. Next, an aggregate EF for each model was calculated as follows:

$$EF_M = \ EFH \ x \ V_M$$

Where,

EF_M = Aggregate EF for all vehicles in BC of a given model (g CO_2/km), which represents the emissions per km for the collection of all vehicles of a given model

EFH = Highway EF for a single vehicle of a given model as determined from Natural Resources Canada data (g CO_2/km)

V_M = Number of vehicles insured in BC for a given model as determined from ICBC data

Next, an overall, BC-specific highway EF was calculated using the following formula:

$$EFBCH = \frac{\sum_{M=1}^{1053} EF_M}{V_{BC}}$$

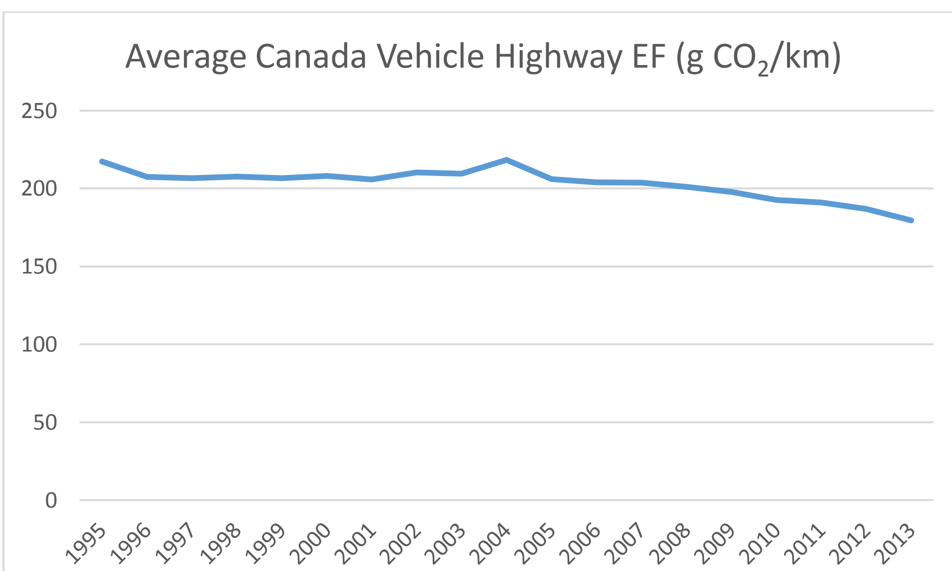
Where,

EFBCH	=	BC-specific highway EF (g CO_2/km)
$\sum_{M=1}^{1053} EF_M$	=	Sum of BC-specific aggregate EFs for all 1053 models M listed by Natural Resources Canada in 2013 (g CO_2/km) = emissions per km in 2013 for the collection of all vehicles for the 1053 models
V_{BC}	=	Total number of vehicles insured in BC in 2014 which could be matched with ICBC data

Using the above-described approach, a BC-specific highway EF of 155.9 grams of CO_2 emitted per kilometer traveled on a BC highway in 2014 was calculated.

The main issues with this approach were that nearly 700,000 vehicles could not be matched to Natural Resources Canada fuel consumption data, that the ICBC data did not distinguish vehicles by model years, and that pickup trucks (which are generally less fuel-efficient than cars) were not included in the ICBC data. Figure 3.1 illustrates how average private vehicle highway EFs in Canada changed between 1995 and 2013. On average, they have decreased.

Figure 3.1: Average Canadian private vehicle EFs from 1995 to 2013



Because of the issues mentioned above, it would have been necessary to assign a multiplier value to raise the EF of 155.9 g CO_2/km to more accurately reflect the actual BC vehicle fleet. If, for example, a multiplier of 25% were to be used, an EF of 194.9 g CO_2/km would have resulted, which is only 3.7% smaller than the Canada-specific highway EF calculated above. However, it was impossible to develop a formula to assign such a multiplier value. Because of these uncertainties, a Canada-specific private vehicle average highway EF, "ACHEFPV", was calculated as previously explained and assumed to equal the BC highway EF.

Annual BC interurban emissions

The following formula was used to calculate annual emissions for each interurban route:

$$EPV_{AR} = \frac{D_R \ x \ ACHEFPV}{10^6}$$

Where,

EPV_{AR} = Annual emissions per interurban route R (tonnes CO_2)
D_R = Annual distance driven on interurban route R (km)
ACHEFPV = BC highway EF (= 202.0 g CO_2/km), assume to be the same as the Canada-specific private vehicle average highway EF

Total annual interurban private vehicle emissions were calculated using the following formula:

$$EPV_A = \sum_{R=1}^{79} EPV_{AR}$$

Where,

EPV_A = Annual emissions of private vehicles on all 79 interurban routes within BC (tonnes CO_2)
EPV_{AR} = Annual emissions per interurban route R (tonnes CO_2)

Changes in emissions 2007 - 2013

To compare emission changes between 2007 and 2013, the below formula was used. The percentage change values were used in the future scenario emission calculations.

$$Percentage\ change_{EPV} = \frac{EPV_{2013} - EPV_{2007}}{EPV_{2007}}\ x\ 100$$

Where,

EPV_{2013} = EPV_A emissions in 2013

EPV_{2007} = EPV_A emissions in 2007

Per-passenger emission factor

One of the comparisons to be made in my research is per passenger emissions; in other words, the amount of CO_2 emitted per passenger carried by a given mode of transportation. For private vehicles, I made the assumption that the EF per vehicle is equivalent to EF per passenger, thus assuming single occupancy of the car. While this will not necessarily hold, I had no way of determining the average occupancy of private vehicles for interurban driving. I therefore made the 'worst case' assumption. Thus, the BC-specific highway EF of 202.0 g CO_2/km also equals the emissions per passenger-kilometre for comparison purposes in this research.

Limitations of private vehicle calculations

Private vehicle calculations were subject to five main limitations. First, some Permanent Count Sites were not reported every year. This could be because the measuring equipment was defective or because their use was discontinued; the Ministry of Transportation did not indicate the reason for missing data. Short-count sites do not collect data for extended periods as Permanent Count Sites do, so they may not have contained data for 2007 or 2013. Where information for the years 2007 or 2013 was not available, this was noted in the Excel spreadsheet and data from the closest suitable year substituted without making adjustments to the values. It would have been preferable to utilize data from only

Permanent Count Sites, but they are not available on all routes (even some heavily travelled routes), or on some routes they are available only for very long segments that may pass through more than one urban area before the next Permanent Count Site. However, utilizing short-count sites along with Permanent Count Sites allowed me to inventory traffic on more routes, as well as to 'split up' routes so that they would in most cases only be between two urban areas and thus more accurately represent traffic on that particular route.

Second, not all Permanent Count Sites and no short-count sites distinguish between different sizes or types of vehicles; they count every vehicle that passes. Where Permanent Count Sites distinguish between vehicles classes, this is only between cars and three different lengths of trucks and only for the year 2014. The Ministry of Transportation has begun to introduce vehicle counters that do distinguish between all vehicle types (including motorcycles, cars, SUVs, buses, and various truck classes), but currently only five such counters exist, which was not enough to obtain a representative value. For those sites for which a split between cars and trucks was not available, I had to assign an average value based on the car/truck split of the 49 sites for which these data were available.

Third, not every interurban route in BC has a traffic counter. If a route did not have a counter, it was not included in my calculations. While the counters are strategically placed in the province and the 79 counters I used cover the vast majority of primary BC interurban routes and a few secondary routes, there are also routes that are not included in my research, for which I had to effectively assume that traffic was zero. If all interurban routes (those with counters and without) had been included, the calculated emissions would be higher.

Fourth, I had to assume that 100% of vehicles driving by a counting site travel the entire distance of any given route because it was not possible to devise a formula to quantitatively determine a limiting multiplier value. This overestimates traffic data and consequently emissions because some people may only drive part of a given route. However, the error introduced by assuming that 100% of vehicles drive the entire distance is likely small for two main reasons: First, many counters are located in rural areas where there are no towns or other points in between the urban areas to which people may travel instead of travelling the entire distance of a route. On these routes, the percentage of people that travel a route in its entirety is likely close to 100%. Second, it is also possible for people to travel segments on each route that lie on either side of the counting site but do not pass it. This kind of travel is not captured by the counting sites. Consequently, while assuming that 100% of vehicles travel the entirety of a route overestimates private vehicle usage, this may be balanced out to a degree by interurban travel on a route that is not captured by the counting sites because it occurs on either side of a counter. With the available data, it was not possible to assess whether this limitation results in private vehicle usage being over- or underestimated.

And fifth, the private vehicle average highway EF was not be based on the actual BC vehicle fleet despite my best efforts. Instead a Canada-specific value was calculated. However, it is an average of more than 16,500 EFs of vehicles sold in Canada in the 18 years preceding my research, so it accounts for older vehicles and pickup trucks in a way that my method for calculating a BC-specific EF could not.

3.2.2 Ferry methodology

For ferries, my method consisted of collecting data on ferry usage, calculating vessel-specific EFs where possible, and then performing emission calculations (in the following order: emissions per sailing, annual emissions, passenger-sailing EFs, and passenger-kilometre EFs).

Collecting data for ferry emissions calculations

To calculate the emissions associated with ferry transportation in BC, the first step was to create a listing of all ferry routes, their frequencies, ships used, and distances traveled. How these data were collected is explained below.

Routes

The BC Ferries website contains a map as well as schedule of all routes served. In total, BC Ferries lists 25 routes, which carry route identification numbers ranging from 1 to 40. It is unclear why there are more route identification numbers than routes being operated, but one possible explanation could be that over time new routes have been added and older ones discontinued, resulting in route identification numbers that are currently unassigned. Some routes that include more than two ports of call are operated in more than one combination (for example, not every sailing may stop at every port of call). All routes that are operated were entered into an Excel spreadsheet with their respective route identification number. These routes were further disaggregated so that every route in my listing had only one vessel operating one itinerary (meaning that some route identification numbers appear more than once in the schedule compilation). Because of this, my listing contained a total of 49 routes (or perhaps more accurately, 'vessel-routes'), whereas BC Ferries records 25 routes.

Frequencies

Schedules listed on the BC Ferries website show weekly departures. These departures can vary over a given time period (e.g., by season). The average number of weekly sailings for each route was collected, which was then multiplied by 52 to obtain annual sailings.

Vessels used

The BC Ferries website contains a list of all ferries the company operates. When one clicks on a specific vessel, information about it is displayed, which in most cases includes engine horsepower, capacity for passengers and vehicles, and the route it typically operates on. It appears that most vessels serve dedicated routes, while only a select few act as 'backups' or change routes. For some routes, more than one vessel operates, especially when there are many daily sailings. In these cases, I selected at least one representative vessel in terms of size and capacity for the route. More than one representative vessel was selected on routes with high frequencies where ships of markedly different sizes operate, to more accurately reflect the vessels used in calculations.

Distances

For the majority of routes, especially longer ones, the scheduling information on the BC ferries website lists the distance in nautical miles, which was converted to kilometres. However, for some routes, no distances are given. This is generally the case for short 'triangular routes' where several islands are served and where the order in which they are served varies among sailings during the day or during the week. In these cases, I used the ArcGIS Online software's distance function to estimate the distance for each trip (http://www.arcgis.com/home/webmap/viewer.html?useExisting=1).

Calculating vessel-specific emission factors

I decided to assign vessel-specific EFs where possible to reflect the diversity of the BC Ferries fleet, which comprises some 35 vessels ranging in capacity from 133 people and 16 vehicles to 2,100 people and 470 vehicles (BC Ferries 2014), rather than using generic ferry EFs; for example, from DEFRA. Vessel-specific EFs allow not only calculation of more accurate total emission values but also comparison of the per-passenger EFs of specific vessels. The methodology adopted here is a variant of that contained in the "Best Practices

Methodology for Quantifying Greenhouse Gas Emissions" by the BC Ministry of Environment (2013), which is a manual designed to set out the current best practices for quantifying and reporting GHG emissions from BC's provincial public sector organizations, local governments, and communities.

Since emission data for BC Ferries were not available, I used ferry engine efficiency, given in "horsepower/L/km" for select vessels (British Columbia Ministry of Environment 2013), as the basis for calculating emissions. However, engine efficiency is only available for five routes and their associated vessels. Therefore, values were assigned to other vessels as closely as possible, and where no appropriate matches were listed, the average efficiency value contained in the Best Practices document was assigned.

Total CO_2 emissions of BC Ferries

The engine efficiency described above was used in conjunction with fuel consumption in order to calculate the CO_2 emissions of BC Ferries. The diesel consumption per sailing was calculated using the following formula:

$$FDC_{SRV} = \frac{(HP_V \ x \ D_R)}{Ef}$$

Where,

FDC_{SRV}	=	Diesel consumption per sailing on route R by vessel V (L); vessel is exact for routes where only one vessel operated or representative on routes with more than one vessel operating.
HP_V	=	Horsepower of vessel (horsepower)
D_R	=	Distance of route R (km)
Ef	=	Engine efficiency (horsepower/L/kilometre), obtained from British Columbia Ministry of Environment (2013)

CO_2 emissions per route were calculated using the following formula:

$$\text{EFR}_{ARV} = \frac{(FDC_{SRV}\ x\ EF_D)}{10^6}\ x\ N_{AS}$$

Where,

EFR_{ARV}	=	Annual CO_2 emissions on a given route R by vessel V (tonnes of CO_2); vessel is exact for routes where only one vessel operated or representative on routes with more than one vessel operating.
FDC_{SRV}	=	Diesel consumption per sailing on route R by vessel V (L)
EF_D	=	EF for diesel fuel (2,663 g CO_2/L), as obtained from Environment Canada (2011)
N_{AS}	=	Annual number of sailings

Total annual BC Ferries emissions were calculated using the following formula:

$$EFR_A = \sum_{R=1}^{49} EFR_{ARV}$$

Where,

EFR_A	=	Annual CO_2 emissions of BC Ferries (tonnes CO_2) across all 49 individual routes
EFR_{ARV}	=	Annual CO_2 emissions on a given route R by vessel V (tonnes CO_2)

Per-passenger EFs of BC Ferries

Having calculated the emissions produced by various BC Ferries vessels on various routes, it was then possible to calculate per-passenger EFs for BC Ferries, which can be compared to other per-passenger values for other transportation modes.

Load factor calculations

First, load factors (LFs)[4] for BC Ferries were calculated to determine per-passenger EFs. I diverged from the Best Practices guidelines and calculated my own LFs because their ferry LF (average occupancy) was unrealistically high at 80%. According to my calculations, this is not achieved on any route. For many routes, BC Ferries provides monthly embarkation data, which I tallied in an Excel spreadsheet to determine an annual value. These data were used to determine passenger and vehicle LFs using the following formulas:

[4] The term load factor (LF) denotes the percentage of seats on a means of transportation that are occupied on any given service.

$$LF_{VPR} = \frac{N_{PR}}{C_P}$$

Where,

LFV_{PR} = Passenger LF for a given vessel V on a given route R in 2013
N_{PR} = Number of passengers embarked on the vessel on route R
C_P = Maximum passenger capacity of vessel

$$LF_{VVehicleR} = \frac{N_{VehicleR}}{C_{Vehicle}}$$

Where,

$LF_{VVehicleR}$ = Vehicle LF for a given vessel V on a given route R in 2013
$N_{VehicleR}$ = Actual number of vehicles on the vessel on route R
$C_{Vehicle}$ = Maximum vehicle capacity of vessel

For vehicles, BC Ferries statistics do not distinguish between types of vehicles loaded onto a ferry. Freight trucks would impact the LF if they are counted as a single vehicle because they take up the space of several cars, for instance. BC Ferries reported that system-wide approximately 5% of vehicles travelling on BC Ferries vessels are trucks (personal communication, Elizabeth Broadly of BC Ferries). Data for specific routes were not available. On routes where the required information was not readily available (for instance, where vessels travel on circular routes with various stops), BC Ferries' overall capacity numbers and passenger and vehicle statistics were taken from annual reports to calculate an average LF.

The LFs calculated in this manner differed significantly from the 80% figure provided by the Provincial Government (British Columbia Ministry of Environment 2013). According to my calculations, the average vehicle LF for BC Ferries is 43.1%, while for passengers it is merely 23.4%. For those routes for which specific LFs could be calculated, the lowest vehicle LF was 23.6% (Earls Cove–Saltery Bay), while the highest was 100% for Haida Gwaii sailings. In fact, for Haida Gwaii sailings the calculated LF was slightly above 100%, which could be due to either a statistical error or incorrect vessel data from BC Ferries. For passengers, the lowest LF calculated was 11.8% (Denman Island–Hornby Island), while the highest LF was 47.9% (Inside Passage).

Per-passenger EFs

Vessel-specific per-passenger EFs were calculated as follows. First, fuel consumption per passenger per sailing and per passenger for a given vessel on a given route were calculated using the following formulas.

$$FCF_{PSRV} = \frac{FDC_{SRV}}{N_{PR}}$$

Where,

FCF_{PSRV}	=	Diesel consumption per passenger per sailing on route R for vessel V (L/passenger); vessel is exact for routes where only one vessel operated or representative on routes with more than one vessel operating
FDC_{SRV}	=	Diesel consumption per sailing on a given route R for vessel V (L)
N_{PR}	=	Number of passengers on the vessel per sailing on route R

$$FCF_{PRV} = \frac{FCF_{PSRV}}{D_R} x\ 100$$

Where,

FCF_{PRV}	=	Diesel consumption per passenger on route R for vessel V (L/passenger/km)
FCF_{PSRV}	=	Diesel consumption per passenger per sailing on route R for vessel V (L/passenger)
D_R	=	Distance of route R (km)

Based on the fuel consumption figures, emissions per passenger per sailing (to compare per-trip emissions per passenger between modes) and per passenger (to compare between modes on a per-kilometre basis) for all routes were calculated using the following formulas. These represent per-sailing and per-passenger-kilometre EFs, respectively.

$$EFR_{PSRV} = \frac{FCF_{PSRV}\ x\ EF_D}{1000}$$

Where,

EFR_{PSRV}	=	Emissions per passenger per sailing on route R for vessel V (kg CO_2/passenger); vessel is exact for routes where only one vessel operated or representative on routes with more than one vessel operating.
FCF_{PSRV}	=	Diesel consumption per passenger per sailing on route R for vessel V (L/passenger)
EF_D	=	Diesel EF (2,663 g CO_2/L) as obtained from Environment Canada (2011)

$$EFR_{PRV} = \frac{FCF_{PRV}\ x\ EF_D}{100}$$

Where,

EFR_{PRV}	=	Emissions per passenger-kilometre on route R for vessel V (g CO_2/passenger/km); vessel is exact for routes where only one vessel operated or representative on routes with more than one vessel operating.
FCF_{PRV}	=	Diesel consumption per passenger on route R for vessel V (L/passenger/km)
EF_D	=	Diesel EF (2,663 g CO_2/L) as obtained from Environment Canada (2011)

Limitations of ferry calculations

There are three main limitations to my ferries calculations. First, BC Ferries schedules vary considerably between seasons. My listing is a conservative estimate of the annual sailings for each route, and thus underestimates emissions. Second, the distances vessels travel may not be exactly those provided by BC Ferries, or calculated by me for those routes for which BC Ferries did not provide information. Ferries can be affected by factors such as weather or traffic, so the distance travelled on any given sailing might be slightly larger than that listed in my compilation. Thus, my listing underestimates emissions. Third, it was not possible to assign a specific EF to each individual vessel because the data were not available. Vessels were matched to EFs as closely as possible.

3.2.3 Passenger aviation methodology

For passenger aviation, my method consisted of collecting usage data, determining plane-specific EFs, and then performing emission calculations (in the following order: emissions per route, annual passenger aviation emissions, city-pair emissions, passenger-flight EFs, and passenger-kilometre EFs).

Passenger aviation schedule listing

To calculate the emissions associated with passenger air transportation in BC, the first step was to catalogue flights that remain entirely within the province. A list of the airlines serving BC was compiled, along with the routes they serve and the number of flights operated weekly, the flight distance for all routes, and the number of passengers that can be carried on each flight. These input data are explained below.

Airlines serving BC

To determine all airlines that fly within BC, two lists of airlines serving BC were consulted (Transport Canada 2011, Travel.bc.ca 2013). The most current year for which Transport Canada information was available at the time of my research was 2011.

Routes and number of flights

To determine routes that remain entirely within BC, the websites of the airlines with flights within BC were consulted. For those (generally larger) airlines that have International Air Transport Association (IATA) codes and are broadly marketed, schedule information was obtained through the KVS Availability Tool software.[5] For non-IATA carriers, schedule information was obtained through searches on the respective airline's website. Two small float plane operators – Corilair and North Pacific Seaplanes – were excluded from the research. Both conduct small operations with many stops that are often based on ad-hoc demand rather than schedule.

Average week

From the schedule information, the number of flights for the week of November 17th, 2013 was determined. This week was chosen because it is 'average' in the sense that it contains no peak travel components such as public or school holidays. While the middle of November is an off-peak travel season and there are likely to be more flights during peak travel seasons, it is a reasonable assessment that the scheduled number of flights throughout the year will be at least as high during the week chosen for this research. From this average week, annual flights by airline by route were determined by multiplying by 52. For a few

[5] The KVS Availability Tool is a subscription service containing a wealth of flight and aviation information for "frequent flyers". It can be found online at www.kvstool.com.

routes which are not operated year-round, the actual number of weeks the flights are operated was used to derive the number of annual flights.

Flight distances

Distances between departure and destination point for each route were obtained using two different techniques. For most routes, distances (also known as stage lengths) were obtained using the Great Circle Mapper website.[6] For a few routes that have no official airport codes (mostly seaplane locations), distances between origin and destination were estimated based on Google Maps. Once this 'shortest distance between two points' was determined, a "diversion factor" was added to account for the fact that it is generally impossible for an airplane to fly exactly the shortest distance between two points because of operational considerations such as air traffic guidance and weather conditions. I was unable to find a formula for how to calculate a diversion factor in my search of the literature. In part this could be because the actual flight distance for any given flight will vary somewhat from flight to flight. Even though I was unable to find such a formula, the need for a diversion factor is obvious, so I attempted to estimate average diversion factors by comparing the 'shortest distance flown' with the actual distance flown for various flights on the website www.flightaware.com, which shows the flight paths of flights as well as statistics about the respective flights, including distance travelled. Based on this, for stage lengths of less than 100 km, I estimated the diversion factor to be 10%; for stage lengths between 100 km and 200 km, I estimated the diversion factor to be 7.5%; and for stage lengths of more than 200 km, I estimated the diversion factor to be 5%. A decreasing diversion factor was chosen because factors such as air traffic guidance and approach patterns often occur at either the origin or destination airport and are unrelated to the flight distance (however, longer flights

[6] The Great Circle Mapper lets users calculate the shortest distance between any two points in the world. It is available online at http://www.gcmap.com/dist.

have a higher probability of having to fly around weather, which adds to the diversion distance). The diversion factor was meant to add at least five kilometres to every route. The yearly kilometres flown by a given airline on a given route and total kilometres travelled by each airline within BC were calculated using the following formulas:

$$DA_{AR} = D_R \; x \; DF \; x \; N_{AR}$$

Where,

DA_{AR}	=	Annual distance flown by airline A on route R (km)
D_R	=	Distance of route R (km)
DF	=	Diversion factor (0.10, 0.075, or 0.05)
N_{AR}	=	Flights operated per year by airline A on route R (number of flights)

$$DA_A = \sum_{R=1}^{n} DA_{AR}$$

Where,

DA_A	=	Annual distance flown per airline A on all BC-internal routes (km)
DA_{AR}	=	Distance flown per route R per year (km)
n	=	Number of BC-internal routes routes for airline A

Number of passengers

The number of seats available per plane was obtained either as an exact figure from each airline's seat maps, or as an average when various plane types are used interchangeably. To account for real-world operating conditions as much as possible, a LF was used. For Air Canada and Westjet, these values are published and were used as exact values. For both airlines, the LF is approximately 80% (Newswire 2013, Times Colonist 2013). For all other airlines, specific LFs could not be obtained and thus a value of 80% was assumed. A LF value does not mean that every flight will always be 80% occupied. LFs are calculated system-wide and the average occupancy of a specific route may be higher or lower; however, information to this degree of specificity is not publicly available.

Emission factors

Review of existing aviation emission factors

There are many aviation emission calculators available online for public use, offered by a variety of providers such as environmental organizations or offsetting companies. These calculators generally compute emissions by multiplying the distance of an individual flight by an EF (usually expressed as grams of CO_2 per passenger per kilometre (g CO_2/pkm)). Generally, the EFs differ for short-haul, medium-haul, and long-haul flights (lower for longer flights to account for the more efficient cruise phase). There are three major problems with such emissions factors and their calculators: (1) the methodology used to arrive at the final emission value is often unclear or even unstated, (2) the distance distinctions between the EFs are arbitrary, and (3) the EFs assume a generic airplane. These problems are discussed in turn.

First, some emission calculators do not describe their methodology or the EFs used. Therefore, the user does not have any idea of how the final emissions figures were arrived at. Second, EFs for many emission calculators are distance-based, which leads to unrealistic cut-offs. For example, DEFRA (2013) categorizes domestic flights as less than 463 km, short-haul flights as between 463 and 1,108 km, and long-haul as greater than 1,108 km. The short-haul EF is 41% smaller than the domestic EF. Such a distance-dependent cut-off is significant in BC because there are a number of flights just below or just above the distance cut-off. This results in some longer flights having lower emissions than shorter flights, which, all other things being equal, is logically inconsistent. Third, EFs are generally generic and do not differ by airplane type. However, in reality, airplanes differ by size and fuel consumption patterns, for instance. Airplanes serving BC range in size from an average passenger capacity of four to 150.

Calculation of BC-specific airplane emission factors

Because of the uncertainties and issues with publicly available EFs, I decided to calculate BC-specific airplane EFs based on fuel consumption. The most accurate source of fuel consumption data is pilot handbooks that allow pilots to plan how much fuel they will need for a specific flight. However, this information is seldom available publicly. Consequently, an alternative, and more complicated, methodology was devised to estimate fuel consumption. First, basic information about the various plane types used in BC was obtained from online sources.[7] These data included the plane's empty weight, its maximum takeoff weight, its fuel capacity, and its maximum range with a full payload. Second, the actual weight of the aircraft was calculated. For a specific flight (assuming the plane would be loaded with the exact amount of fuel needed to complete the trip), the fuel weight was calculated using the following formula:

$$WJT_F = \left(\frac{D_{RDF}}{RMAX_P}\right) x\ CF_P\ x\ WF$$

Where,

WJT_F	=	Weight of total fuel for flight F (kg)
D_{RDF}	=	$D_R\ x\ DF$ = Stage length including diversion factor of route R (km)
$RMAX_P$	=	Maximum range of plane P with full payload (km)
CF_P	=	Fuel capacity of plane P (L)
WF	=	Weight of jet fuel (0.798 kg/L), as obtained from Imperial Oil (n.d.)

The actual take-off weight of the airplane was then calculated using the following formula:

$$W_T = W_P + (LF\ x\ W_{Pax}\ x\ S_P) + WJT_F$$

Where,

W_T	=	Take-off weight of airplane for flight F (kg)
W_P	=	Empty weight of airplane P (kg)
LF	=	Load factor (%)
W_{Pax}	=	Average weight of passenger (kg)[8]
S_P	=	Seat capacity of airplane P
WJT_F	=	Weight of fuel for flight F (kg)

[7] Most of the information was taken from the websites www.airlines-inform.com and www.what2fly.com.
[8] Average passenger weight is 84.1 kg (Federal Aviation Administration 2005).

As an intermediate step to calculate actual flight fuel consumption, the plane's fuel consumption if it were fully loaded was calculated using the following formula:

$$FCF_P = \frac{CF_P}{RMAX_P}$$

Where,

FCF_P	=	Fuel consumption of plane P when fully loaded (L/km)
CF_P	=	Fuel capacity of plane P (L)
$RMAX_P$	=	Maximum range of plane P with full payload (km)

Finally, the plane's actual consumption for a specific flight was calculated using the following formula:

$$FCA_{PF} = FCF_P \ x \ (\frac{W_{TP}}{W_{MP}}),$$

Where,

FCA_{PF} = Actual fuel consumption of plane P on flight F (L/km)
FCF_P = Fuel consumption of plane P if fully loaded (L/km)
W_{TP} = Take-off weight of plane P (kg)
W_{MP} = Maximum take-off weight of plane P (kg)

The above-described formulas are used for calculating BC-specific airplane EFs; they reflect real-world operating conditions as closely as possible in the absence of having access to proprietary aircraft and airline information.

Annual CO_2 emissions of BC passenger aviation

In this section, the following sequence of calculations was used to determine annual emissions: emissions per flight per route, emissions per route per year, emissions of each airline for routes it operates in BC, emissions of all airlines for all routes they operate in BC, and finally city-pair emissions.

Emissions on individual routes

The EF for each flight (for a given plane) was calculated using the following formula:

$$EF_{FRP} = FCA_{FRP} \ x \ EF_J$$

Where,

EF_{FRP}	=	EF for flight F on route R for plane P (kg CO_2/km)
FCA_{FRP}	=	Actual fuel consumption for flight F on route R for plane P (L/km)
EF_J	=	EF of jet fuel (2.55 kg CO_2/L), as obtained from International Carbon Bank & Exchange (2000)

Next, total emissions per flight were calculated using the following formula:

$$EA_{FRP} = EF_{FRP} \ x \ D_{RDF}$$

Where,

EA_{FRP}	=	Emissions per flight F on route R for plane P (kg CO_2)
EF_{FRP}	=	EF for flight F on route R for plane P (kg CO_2/km)
D_{RDF}	=	Stage length including diversion factor on route R (km)

Total annual emissions were then calculated using the following formula:

$$EA_{AR} = \frac{EA_{FRP} \ x \ N_F}{10^3}$$

Where,

EA_{AR}	=	Annual emissions of airline A on route R (tonnes CO_2)
EA_{FRP}	=	Emissions per flight F on route R for plane P (kg CO_2)
N_F	=	Number of flights per year

Annual emissions for all flights by all airlines were compiled and ranked in an Excel sheet in order of decreasing annual emissions in order to facilitate analysis of annual route emissions. Total annual emissions by each airline were calculated using the following formula:

$$EA_{AA} = \sum_{R=1}^{n} EA_{AR}$$

Where,

EA_{AA}	=	Annual CO_2 emissions of airline A on all routes operated by the airline within BC (tonnes CO_2)
EA_{AR}	=	Annual emissions of airline A on route R (tonnes CO_2)
n	=	Number of individual routes operated by airline A within BC

Total annual emissions of all BC passenger aviation were calculated using the annual emissions for each airline summed over all of its routes, as follows:

$$EA_A = \sum_{N=1}^{15} EA_{AA}$$

Where,

EA_A	=	Annual CO_2 emissions of BC passenger aviation (tonnes CO_2)
EA_{AA}	=	Annual CO_2 emissions of airline A on all routes operated by the airline within BC (tonnes CO_2)
N	=	Number of airlines operating flights within BC (=15)

City-pair emissions

When analyzing the emissions of aviation in BC and their geographical distribution, it is important to look not only at individual routes but also at city-pairs, as several airlines might serve the same route. A city-pair comprises the following: all airplane types an airline operates between the same two cities; all airlines that operate between the two cities; and all routes between the same cities (for example between various airports in Greater Vancouver and various airports in Greater Victoria). City-pair emissions were summed using the following formula:

$$EA_{CP} = \sum_{R=1}^{n} \sum_{A=1}^{m} \mathrm{EA}_{AR}$$

Where,

EA_{CP}	=	Total annual CO_2 emissions for all airlines serving routes between city-pair CP (tonnes CO2/year)
EA_{AR}	=	Annual emissions of an airline A operating flights on route R that is part of city-pair CP (tonnes CO_2)
R	=	Number of routes for city-pair CP
A	=	Number of airlines serving a given route R for city-pair CP

Per-passenger EF of BC passenger aviation

Emissions per passenger per flight (used to compare per trip emissions between modes), taking into consideration the respective LF, were calculated using the following formula.

$$EFA_{PRPax-Flight} = \frac{EA_{FRP}}{CS_P \ x \ LF}$$

Where,

$EFA_{PRPax\text{-}Flight}$	= EF per passenger-flight on route R for plane P (kg CO_2/passenger)
EA_{FRP}	= Emissions per flight F on route R for plane P (kg CO_2)
CS_P	= Seating capacity of plane P
LF	= Load factor

All emissions per passenger per flight were compiled and ranked in an Excel sheet in order of decreasing emissions.

Lastly, the per-passenger EF was calculated using the following formula:

$$EFA_{PRPax-Distance} = \frac{EA_{PRPax-Flight}}{D_{RDF}}$$

Where,

$EFA_{PRPax\text{-}Distance}$	=	EF per passenger-distance on route R for plane P (kg CO_2/km)
$EA_{PRPax\text{-}Flight}$	=	Emissions per passenger per flight F on route R for plane P (kg CO_2)
D_{RDF}	=	Stage length including diversion factor on route R (km)

All per-passenger EFs were compiled and ranked in an Excel sheet in order of decreasing emissions per passenger-kilometre.

Limitations of passenger aviation calculations

The passenger aviation schedule listing and emission inventory is subject to six main limitations. First, the inventory only includes scheduled, civil aviation flights. Private, charter, military, and agricultural flights are not included in the inventory. Second, while most (and all major) airlines serving BC routes are included in the inventory, a few had to be omitted because of accounting difficulties. The emission values would be slightly higher if these airlines had been included since they were small airline companies. Third, the inventory was based on an off-peak week. The number of flights (and consequently emissions) during peak seasons are likely slightly higher. Fourth, diversion factors were assigned that are meant to account for real-life operating conditions in which flying the shortest distance between origin and destination is generally not possible. The actual distances flown on any given day may be longer or shorter than the values assumed. Fifth, it was assumed that all airlines had an 80% LF. Actual LFs may be higher or lower, resulting in different emission values. Sixth, it was assumed that every plane carries exactly the amount of fuel needed to complete a specific flight. In all cases, airplanes carry more fuel, for example to be able to divert based on winter weather conditions, or where destination airports do not offer fuel services and the airplane carries enough fuel on the outbound flight to also operate the inbound flight. Because of the added weight of the extra fuel, emissions would be slightly higher. Overall, the error introduced by the above limitations should be fairly small and consequently not significantly affect the results obtained in this research.

3.2.4 Bus methodology

For bus travel, my method consisted of compiling usage information and then calculating emissions per route and per year.

Bus travel schedule listing

For buses, just as for aviation, a listing of weekly and annual services was first compiled and then aggregate emissions were calculated. Greyhound Canada is the only company that operates interurban bus services within BC. The Greyhound website (www.greyhound.ca) was used to identify routes and service. A route map available through the website[9] was consulted to identify which routes are serviced within BC, based on which

[9] Available at http://extranet.greyhound.com/Revsup/schedules/sa-50.pdf.

31 routes were identified. Distances for each route were obtained by inputting the origin and destination into the directions section of Google Maps. The website was then used to identify schedules during the off-peak week of November 9th, 2013.

Weekly and annual distance travelled

The annual kilometres travelled per route were calculated as follows:

$$D_{AR} = D_R \; x \; N_B \; x \; 52$$

Where,

D_{AR}	=	Annual distance travelled on route R (km)
D_R	=	Distance of route R (km)
N_B	=	Frequency of bus service per week on route R

Weekly and annual emissions

I had hoped to calculate BC-specific EFs for the Greyhound fleet based on fuel consumption data for the coaches in use but was unable to obtain such data; hence I had to use a generic bus EF obtained from DEFRA. To calculate per passenger Greyhound emissions, the following formula was used:

$$EBP_R = D_R \; x \; EF_B$$

Where,

EBP_R	=	Emissions per passenger on route R (kg CO_2/passenger)
D_R	=	Distance of route R (km)
EF_B	=	EF bus (0.0287 kg CO_2/pkm), obtained from DEFRA (2011)

The emissions per bus per route were calculated using the following formula:

$$EB_R = EBP_R \; x \; CS_B$$

Where,

EB_R	=	Emissions per bus trip on a given route R (kg CO_2)
EBP_R	=	Emissions per passenger on route R (kg CO_2/passenger)
CS_B	=	Western Canada seating capacity of bus (average of 51), obtained from Greyhound (2014), thus assuming the bus is 100% occupied.

Annual emissions per route were calculated using the following formula:

$$EB_{AR} = EB_R \ x \ N_B \ x \ 52$$

Where,
EB_{AR} = Annual bus emissions on route R (kg CO_2)
EB_R = Emissions per bus trip on a given route R (kg CO_2)
N_B = Frequency of service per week

Total annual CO_2 emissions for the Greyhound were calculated using the following formula:

$$EB_A = \sum_{R=1}^{31} EB_{AR}$$

Where,
EB_A = Annual CO_2 emissions of Greyhound bus service within BC (tonnes CO_2)
EB_{AR} = Annual bus emissions on route R (tonnes CO_2)
R = Route; there are 31 routes within BC

Limitations of bus calculations

The bus schedule listing and emission inventory are subject to two main limitations. First, an off-peak week was assumed to be reflective of the overall schedule. Actual service frequencies may be slightly higher, but this week was chosen to obtain a conservative estimate of bus service within BC. Second, I had to use a generic passenger-kilometre EF for buses because I was unable to calculate a BC-specific EF. While the generic EF is based on buses in the United Kingdom, a BC-specific EF likely would not differ much from the generic EF because modern coaches used in Europe and North America tend to be similar in their engine and vehicle size characteristics. Nevertheless, it may have been somewhat lower or higher, resulting in lower or higher emissions, respectively.

3.2.5 Passenger train methodology

For passenger trains, my methodology consisted of inventorying schedule information, and then calculating annual emissions per route and in aggregate.

Passenger train schedule listing

There is only one passenger rail service in BC, VIA Rail. The VIA Rail website (www.viarail.ca) was consulted to determine train routes and schedules. There are only two passenger train routes within BC: from the Alberta Border to Prince Rupert and from the Alberta Border to Vancouver. Both routes were divided into two sections each (for the Alberta Border to Prince Rupert route, to account for the train stopping in Prince George over night, and for the Alberta Border to Vancouver route, to account for the long distance and passengers possibly embarking or disembarking in Kamloops). The distances of each segment were determined based on VIA Rail documents (VIA Rail 2013, 2009). Schedules for both routes were compiled from the VIA Rail website.

Annual CO_2 emissions of BC passenger trains

To calculate annual emissions, emissions per passenger per train were first determined. Trains operating in BC are generally short, and can contain as few as two cars in the off-season. An average occupancy of 50 passengers per train was assumed since there is no publicly available LF. The emissions per train were calculated as follows:

$$ET_R = \frac{D_R \; x \; EF_T}{10^6} \; x \; 50$$

Where,

ET_R = Emissions per train trip on route R (tonnes CO_2 / passenger)

D_R = Distance of route R (km)

EF_T = EF for VIA Rail trains (117 g CO_2/pkm), obtained from the VIA Rail site on Wikipedia (2014)

Annual CO_2 emissions for each passenger train route were then calculated:

$$ET_{AR} = ET_R \; x \; N_T \; x \; 52$$

Where,

ET_{AR} = Annual train emissions on route R (tonnes CO_2)

ET_R = Emissions per train trip on route R

N_T = Frequency of service on route R per week in both directions

Total annual train CO_2 emissions were calculated using the following formula:

$$ET_A = \sum_{R=1}^{4} ET_{AR}$$

Where,

ET_A = Annual CO_2 emissions of passenger train service within BC (tonnes CO_2)
ET_{AR} = Annual train emissions on route R (tonnes CO_2)
R = Route; there are 4 routes within BC

Passenger train limitations

The passenger train schedule listing and emission calculations are subject to three main limitations. First, an average occupancy of each train had to be assumed. Occupancy information is not publicly available and likely differs across various regions served by VIA Rail as well. In BC, the average occupancy likely also changes significantly with the seasons, where trains during the summer carry tourists and have a much higher average passenger load. Second, it was not possible to obtain a LF or estimate one. Calculating an average LF for a train is more difficult than for other transportation modes because the capacity of the train can easily be changed by adding or removing train cars. Third, it was not possible to calculate a BC-specific passenger-kilometre EF because of a lack of statistics. Such an EF may have been slightly lower or higher than the generic VIA Rail EF, resulting in slightly lower or higher emission values.

3.3 Present-day emissions of freight transportation methodology

This section contains the methodologies employed for calculating present-day freight transportation emissions. The methods for the various transportation modes are discussed in the order of the respective mode's aggregate contribution to BC freight transportation emissions, namely trucking, marine, train, and aviation.

3.3.1 Freight trucking methodology

My freight trucking methodology was closely based on that for private vehicles. It involved compiling usage statistics, calculating a BC-specific tonne-kilometre EF, and then calculating trucking emissions (in the following order: kilometres travelled, changes in kilometres travelled between 2007 and 2013, annual emissions, and changes in emissions between 2007 and 2013).

Collecting BC data for trucking emissions calculations

To inventory trucking data, I used the same Average Annual Daily Traffic (AADT) data for 2007 and 2013 as for private vehicles, which was collected from 66 Permanent Count Sites and 13 short-count sites as discussed in Section 3.2.1. This was possible because the data from these sites tabulated all vehicles that travelled past them, including trucks. This daily value was multiplied by 365 to obtain the number of vehicles including trucks travelling past the counting site in a given year. Just as for private vehicles, I had to assume that all trucks contained in the AADT values would travel the entirety of a given route.

Percentage of vehicles that are trucks

Similar to private vehicles, it was necessary to assign a percentage to the AADT values to determine the number of vehicles that were trucks. Since the percentages included in the traffic data only distinguish between cars and trucks (as opposed to buses, motorcycles, etc.), the percentage of trucks for those sites for which data on the split between cars and trucks was available was calculated using the following formula:

$$PT = 1 - PPV$$

Where,

PT = Proportion of vehicles that are trucks (= percentage on route R / 100)
PPV = Proportion of vehicles that are private vehicles (cars) (= percentage on route R / 100)

For those sites for which a split was not available, an average proportion was calculated using the following formula:

$$APT = 1 - APPV$$

Where,

APT	=	Average proportion of vehicles that are trucks (= percentage on route R / 100)
APPV	=	Average proportion of vehicles that are private vehicles (cars) (74%, see discussion in section 3.2.1) (= percentage on route R / 100)

The average value for percentage of freight trucks was 26%.

Average freight weight of BC trucks

Because the trucking EF is per tonne-kilometre, it was necessary to calculate the average weight of freight carried by trucks in BC (rather than the weight of the truck and its freight, as the EF only applies to the freight). There are five traffic counting sites in BC which are capable of measuring the weight of the vehicles that travel past them, as well as of categorizing the vehicles into classes, including nine different types of trucks. For each site and each truck category, total weight of trucks was calculated using the following formula:

$$TWT_C = NT\ x\ GVW\ x\ CF$$

Where,

TWT_C	=	Total weight of trucks in a given class C (kg)
NT	=	Number of trucks
GVW	=	Gross vehicle weight (in pounds), obtained from traffic counting site data
CF	=	Conversion factor to convert from pounds to kilograms (0.4536)

Next, the average weight across all truck classes at each specific site was calculated using the following formula:

$$AWT_S = \frac{\sum_{C=1}^{9} TWT_C}{\sum_{C=1}^{9} NT_C}$$

Where,

AWT_S	= Average weight of trucks at a given counting site S (kg)
$\sum_{C=1}^{9} TWT_C$	= Total weight of trucks across nine classes of trucks C (kg)
$\sum_{C=1}^{9} NT_C$	= Total number of trucks across nine classes of trucks C

Following this, the average weight of BC trucks across all five counting sites was calculating using the following formula:

$$AWTBC = \frac{\sum_{S=1}^{5} AWT_S}{NS\ x\ 0.001}$$

Where,

AWTBC	= Average weight of trucks in BC (tonnes)
$\sum_{S=1}^{5} AWT_S$	= Sum of average weights of trucks at five counting sites S (kg)
NS	= Number of sites; there are five sites in BC

The average weight for trucks obtained using this method was 24.116 tonnes. Because the tonne-km EF is only for freight, the average weight of freight in BC was calculated using the following formula:

$$AWF = AWTBC - WTractor - WTrailer$$

Where,

AWF	=	Average weight of freight (tonnes)
AWTBC	=	Average total weight of trucks in BC (tonnes)
WTractor	=	Average weight of a truck tractor (9.07 tonnes), derived from Truckers Report (2008)
WTrailer	=	Average weight of a truck trailer (5.90 tonnes), derived from ShipNorthAmerica Transportation (2013)

Using this method, an average freight weight of 9.15 tonnes was calculated.

BC-specific freight trucking EF

A freight trucking tonne-kilometre EF was calculated at the national level because statistics do not exist at the provincial level, and was assumed to hold for BC. This EF was calculated based on data obtained from Statistics Canada (2014a). Because these data pertain to trucking revenues, not a trucking EF, I had to follow a four-step process to calculate a Canada trucking EF. The first step was to calculate a ratio of tonne-km travelled to weight carried using the following formula:

$$\text{RTKMW} = \frac{TKMC}{WTC\ x\ 0.001}$$

Where,

RTKMW	=	Ratio of tonne-km to weight carried for a given year in Canada

TKMC	=	Tonne-km for trucks in Canada, obtained from Statistics Canada (2014a)
WTC	=	Total weight carried by trucks in Canada (kg), obtained from Statistics Canada (2014a), then converted to tonnes

An average of this ratio was calculated using the following formula:

$$RATKMCW = \frac{\sum_{A=1}^{6} RTKMW}{6}$$

Where,

RATKMCW	=	Average ratio of tonne-km to weight carried in Canada between 2007 and 2012
RTKMW	=	Ratio of tonne-km to weight carried for a given year in Canada
A	=	Year (total of six from 2007 to 2012)

Tonne-km operated by trucks in BC were estimated using the following formula:

$$TKMBC = WTBC \text{ x } RATKMCW$$

Where,

TKMBC	=	Tonne-km operated in BC
WTBC	=	Weight of freight operated by trucks in BC (kg), derived from Statistics Canada (2012c)
RATKMCW	=	Average ratio of tonne-km to weight carried in Canada

A BC-specific freight trucking EF was estimated using the following formula:

$$EFTBC = \frac{ETFBC}{TKMBC}$$

Where,

EFTBC	=	EF of BC trucking (g CO_2/tonne-km)
ETFBC	=	Annual (urban and interurban) emissions of BC trucking (tonnes CO_2)
TKMBC	=	Tonne-km operated by trucks in BC

Using this method, a BC trucking EF of 196 g CO_2/tkm was calculated.

Trucking emissions calculations

The annual kilometres driven between origin and destination of a given route were calculated using the following formula:

$$D_{RA} = T_{RA} \ x \ P_R \ x \ D_R$$

Where,

D_{RA}	=	Annual distance driven on a given route R (km)
T_{RA}	=	Annual traffic on route R obtained from Ministry of Transportation's AADT (number of vehicles)

P_R	=	Proportion of vehicles captured by counting site that are trucks for route R (= percentage on route R / 100)
D_R	=	One way distance between origin and destination (km), derived from Google Maps

The D_{RA} values were determined for the years 2007 and 2013. The change in kilometres driven on route R between 2007 and 2013 was calculated using the below formula. The percentage change values were used in the future scenario emission calculations.

$$Percentage\ change_{DR} = \frac{D_{R\,2013} - D_{R\,2007}}{D_{R\,2007}}\ x\ 100$$

Where,

$D_{R\,2013}$	=	D_{RA} kilometres driven in 2013 on route R
$D_{R\,2007}$	=	D_{RA} kilometres driven in 2007 on route R

Annual CO_2 emissions of interurban truck travel in BC

The following formula was used to calculate annual emissions for each interurban route:

$$ETF_{AR} = \frac{D_R\ x\ EFT_{BC}}{10^6}$$

Where,

ETF_{AR}	=	Annual emissions per interurban route R (tonnes CO_2)
D_R	=	Annual distance driven on interurban route R (km)
EFT_{BC}	=	EF of BC trucking (= 196 g CO_2/tkm)

Total annual interurban trucking emissions were calculated using the following formula:

$$ETF_A = \sum_{R=1}^{79} ETF_{AR}$$

Where,

ETF_A	=	Annual emissions of trucks on all 79 interurban routes within BC (tonnes CO_2)
ETF_{AR}	=	Annual emissions per interurban route R (tonnes CO_2)

Changes in emissions 2007 - 2013

To compare emission changes between 2007 and 2013, the below formula was used. The percentage change values were used in the future scenario emission calculations.

$$Percentage\ change_{EPV} = \frac{ETF_{2013} - ETF_{2007}}{ETF_{2007}}\ x\ 100$$

Where,

ETF_{2013} = ETF_A emissions in 2013

ETF_{2007} = ETF_A emissions in 2007

Freight trucking limitations

Trucking calculations were subject to seven main limitations, several of which mirror those for private vehicles as a similar methodology was employed. They are discussed in the order in which the methodology was presented above.

First, some Permanent Count Sites are not reported every year, while short-count sites do not collect data for extended periods as Permanent Count Sites do, so they may not have contained data for 2007 or 2013. Where information for the years 2007 or 2013 was not available, this was noted in the Excel spreadsheet and data from the closest suitable year substituted without making adjustments to the values.

Second, a split between cars and trucks was not available for all counting sites, so I had to assign an average for those sites for which this information was not available. The actual number of trucks at these sites may be higher or lower, resulting in higher or lower emission values.

Third, where Permanent Count Sites distinguish between cars and trucks, they distinguish between three different length (sizes) of trucks. Because an average truck weight was needed for calculations and because determining the empty weights of different truck sizes proved impossible, I had to combine all types of trucks into one category. If several truck classes and weights could have been included in the calculations, the values would have more accurately reflected the weight of freight carried and consequently emissions. This may have resulted in slightly lower or slightly higher emission values.

Fourth, not every interurban route in BC has a traffic counter. If a route did not have a counter, it was not included in my calculations. While the counters are strategically placed in the province and the 79 counters I used cover the vast majority of primary BC interurban routes and a few secondary routes, there are also routes that are not included in my research, for which I had to assume that traffic was zero. If all interurban routes (those with counters and without) had been included, the calculated emissions would be higher.

Fifth, just as for cars I had to assume that 100% of trucks counted on a given route travel the entirety of that route. While this will overestimate usage and emissions, it was not possible to quantitatively calculate an accurate percentage of trucks that do or do not travel an entire route. If such a percentage could have been calculated for all routes, the emission values would have been lower than my values.

Sixth, a trucking tonne-km EF, based on ratios for freight carried relative to kilometres and tonne-kilometres relative to weight carried, was calculated based on national data, because the relevant data does not exist at the provincial level. While the national data does include aggregated BC data, BC-specific data may have resulted in slightly higher or lower ratios, which would have influenced emission calculations.

Seventh, calculating emissions required the average weight of freight of BC trucks to be calculated. Average freight weight, rather than average overall truck weight, was required because the tonne-km EF for freight trucking applies only to the amount of freight carried, and not the weight of the overall truck. Because I was only able to calculate one average freight weight, the actual weight of freight on any given route and trip may be higher or lower, resulting in higher or lower emissions. The average freight weight is comparatively low because it is an average of loaded and empty trucks.

3.3.2 Marine freight methodology

For marine freight, my method involved obtaining information on the amount of marine freight carried to be able to calculate marine freight emissions. Unlike the other modes covered in this study, for marine freight, it was not possible to determine the geographical distribution of emissions in BC.

Amount of marine freight carried

Data on the amount of marine freight carried within BC for a given year was obtained from Statistics Canada's series "Shipping in Canada" (Statistics Canada 2012b). This data series, however, was discontinued in 2011. The amount of domestic freight handled in BC and its composition in the years 2007 and 2011 were obtained from two documents (Statistics Canada 2010, 2012a) in order to analyze whether marine freight shipments within BC had increased or decreased in that period of time. In the report for 2007 (Statistics Canada 2010), there are three port sites listed for Vancouver, but these were amalgamated (in name only) into what is now Port Metro Vancouver in 2008 (Port Metro Vancouver 2014). In order to compare values for Vancouver between years more easily, the values for the individual Vancouver port sites for 2007 were combined.

Total CO_2 emissions of marine freight in BC

It was not possible to find schedule information for BC marine freight. The Port of Vancouver was contacted for assistance but no reply was received. Consequently, an independent inventory of BC marine freight emissions could not be compiled and a secondary approach had to be devised. The "Report on Energy Supply and Demand in Canada" (Statistics Canada 2015b) lists fuel consumption by various sector of the BC economy, including "domestic marine". Emissions of domestic marine freight in BC were calculated by year using the following formula:

$$EMF_A = \left(\frac{EF_D \ x \ FC_D}{10^6}\right) - EFR_A$$

Where,

EMF_A	=	Annual emissions from marine freight transport in BC (tonnes CO_2)
EF_D	=	EF diesel (2,663 g CO_2/L), as obtained from Environment Canada (2011)
FC_D	=	Annual consumption of "domestic marine" diesel fuel in BC (L)
EFR_A	=	Annual emissions of BC Ferries (tonnes CO_2); from ferry emission value as calculated using SMITE (see Section 3.2.2 above)

Marine freight limitations

The marine freight inventory is subject to three main limitations. First, it was not possible to compile BC-specific data on marine freight routes, schedules, etc., because such information is not publicly available. Also, it was not possible to determine the geographical distribution of marine freight emissions because, while statistics on the amount of marine freight handled by BC ports are available, there were no indications as to where the freight was travelling (other than that it travelled to other destinations within BC).

Second, "Domestic marine" category in the "Report on Energy Supply and Demand in Canada" represents Canadian-registered vessels fuelled in BC, but no information is collected on whether the fuel is consumed in BC waters or outside the province, nor is there a split between freight ships and pleasure boats (Ng 2015a). While this means that the Statistics Canada data could include vessels that are fuelled in BC and then leave the province, the emissions of which should not be included in this study, any error introduced in this way should be minimal. Based on a search of the Transport Canada Vessel Registration System, 15,452 vessels are registered in BC, but of the subcategories of vessels, only "cargo" and "tanker" could be ocean-going, and there are only 52 cargo vessels and 3 tankers registered (Transport Canada 2015). Therefore, the vast majority of fuel sold to BC-registered vessels is likely also consumed within BC waters. However, this includes fishing vessels which do not qualify as interurban transportation, but there were no appropriate statistics to disaggregate fishing vessel fuel consumption. My value for marine freight emissions, because I am using Statistics Canada data, can be considered an upper limit. The value for marine freight emissions listed in the BC Provincial Inventory (British Columbia Ministry of Environment 2012) is larger than that calculated using the method outlined above. However, this may be because it contains all vessels, where the Statistics Canada data includes only registered vessels. There is a difference between *licensing* a vessel (a free service, for example for pleasure boats) and *registering* a vessel (a paid service, for example for commercial vessels) (Transport Canada 2015). Consequently, if the BC Provincial Inventory Report (PIR) includes all boating, including pleasure boating, this would explain why the value is larger than that derived from all fuel consumed by registered vessels in BC.

Third, it was not possible to calculate a BC-specific marine freight EF because it was not possible to find information on fuel consumption and the overall distance travelled by marine freight vessels in BC. Data on fuel consumption and weight of freight handled by ports is available, but without distance statistics, a specific EF could not be calculated. Calculating a BC-specific EF would have allowed comparisons of marine freight emissions to other transportation modes.

3.3.3 Rail freight methodology

My rail freight method consisted of calculating annual CO_2 emissions and calculating a tonne-kilometre EF.

Annual CO_2 emission calculations

To calculate rail freight emissions, statistics on diesel fuel consumption by railways in BC were obtained from Statistics Canada (2014c). Because fuel consumption was used, no

BC-specific freight rail EF could be determined. Emissions for both 2007 and 2012 were calculated using the following formula:

$$ERF_A = \frac{EF_D \; x \; FCBCD}{10^6}$$

Where,

ERF_A	=	Annual emissions of rail freight in BC (tonnes CO_2)
EF_D	=	EF of diesel (2,663 g CO_2/L), as obtained from Environment Canada (2011)
FCBCD	=	Annual consumption of diesel fuel for railways in BC (L), as obtained from Statistics Canada (2014c)

EF for rail freight calculations

A rail freight EF was calculated based on national rather than provincial statistics because provincial level data were not available. These calculations included data for Canada-wide railway diesel fuel consumption (Statistics Canada 2014c) and operating statistics, including tonne-kilometre data (Statistics Canada 2014d). Annual CO_2 emissions Canada-wide were calculated using the following formula:

$$ERFC_A = \frac{EF_D \; x \; FCCD}{10^6}$$

Where,

$ERFC_A$	=	Annual emissions of rail freight in Canada (tonnes CO_2)
EF_D	=	EF of diesel (2,663 g CO_2/L), as obtained from Environment Canada (2011)
FCCD	=	Annual consumption of diesel fuel for railways in Canada (L), as obtained from Statistics Canada (2014c)

Next, a Canada-specific EF for rail freight was calculated using the following formula:

$$EFRFC = \frac{ERFC_A}{Tkm_A}$$

Where,

EFRFC	=	EF of rail freight in Canada (kg CO_2/tonne-km)
$ERFC_A$	=	Annual emissions of rail freight in Canada (tonnes CO_2)
Tkm_A	=	Annual tonne-kilometres travelled by Canadian rail freight

Freight train limitations

The freight train inventory is subject to two main limitations. First, Statistics Canada data had to be relied on for emissions and usage information. It was not possible to compile an independent inventory of rail freight transportation in BC. The railway emission value listed in the BC PIR (British Columbia Ministry of Environment 2012) is significantly smaller than that calculated using the method outlined above. However, although both sources are ultimately from Statistics Canada, the method outlined above utilizes the data set which comprises “common carrier railways operating in Canada that provide for-hire passenger and freight services” and is incompatible with the BC PIR dataset which comprises “all refiners and major distributors of refined petroleum products in Canada” (Ng 2015b). While it seems contradictory that railways in BC could use more fuel than what is provided by refineries, it make sense when one considers that fuel can be loaded outside of BC and still consumed in BC. The second limitation is that it was only possible to calculate an EF at the national rather than provincial level due to lack of provincial-level statistics. While BC data are part of the aggregated national data, the BC-specific value may be larger or smaller.

3.3.4 Aviation freight methodology

For aviation freight, a methodology similar to that for passenger aviation was developed, which included inventorying schedule information, determining plane-specific EFs, and then calculating emissions (in the order of emissions per route, annual emissions, emissions per flight, and tonne-kilometre EFs).

Aviation freight inventory

BC air freight operators and freight flights within BC were identified through an online search. The website www.flightaware.com allows users to select an airport and see all of that airport’s flight activities, including passenger and freight flights. Knowing the destinations and names (or, for the purposes of my search, call-signs) of the airlines in question, it was possible to catalogue the three routes with aviation freight service within BC and frequencies operated during the week of October 7th, 2014, which as far as I could determine was an 'average' week for transport of freight by air.

In order to calculate aviation freight emissions accurately, base data about the respective airplanes used were compiled. The methodology employed to calculate data such as the weight of fuel for a specific flight was identical to that employed to calculate these values for passenger aviation, as discussed in section 3.2.3.

Emissions per flight

Emissions per flight were calculated using the following formula:

$$EAF_{FRP} = EF_{FRP} \; x \; D_{RDF}$$

Where,

EAF_{FRP}	=	Emissions per flight F on route R for plane P (kg CO_2)
EF_{FRP}	=	EF for flight F on route R for plane P (kg CO_2/km)
D_{RDF}	=	Stage length including diversion factor on route R (km)

Annual emissions for each route were calculated using the following formula:

$$EAF_{AR} = \frac{EAF_{FRP} \; x \; N_F}{10^3}$$

Where,

EAF_{AR}	=	Annual emissions of airline A on route R (tonnes CO_2)
EAF_{FRP}	=	Emissions per flight F on route R for plane P (kg CO_2)
N_F	=	Number of flights per year on route R

Total emissions of BC aviation freight were calculated using the following formula:

$$EAF_A = \sum_{R=1}^{3} EAF_{AR}$$

Where,

EAF_A	=	Annual CO_2 emissions of BC freight aviation (tonnes CO_2)
EAF_{AR}	=	Annual emissions of airline A on route R (tonnes CO_2)
R	=	Route; there are 3 routes

Freight-flight EFs were calculated using the following formula:

$$EFAF_{R-weight} = \frac{EAF_{FRP}}{CF_P \; x \; LF}$$

Where,

$EFAF_{R\text{-weight}}$	=	EF per unit of freight per flight F (kg CO_2)
EAF_{FRP}	=	Emissions per flight F on route R for plane P (kg CO_2)
CF_P	=	Capacity of freight for airplane (kg)
LF	=	Load factor

Freight-kilometre EFs were calculated using the following formula:

$$EFAF_{R-weight-distance} = \frac{EAF_{R-weight}}{D_{RDF}}$$

Where,

$EFAF_{R\text{-weight-distance}}$	= EF per unit of freight per kilometre in BC (kg CO_2/tonne-km)
$EAF_{R\text{-weight}}$	= EF per unit of freight per flight F (kg CO_2)
D_{RDF}	= Stage length including diversion factor of route R (km)

Aviation freight limitations

The aviation freight schedule listing and emission inventory are subject to two main limitations. First, only flights that are operated as all-freight operations are included. It is possible that passenger flights also carry some cargo, such as mail, but this was not included in my inventory because these flights are already included in the passenger aviation inventory. Second, while the inventory is representative of the time at which it was compiled (October 2014), it is difficult to judge without schedules if operations during the rest of the year are the same. Moreover, it is possible that at least some freight is flown on an ad-hoc basis rather than on a schedule. If a company spontaneously chartered a plane to carry a given amount of cargo on a flight within BC, this should be included in my inventory; however, it would be exceedingly difficult to catalogue ad-hoc cargo flights without direct access to airline company data.

3.3.5 Data uncertainty assessment

In this section, data uncertainties for each mode are catalogued based on four questions that assist in understanding the credibility of SMITE calculations. This assessment can be combined with the comparison data presented in Chapter 4 to gain perspective on the reliability of SMITE results. The four questions used in my assessment were:

What was the nature of data availability? Availability was assessed as ‘minimal BC-specific data’, ‘limited BC-specific data’, or ‘significant BC-specific data’.

Was it possible to create a fine resolution inventory of the transportation mode with the available data? The ability to create a geographically detailed inventory was assessed as ‘no inventory created’, ‘basic inventory created’, or ‘detailed inventory created’.

Was it possible to devise calculation methods for each mode that reflect BC operations? The ability to perform calculations that reflect operations in BC (e.g., BC-specific EFs or using BC usage statistics) was assessed as either ‘very limited BC-specific calculations’, ‘limited BC -specific calculations’, or ‘detailed BC -specific calculations’.

Was it possible to compare or validate results with other sources? An assessment of ‘not possible’ was assigned where validation was not possible or, if it was, results were significantly different from other sources and the differences could not be explained. An assessment of ‘possible’ was assigned where validation was possible and values were either comparable or the differences could be explained, such as differing methodological approaches.

Table 3.1 summarizes the answers to each question for each mode. Discussion of validation is continued in Section 4.4 of the next chapter.

Table 3.1: Data uncertainty assessment

Mode	Question 1: Data availability	Question 2: Inventory creation	Question 3: BC-specific calculations	Question 4: Data validation
Passenger				
Private vehicle	Significant BC-specific data	Detailed inventory created	Detailed BC-specific calculations	Possible
Ferries	Significant BC-specific data	Detailed inventory created	Detailed BC-specific calculations	Possible
Passenger aviation	Significant BC-specific data	Detailed inventory created	Detailed BC-specific calculations	Possible
Bus	Limited BC-specific data	Basic inventory created	Limited BC-specific calculations	Not possible
Passenger trains	Minimal BC-specific data	Basic inventory created	Limited BC-specific calculations	Possible
Freight				
Trucking freight	Significant BC-specific data	Detailed inventory created	Detailed BC-specific calculations	Possible
Marine freight	Minimal BC-specific data	No inventory created	Very limited BC-specific calculations	Possible
Rail freight	Minimal BC-specific data	No inventory created	Limited BC-specific calculations	Possible
Aviation freight	Limited BC-specific data	Detailed inventory created	Detailed BC-specific calculations	Not possible

3.4 Future emission scenario methodology

This section outlines the methodological approach taken to answer Research Question 2 on how the province can achieve its legislated GHG emission reduction targets for 2020 and 2050. A methodology was developed for creating future emission scenarios, calculating emissions from these scenarios, comparing these emissions to the legislated targets, and calculating offset costs for scenarios that fail to meet the target reductions (and offset 'returns' for scenarios that meet the targets). This methodology is the future emission scenario component of the SMITE tool.

3.4.1 Future emission scenario component of SMITE

In addition to calculating present-day BC interurban transportation emissions, the SMITE tool was used to study the effect of changes to BC's interurban transportation emissions on meeting (or not) the province's legislated emission reduction targets. This part of SMITE consists of a master template that can be copied to run scenarios. The master template contains all transportation modes. For each transportation mode, there are two columns for inputing or calculating what I call "actual/projected values" and "target values" between the years from 2007 to 2050.

Actual values are the 'present-day' values calculated using the present-day methodologies described in the above present-day methodology sections of this chapter. They are the estimated yearly emission values between 2007 and 2014. As described in the present-day methodology sections, the year for which emissions could be calculated varies depending on the transportation mode. Projected values were then calculated for each mode for the years that follow the last year for which actual values could be calculated. The projected values change depending on the scenario used. For example, if the latest calculated actual value was for the year 2012, and a scenario dictated that emissions were to be reduced by 1% every year in a sector, then each year's emissions were determined from 2013 to 2050 by multiplying the previous year's value by a factor of 0.99. Thus, SMITE contains or determines annual emissions values for every year between 2007 and 2050.

Target values are the emission values that need to be obtained for the province to meet its 2020 and 2050 targets. For each transportation mode, the 2007 target value equals the 2007 actual value. The year 2007 is when BC's GHG reduction targets were set. Then, for every year from 2008 to 2020, the target value is reduced by 3.03% over the previous year, which results in the compound reduction required to obtain a 33% reduction by 2020. Between 2020 and 2050, the annual reduction rate increases to 3.95% to obtain the overall reduction target of 80% over 2007 values by 2050.

For every year and every transportation mode, the discrepancy of the actual/projected value and the target value is calculated using the following formula:

$$Discrepancy_Y = \frac{E_{AP} - E_T}{E_T} x\ 100$$

Where,

E_{AP} = Actual/Projected emissions for a given year Y (tonnes CO_2)
where,
Actual emissions = yearly emissions values as calculated using the 'present-day methodologies between 2007 and 2014, or latest year between these years for which they could be calculated;
Projected emissions = yearly emissions projected for a given scenario from the latest 'present-day' year to 2050

E_T = Target emissions for a given year Y (tonnes CO_2)

$Discrepancy_Y$ = discrepancy between actual/projected emissions and target emissions for a given year Y (%)

SMITE contains, below every data series, a line chart that compares the projected and target values visually to illustrate the discrepancy between the two values and whether the values are diverging or converging over time. Figure 3.2 provides an illustrative example of a line chart in which emissions, while decreasing over time, are unable to meet the target values, while Figure 3.3 provides an illustrative example of a line chart in which emission reductions exceed target values.

Figure 3.2: Illustrative example of line chart in which targets are not met

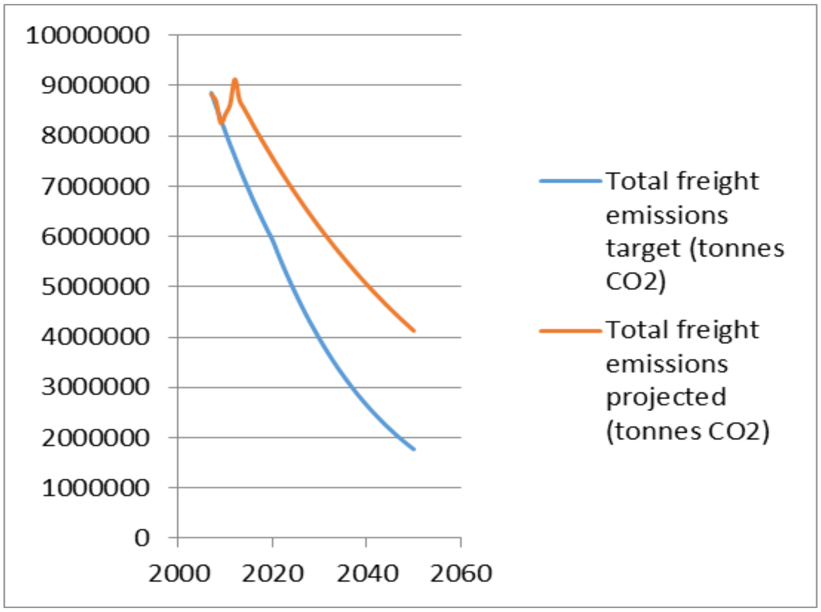
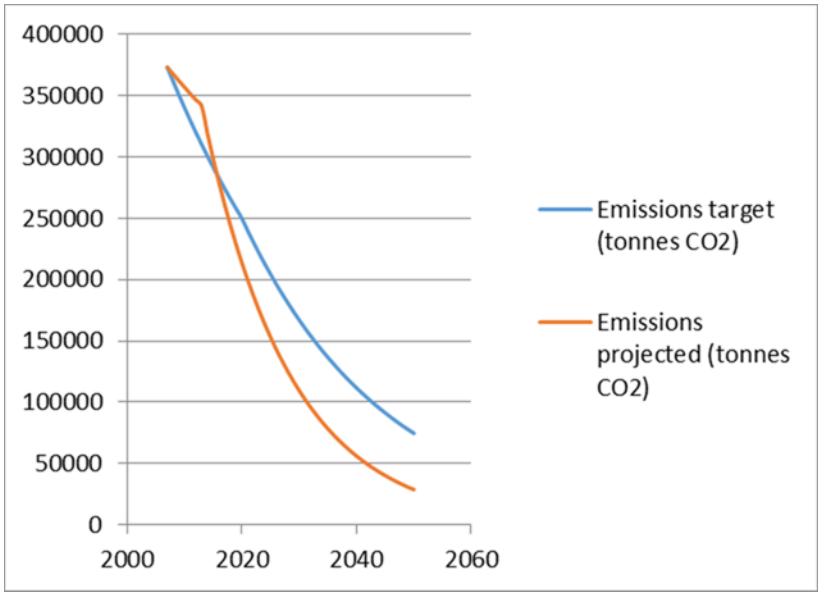


Figure 3.3: Illustrative example of line chart in which targets are exceeded



No line charts were included in Chapter 5.

Passenger and freight are calculated separately and then summed, as follows:

$$E_{Pass} = \sum_{M=1}^{5} E_M$$

Where,

E_{Pass} = Total passenger emissions for all modes for a given year Y (tonnes CO_2)

E_M = Total emissions from a given mode for a given year Y (aviation, bus, private vehicle, ferry, train) (tonnes CO_2)

$$E_{Freight} = \sum_{M=1}^{4} E_M$$

Where,

$E_{Freight}$ = Total freight emissions for all modes for a given year Y (tonnes CO_2)

E_M = Total emissions from a given mode for a given year Y (aviation, marine, train, truck) (tonnes CO_2)

$$ET = E_{Pass} + E_{Freight}$$

Where,

ET = Total interurban transportation emissions in BC in year Y (tonnes CO_2)

E_{Pass} = Total passenger interurban transportation emissions in year Y (tonnes CO_2)

$E_{Freight}$ = Total freight interurban transportation emissions in year Y (tonnes CO_2)

Comparing scenarios and target values

SMITE was constructed to display in pie charts, for each scenario, the share of each interurban transportation mode for the years 2007, 2013 (or latest year for which an actual value could be calculated), 2020, and 2050. It determines whether the 2020 and 2050 targets have been met for a given year for a given scenario, calculates the discrepancy, and determines whether the targets are met within a margin of 20%. The purpose of this latter value is to be able to rank simulations based on which ones allow BC to achieve its GHG reduction targets, or, if the targets cannot be achieved, which scenarios come close to achieving the mandated goals.

Furthermore, SMITE contains 'tracker' sheets that contain a list of all scenarios that were run along with the changes incorporated into the scenario, the projected 2020 and 2050 emission values, and whether the targets have been met, or met with a margin of 20%, in each scenario. Scenarios are ranked in order of increasing discrepancy from the target value (i.e., the greater the discrepancy, the greater the scenario misses the target value). The scenario with the lowest overall projected emissions, and hence lowest discrepancy, is ranked #1.

Cost comparison

The cost of offsetting excess emissions, or the worth of excess credits if scenarios exceed target values, were also estimated. For this, the following carbon prices (per tonne of CO_2) were assumed: $5 for 2007, $10 for 2008, $15 for 2009, $20 for 2010, $25 for 2011, $30 from 2012 to 2019 (all based on the actual carbon prices used by the province of BC (British Columbia Ministry of Finance 2008)), and $100 from 2020 to 2050 (National Round Table on the Environment and the Economy 2009). Projections for future carbon prices vary widely in the literature, based in part on objectives and circumstances. In order to provide a conservative value, the $100 dollar value was chosen because it was in the lower to mid-range. It was assumed that if projected emissions were below the target value, the province would be able to sell these credits on the carbon market at market value. Offset costs for each year were calculated using the following formula:

$$Cost_{SY} = (ET_{Projected} - ET_{Target})\ x\ Cost_{OY}$$

Where,

$Cost_{SY}$	=	Cost of scenario S for year Y (dollars)
$ET_{Projected}$	=	Total projected emissions for year Y (tonnes CO_2)
ET_{Target}	=	Total target emissions for year Y (tonnes CO_2)
$Cost_{OY}$	=	Cost of carbon offsets in the year Y (dollars/tonne CO_2)

Total offset costs or credit values for each scenario were then calculated as follows:

$$Cost_S = \sum_{A=1}^{44} Cost_{SY}$$

Where,
$Cost_S$ = Total cost of scenario S (dollars)
Y = Year between 2007 and 2050 (2050-2007+1=44 years over which to sum costs)
$Cost_{SY}$ = Cost of scenario in a given year Y (dollars)

3.4.2 Choosing scenarios to model

There is an infinite number of possible changes to each individual transportation modes and to the transportation system overall that could be modelled using SMITE. Since it is not possible to model all possible scenarios, parameters for devising scenarios had to be set. The process of scenario selection is explained in Chapter 5.

CHAPTER 4: INVENTORY OF BC'S INTERURBAN TRANSPORTATION CO_2 EMISSIONS AND EMISSION FACTORS

4.1 Introduction

This chapter contains answers to Research Question One, *What are the present-day CO_2 emissions and emission factors of interurban passenger and freight transportation in BC?* Transportation of people and freight is a vital part of BC's economy and the lifestyle of British Columbians, but it produces significant CO_2 emissions.[10] According to SMITE model results, in 2013, interurban transportation in BC produced approximately 11,194,000 tonnes of CO_2. Passenger transportation produced approximately 2,443,000 tonnes of CO_2 (21.8% of total emissions), while freight transportation produced approximately 8,751,000 tonnes of CO_2 (78.2% of total emissions). The purpose of this chapter is to present and analyze the contribution of each interurban transportation mode in BC to these emissions totals and, where applicable, analyze their EFs for carrying people or goods. The chapter is divided into two major subsections: passenger and freight transportation. Within these sections, transportation modes are discussed in the order of their contribution to overall BC transportation CO_2 emissions, as follows: for passenger transportation, (1) private vehicles, (2) ferries, (3) passenger aviation, (4) bus travel, (5) passenger trains; and for freight transportation, (6) freight trucking, (7) marine freight, (8) freight rail, and (9) aviation freight.

[10] All values in this chapter are for CO_2, not CO_2e. Where appropriate, select CO_2e factors were converted to CO_2. Using CO_2 instead of CO_2e does not have a significant impact on overall emissions because CO_2e values are typically only about 1% larger than CO_2 values.

4.2 Passenger transportation within BC

4.2.1 Private vehicles

Introduction

Private vehicles are the most common form of daily passenger transportation in BC. Benefits of private vehicles for interurban transportation include flexibility and access to many locations that may either not be well or at all serviced by publicly available transportation. In total, the 79 interurban vehicle counting sites considered in this study captured 117,870,669 vehicle movements in 2007, and 121,201,608 in 2013. According to SMITE calculations, total BC interurban private vehicle emissions were 1,809,667 tonnes CO_2 in 2007 and 1,917,247 tonnes CO_2 in 2013. Private vehicles were responsible for 17.1% of total interurban transportation emissions and 78.4% of total passenger transportation emissions.

In this section, private vehicle usage and emissions are discussed in the following order: (1) total interurban private vehicle distances driven in 2007 and 2013, (2) percentage change of distances driven between 2007 and 2013, (3) private vehicle emissions per kilometre of road, and (4) emissions produced by interurban private vehicle usage.

Total distance driven

According to SMITE calculations, British Columbians drove a total of 8.96 billion interurban kilometres in 2007 and 9.49 billion interurban kilometres in 2013. The breakdown of these distances driven by passenger vehicles on all 79 interurban routes is contained in Table A2.1 in Appendix 2. To illustrate these results, Table 4.1 below lists the 10 routes from Table A2.1 with the longest distances driven in BC in 2007 and in 2013. For the 69 routes not show in the table below, their distance values range from 211 million kilometres driven for rank #11 to 3.9 million kilometres for rank #79. Figure 4.1 displays the geographical distribution of kilometres driven in 2013. The figure is also illustrative for 2007 because the vast majority of the routes considered did not change their kilometres-driven category on the map.

Table 4.1: Ranking of BC routes by kilometres driven in 2007 and 2013

Rank	2007 distance driven (km)	Route	2013 distance driven (km)	Route
1	1,156,784,280	Vancouver–Chilliwack	1,120,642,345	Vancouver–Chilliwack
2	598,329,845	Ladysmith–Victoria	619,618,890	Ladysmith–Victoria
3	319,172,308	Vernon–Kelowna	345,182,544	Parksville–Campbell River
4	314,236,267	Hope–Merritt	339,781,478	Vernon–Kelowna
5	305,851,896	Parksville–Campbell River	327,401,725	Hope–Merritt
6	293,216,238	Parksville–Nanaimo	306,142,144	Kelowna–Penticton
7	275,043,910	Kelowna–Penticton	290,824,773	Parksville–Nanaimo
8	259,536,827	Chilliwack–Hope	267,043,271	Chilliwack–Hope
9	245,903,653	Vancouver–Squamish	250,063,982	Tete Jaune Cache–Kamloops
10	234,430,740	Hope–Penticton	245,903,653	Vancouver–Squamish

Figure 4.1: Geographical distribution of kilometres driven in BC in 2013

The rank of the two highest counting sites in terms of total distances driven annually did not change between 2007 and 2013. The longest distance driven was recorded at the Vedder site (Route 1 between Vancouver and Chilliwack), with approximately 1.16 billion kilometres driven in 2007 and 1.12 billion kilometres in 2013. The second longest distance driven was recorded at the Hidden Hills site (Route 1 between Ladysmith and Victoria), with approximately 598 million kilometres in 2007 and 620 million kilometres in 2013. The third longest was at the Buckley Bay site (Route 19 between Parksville and Campbell River), with approximately 306 million kilometres in 2007 and 345 million kilometres in 2013. By contrast, the shortest distance driven was recorded at the Windy Point Bridge site (Route 37A between Meziadin Junction and Stewart), with approximately 4.6 million kilometres in 2007 and 4.0 million kilometres in 2013. The geographic distribution of distance driven is, expectedly, linked to population density, with most kilometres driven in more densely populated areas such as the Lower Mainland area around Vancouver and least kilometres driven in less densely populated areas such as BC's northern areas.

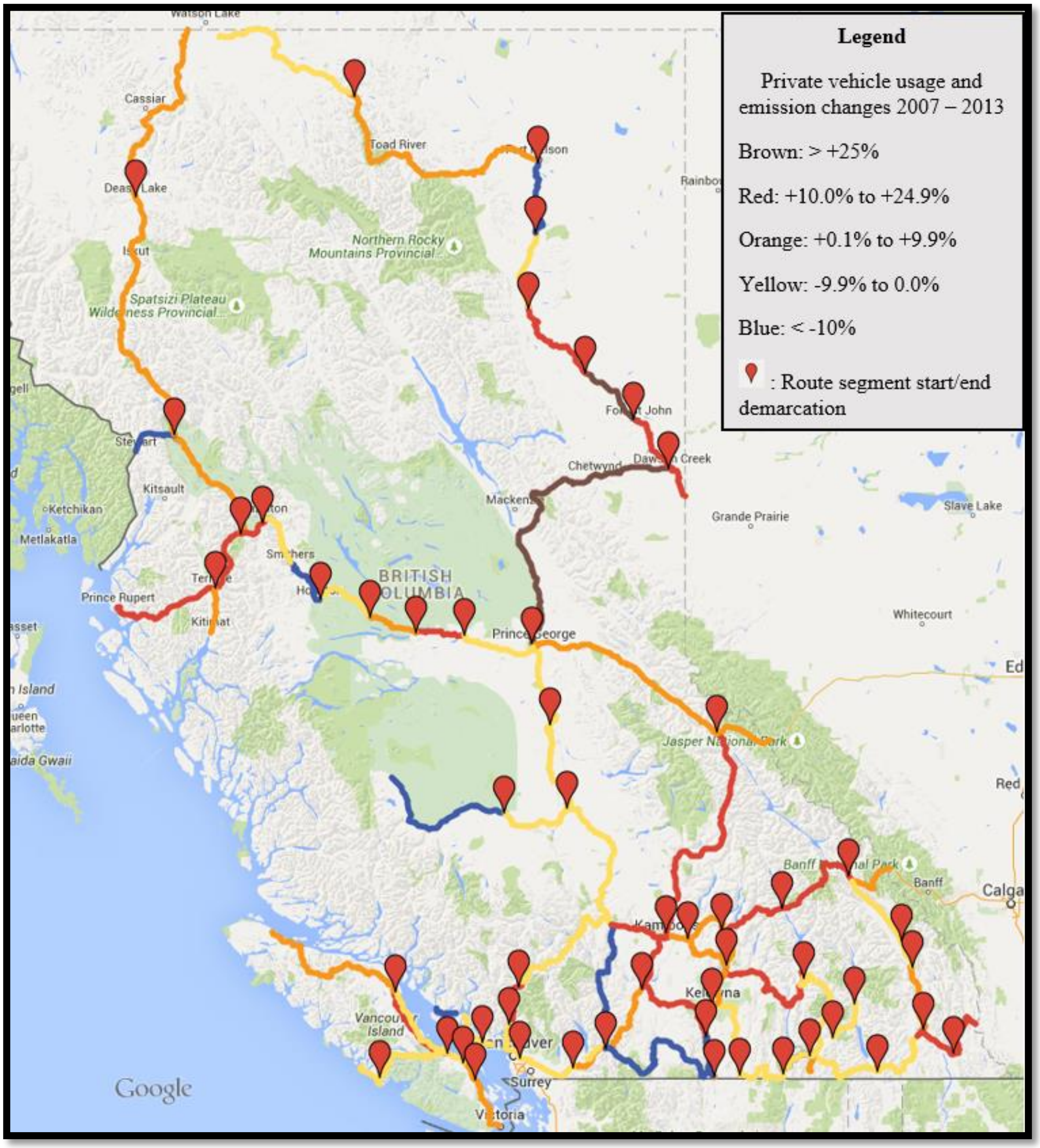
Change in distances driven between 2007 and 2013

Comparison of traffic statistics permitted calculation of changes in traffic volumes between 2007 and 2013. The percentage change in distance driven by interurban passenger vehicles is contained in Table A2.2 in Appendix 2. Out of the 79 counting sites considered for interurban passenger vehicle traffic, 43 sites had increased vehicle numbers, five sites had no change, and 31 sites had decreased vehicle numbers. To illustrate these results, Table 4.2 below contains the three largest and three smallest changes between 2007 and 2013. Figure 4.2 displays on which routes within BC kilometres driven have increased or decreased.

Table 4.2: Percentage changes in distance driven on BC routes 2007-2013

Rank	Route	2007 distance driven (km)	2013 distance driven (km)	% Change
1	Dawson Creek–Prince George	104,349,668	149,029,774	42.8
2	Fort St. John–Wonowon	25,745,337	35,294,953	37.1
3	Salmon Arm–Revelstoke	113,350,429	141,044,410	24.4
. . .				
77	Hope–Cache Creek	141,632,994	113,984,025	-19.5
78	Hope–Penticton	234,430,740	181,927,242	-22.4
79	Alexis Creek–Anahim Lake	14,875,531	9,415,598	-36.7

Figure 4.2: Geographical distribution of percentage change in distance driven 2007-2013



Increases across the province in distances driven by interurban passenger vehicles ranged from +42.8% to +0.1%. The largest increase in vehicle numbers was at the Willow Flats counting site, which reports traffic between Dawson Creek and Prince George on Route 97. Between 2007 and 2013, this site had an increase of 42.8%. The second highest increase was at the Inga Lake site, which reports traffic between Fort St. John and Wonowon on Route 97, and which had an increase of 37.1%. The third highest increase was at the Craigellachie site, which reports traffic between Revelstoke and Salmon Arm on Route 1, and which had an increase of 24.4%. The remaining increases across BC range from 20.1% to 0.1%.

Five sites reported no change in traffic counts. Decreases ranged from -0.2% to -36.7%. The third highest decrease was at the China Bar site, which counts traffic between Hope and Cache Creek on Route 1, and which had a decrease of -19.5%. The second highest decrease was at the Nicolum site, which counts traffic between Hope and Penticton on Route 3, and which had a decrease of -22.4%. The largest decrease in vehicle numbers was reported at the Kleena Kleene Bridge site, which counts traffic between Alexis Creek and Anahim Lake on Route 20. Between 2007 and 2013, this site had a decrease in vehicles, and hence kilometres driven, of -36.7%.

Emissions per kilometre of road

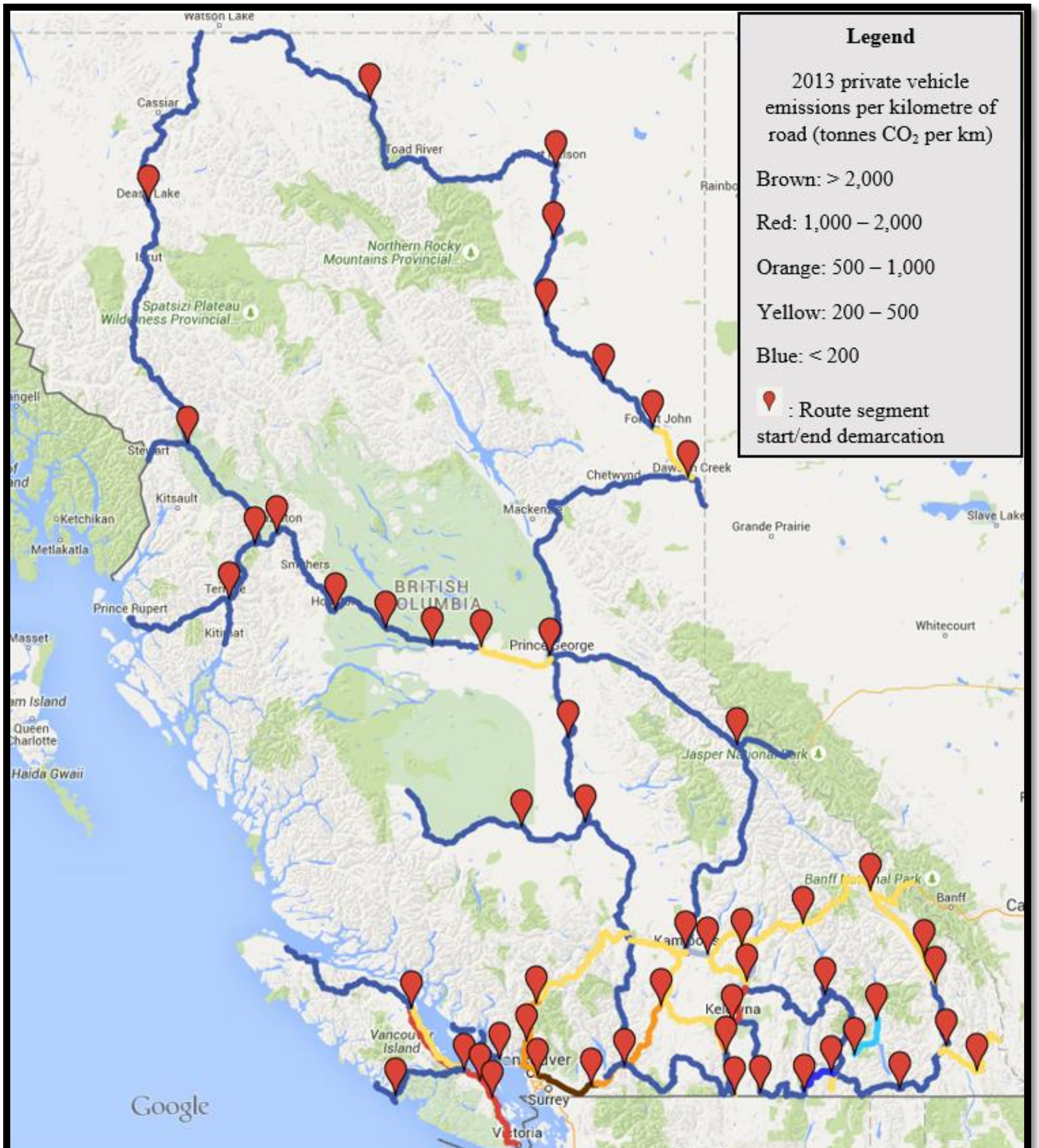
In addition to total vehicle-kilometres driven, which are directly related to the length of a particular route on which traffic is counted, it is possible to calculate emissions generated per kilometre of road. These values give an indication of how heavily a given route is travelled. This is helpful in devising emission reduction scenarios because reduction measures such as increased public transit will be more effective for higher relative traffic volume roads. The emissions per kilometre of road per year on all routes are contained in

Table A2.3 in Appendix 2. To illustrate these results, Table 4.3 below contains the three largest and three smallest values for 2007 and 2013, ranked by 2013 values. Figure 4.3 illustrates the emissions per kilometre of road for each route in 2013. The map is also illustrative for 2007 because the map category of nearly all routes has not changed between 2007 and 2013.

Table 4.3: Emissions per kilometre of road for 2007 and 2013

Rank	Route	2007 emissions per km of road (tonnes CO_2/km)	2013 emissions per km of road (tonnes CO_2/km)
1	Vancouver–Chilliwack	2,337	2,264
2	Nanaimo-Ladysmith	1,591	1,604
3	Parksville–Nanaimo	1,559	1,546
…			
77	Dease Lake–Yukon Border	14	11
78	Meziadin Junction–Dease Lake	10	11
79	Alexis Creek–Anahim Lake	10	9

Figure 4.3: Emissions per kilometre of road on BC routes in 2013



In BC, the route with the highest emissions per kilometer was at the Vedder site, which counts traffic between Vancouver and Chilliwack on Route 1, which had 2,337 tonnes CO_2 per kilometre of road in 2007 and 2,264 tonnes CO_2 per kilometre of road in 2013. The second highest route was at the Cassidy site, which counts traffic between Nanaimo and Ladysmith on Route 1, and which had approximately 1,591 tonnes CO_2 per kilometre of road in 2007 and 1,604 tonnes CO_2 per kilometre of road in 2013. The third highest route was at the Parksville site, which counts traffic between Parksville and Nanaimo on Route 19, and which had 1,559 tonnes CO_2 per kilometre of road in 2007 and 1,546 tonnes CO_2 per kilometre of road in 2013.

The route with the third lowest emissions per kilometre of road was at the Cassiar Junction site, which counts traffic between Dease Lake and the Yukon Border on Route 37, and which had 14 tonnes CO_2 per kilometre of road in 2007 and 11 tonnes of CO_2 per kilometre of road in 2013. The route with the second lowest emissions per kilometre of road was at the Stikine River Bridge site, which counts traffic between Meziadin Junction and Dease Lake on Route 37, and which had 11 tonnes CO_2 per kilometre of road in 2007 and 10 tonnes CO_2 per kilometre of road in 2013. The lowest emissions per kilometre of road in the province were at the Kleena Kleene Bridge site, which counts traffic between Anahim Lake and Alexis Creek on Route 20, and which had 10 tonnes CO_2 per kilometre of road in 2007 and 9 tonnes CO_2 per kilometre of road in 2013.

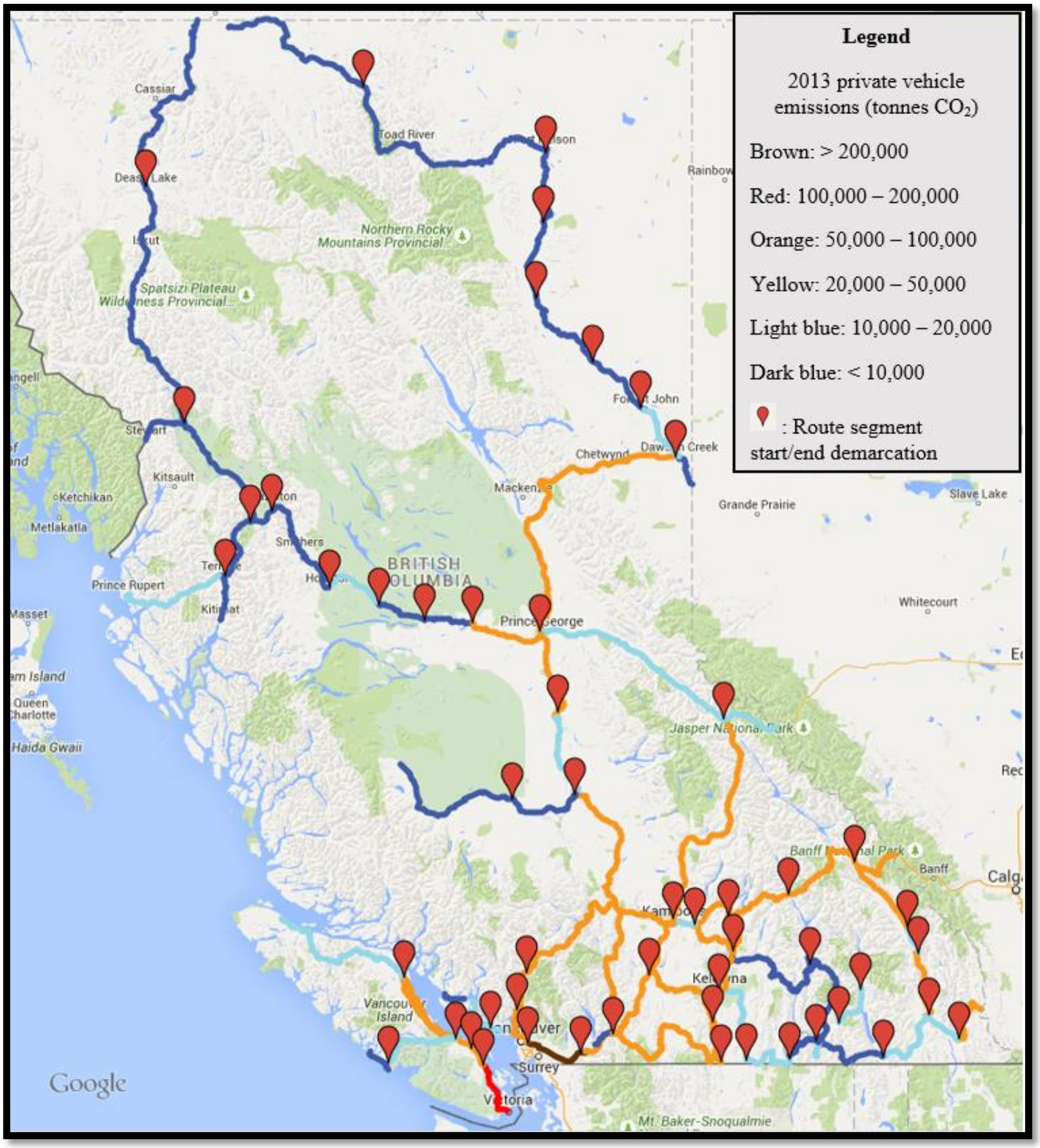
Total CO_2 emissions of private vehicle travel in BC

Total interurban private vehicle emissions in 2007 were approximately 1,809,667 tonnes CO_2, while in 2013 they were approximately 1,916,108 tonnes CO_2. The breakdown of these emissions for all 79 interurban routes in BC is contained in Table A2.4 in Appendix 2. To illustrate these results, Table 4.4 below contains the 10 routes from Table A2.4 with the highest CO_2 emissions in 2007 and 2013. The remaining routes range in values from 42,000 tonnes CO_2 for rank #11 to 800 tonnes CO_2 for rank #79. Figure 4.4 displays the geographical distribution of the emissions in 2013. The map is also illustrative for 2007 because the map categories of the vast majority of routes have not changed between 2007 and 2013.

Table 4.4: Private vehicle interurban CO_2 emissions by route in BC

Rank	**2007 emissions (tonnes CO_2)**	**Route**	**2013 emissions (tonnes CO_2)**	**Route**
1	233,670	Vancouver–Chilliwack	226,370	Vancouver–Chilliwack
2	120,863	Ladysmith–Victoria	125,163	Ladysmith–Victoria
3	64,473	Vernon–Kelowna	69,727	Parksville–Campbell River
4	63,476	Hope–Merritt	68,636	Vernon–Kelowna
5	61,782	Parksville–Campbell River	66,135	Hope–Merritt
6	59,230	Parksville–Nanaimo	61,841	Kelowna–Penticton
7	55,559	Kelowna–Penticton	58,747	Parksville–Nanaimo
8	52,426	Chilliwack–Hope	53,943	Chilliwack–Hope
9	49,673	Vancouver–Squamish	50,513	Tete Jaune Cache–Kamloops
10	47,355	Hope–Penticton	49,673	Vancouver–Squamish

Figure 4.4: Private vehicle interurban CO_2 emissions by route in BC in 2013



Emissions follow the same ranking as those values for distances driven (Table 4.1) because the same EF was used for all private vehicle highway driving. The route with the highest emissions is Vancouver–Chilliwack, with 226,370 tonnes CO_2. This route leads from Vancouver, BC's biggest city, to several of its suburbs, which likely explains the high vehicle volume and emissions. The route with the second highest emissions is Ladysmith–Victoria, with 125,163 tonnes CO_2. This short route leads from Victoria, one of BC's biggest cities and its capital, north towards Nanaimo. Because the distance is comparatively short, high emissions result from a high traffic volume. The route with the third-highest emissions is Parksville–Campbell River, with 69,727 tonnes CO_2. This route also forms part of the route from Victoria north, and high emissions result from a high traffic volume because the distance is comparatively short.

Discussion

Private vehicles are an important part of the BC interurban transportation system, and responsible for the highest share of passenger transportation emissions. Because private vehicle usage increased between 2007 and 2013, and because the average vehicle EF did not significantly improve in this period, the emissions associated with private vehicles in BC increased between 2007 and 2013. However, they should have decreased in order to be on track to meet BC's GHG reduction targets.

Assuming single occupancy for private vehicles, the vehicle-specific EF is equivalent to the per-passenger EF, since the driver is the sole passenger. At approximately 202 g CO_2/pkm, the Canada-specific private vehicle EF is virtually identical to the generic car EF provided by DEFRA. However, the value used in SMITE is only for highway driving, whereas the DEFRA EF also includes less efficient urban driving, which indicates that the average Canadian car is slightly less efficient than the average car considered by DEFRA.

Overall, two factors influence route-specific interurban passenger emissions from private vehicles in SMITE: distance and volume of vehicles. Emissions are a product of the distance of a route and the number of vehicles that travel it. Therefore, a long route with low traffic volume can have similar emissions to a short route with a high traffic volume. Determining route-specific emissions is essential for determining their geographic distribution, such as illustrated in Figure 4.4. This information can, in turn, be used by the public and policymakers to devise geography-specific strategies for reducing CO_2 emissions.

4.2.2 Ferries

Introduction

Ferries play an important role in BC's transportation network because they serve people living on islands off the coast of BC and coastal communities. Of BC's population of 4.5 million, approximately 780,000 or 17% live on Vancouver Island (Vancouver Island Economy Alliance 2013), while approximately 23,000 or 0.5% live on the 13 main islands that comprise the Gulf Islands between Vancouver Island and the BC mainland (Newton n.d.). Moreover, those people living in the Sunshine Coast area, which is just northwest of Vancouver, rely on ferries for connections to the rest of the province. Passenger ferry services within BC are provided by BC Ferries. BC Ferries has a fleet of 35 vessels, ranging in capacity from 133 people and 16 vehicles to 2,100 people and 470 vehicles (BC Ferries 2014). They operated approximately 154,627 sailings on 49 routes in 2013, travelling a total distance of 2,514,824 km. On these sailings, they carried 7.37 million vehicles (out of a possible 17.97 million vehicles at full capacity) and 18.98 million passengers (out of a possible 85.08 million passengers at full capacity), while consuming approximately 128.3 million litres of diesel fuel, which resulted in emission of 342,400 tonnes of CO_2. Ferries accounted for 3.1% of total interurban transportation emissions and 14.0% of passenger transportation emissions. In this section, calculations are discussed in the following order: (1) total BC Ferries emissions, (2) passenger-sailing EFs, and (3) passenger-kilometre EFs.

Total ferry travel CO_2 emissions in BC

The total CO_2 emissions produced by BC Ferries in 2013 were approximately 342,000 tonnes of CO_2. The breakdown of these emissions for all 39 origin and destination pairs is contained in Table A2.5 in Appendix 2. To illustrate these results, Table 4.5 below contains the 10 most emission-intensive pairs. These 10 routes account for approximately 301,000 tonnes CO_2, or 88% of the total of 342,000 tonnes, and the remaining 29 routes together only account for approximately 41,000 tonnes CO_2, or 12% of the total. Figure 4.5 displays the geographic distribution of BC Ferries' annual emissions on the level of the entire province (with northern routes emphasized for improved visibility), while Figure 4.6 displays the geographic distribution of BC Ferries' annual emissions zoomed into the southwestern corner of the province, because this is where most BC Ferries routes are operated.

Table 4.5: Annual emissions of BC Ferries routes

Rank	**Route and number**	**Annual emissions (tonnes CO_2)**
1	Tsawwassen–Duke Point	81,097
2	Tsawwassen–Swartz Bay	80,686
3	Horseshoe Bay–Departure Bay	74,075
4	Horseshoe Bay–Langdale	18,561
5	Inside passage Prince Rupert–Port Hardy	10,966
6	Earls Cove–Saltery Bay	10,396
7	Haida Gwaii–Prince Rupert	6,893
8	Powell River–Comox	6,229
9	Salt Spring/Fulford–Victoria	5,664
10	Pender Island–Swartz Bay	5,533

Figure 4.5: Geographic distribution of BC Ferries annual CO_2 emissions (entire province)

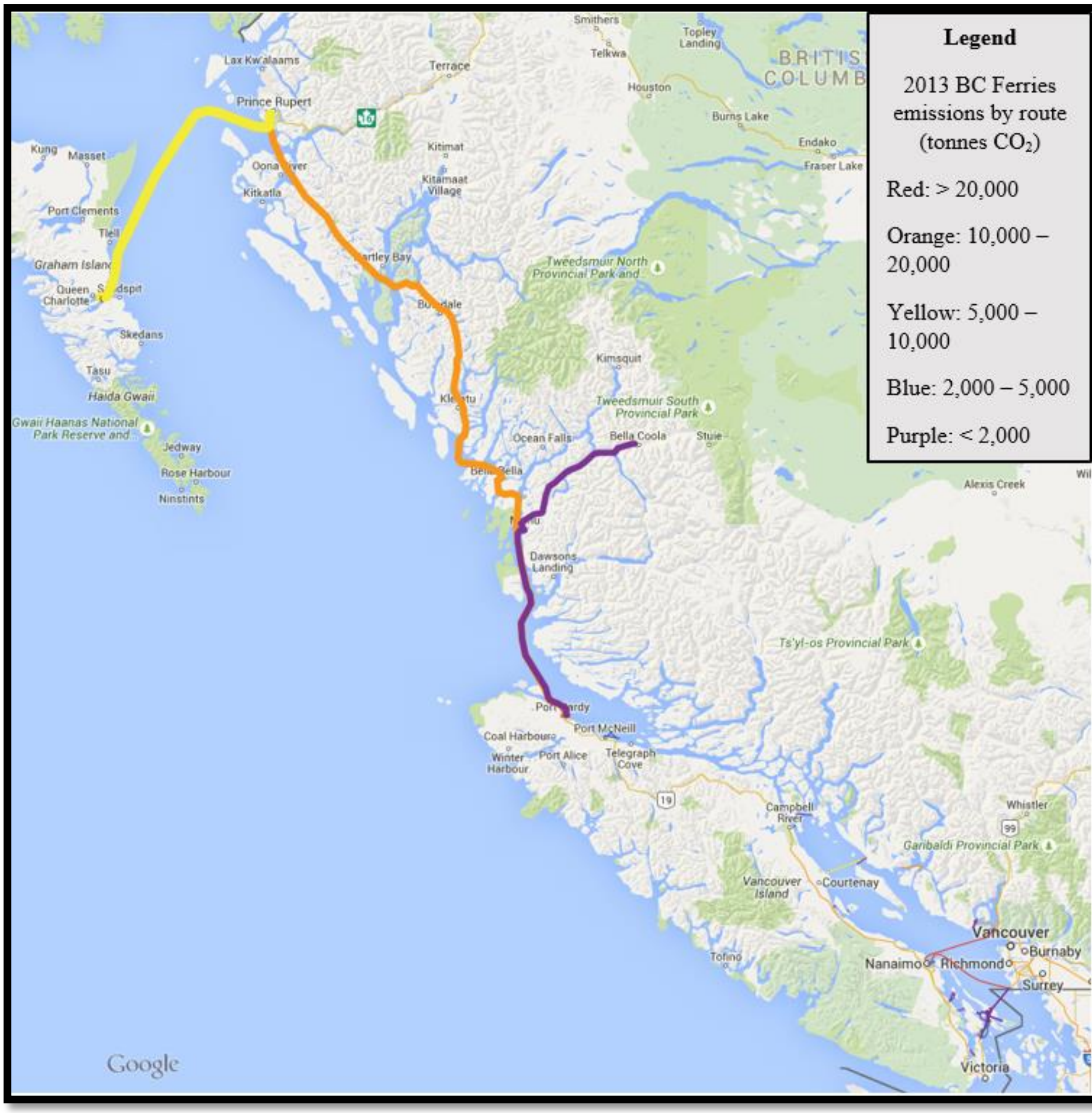
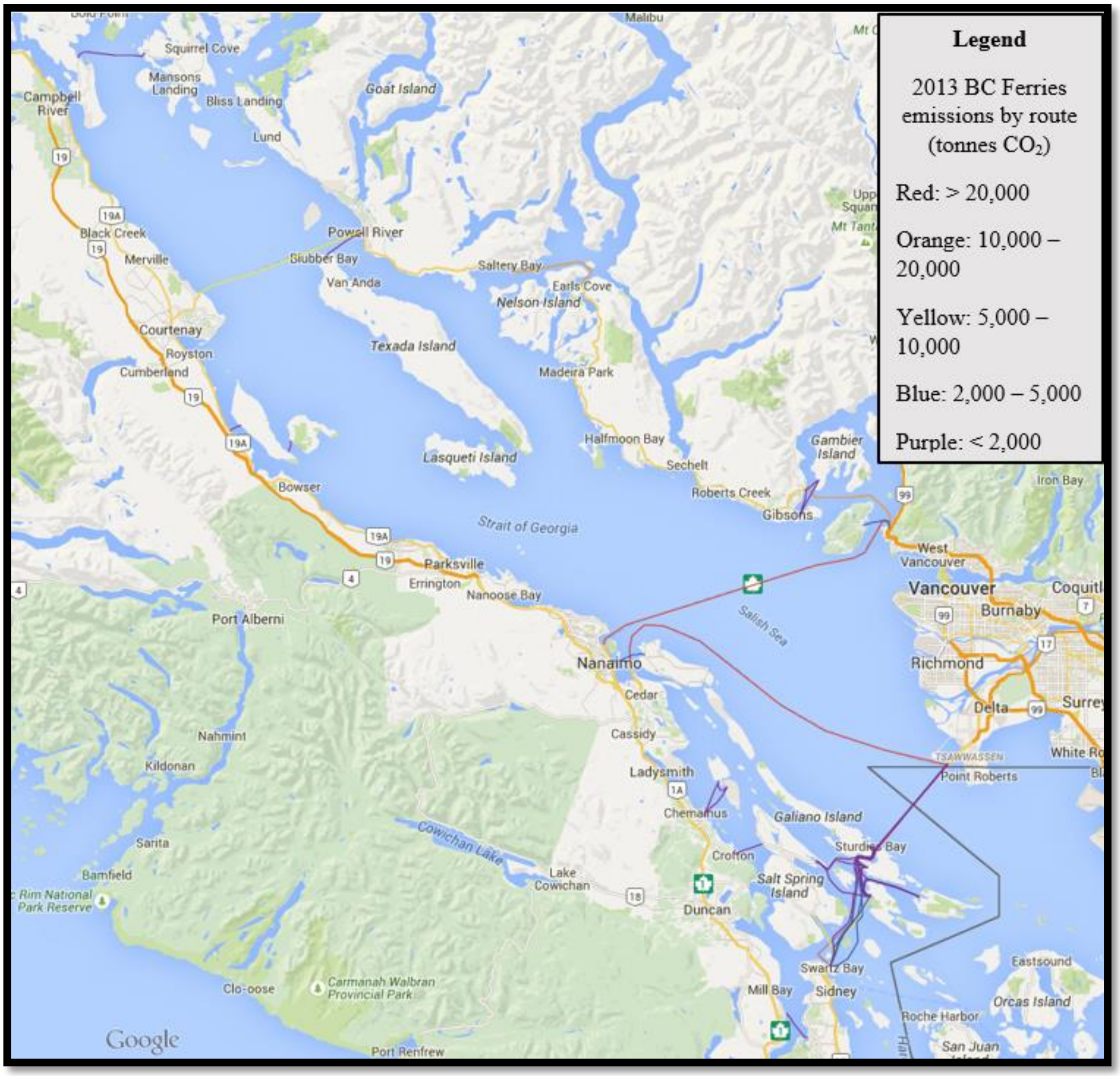


Figure 4.6: Geographic distribution of BC Ferries annual CO_2 emissions (southwestern BC)



High emissions are attributable to three factors: distance of sailing, frequency of sailing, and size of vessel used. The three most emission-intensive routes are all main routes between Vancouver and Vancouver Island (Tsawwassen and Horseshoe Bay are Vancouver's ferry ports; Swartz Bay is near Victoria; Duke Point and Departure Bay are near Nanaimo). All three routes are comparatively long, have a high sailing frequency (as often as hourly), and use the largest ferries in BC Ferries' fleet. The 5th and 7th ranked routes have a low frequency but use large vessels and cover long distances, while the remaining routes in Table 4.5 are all short but with very high sailing frequencies. BC Ferries emissions are concentrated in the province's southwest corner between Vancouver and Vancouver Island, although the northern ferry routes also have high emissions, mostly by virtue of their long distances.

Passenger-sailing EFs on BC Ferries routes

Passenger-sailing EFs (which can be used to compare the emissions of a given trip between transportation modes) for all 49 routes are contained in Table A2.6 in Appendix 2. To illustrate these results, Table 4.6 lists the 10 most emission-intensive sailings per passenger. These routes have passenger-sailing EFs greater or equal to 25 kg CO_2. All remaining routes have values that are below 25 kg CO_2.

Table 4.6: Passenger-sailing EFs on BC Ferries routes

Rank	**Route**	**Vessel**	**Passenger-sailing EF (kg CO_2)**
1	Inside Passage Prince Rupert–Port Hardy	*Northern Expedition*	288
2	Haida Gwaii–Prince Rupert	*Northern Adventure*	193
3	Port Hardy–Bella Coola Discovery Coast	*Queen of Chilliwack*	183
4	Tsawwassen–Duke Point	*Coastal Inspiration*	62
5	Tsawwassen–Duke Point	*Queen of Alberni*	55

6	Day trip from Swartz Bay (via Pender, Mayne, Galiano, Pender)	*Queen of Cumberland*	51
7	Earls Cove–Saltery Bay	*MV Island Sky*	31
8	Saturna Is–Swartz Bay	*Queen of Cumberland*	30
9	Horseshoe Bay–Departure Bay	*Coastal Renaissance*	26
10	Galiano–Swartz Bay	*Queen of Cumberland*	25

The Inside Passage, from Prince Rupert to Port Hardy, has by far the highest passenger-sailing EF at 288 kg CO_2. However, this is also by far the longest sailing operated by BC Ferries, at approximately 507 km. The second highest value is for the Prince Rupert–Haida Gwaii sailing. The passenger-sailing EF is 67% of the highest route but its distance of 172 km is only 34% of the first route, which means that the sailing is significantly more emission-intensive on a per passenger basis. An even more drastic example of a passenger-sailing EF put in context is the Earls Cove–Saltery Bay route, which is ranked seventh for passenger-sailing EF. At 17.6 km this route is approximately 3% of the distance of the Inside Passage route, yet at 31 kg CO_2 per passenger its passenger-sailing EF is almost 11% of that of the Inside Passage.

Passenger-kilometre EFs on BC Ferries routes

The passenger-kilometre EFs of all 49 BC Ferry routes, which were calculated using the LFs computed for this research rather than those provided by the Provincial Government, are contained in Table A2.7 in Appendix 2. To illustrate these results, Table 4.7 below lists the five routes with the lowest passenger-kilometre EFs. These routes all have passenger-kilometre EFs of between roughly 250 and 370 g CO_2/pkm. The table also contains the five routes with the highest passenger-kilometre EFs. These routes all have passenger-kilometre EFs of between roughly 1,000 and 1,800 g CO_2/pkm. Figure 4.7 displays the geographic distribution of BC Ferries' passenger-kilometre EFs at the level of the entire province, while Figure 4.8 displays the geographic distribution of BC Ferries' passenger-kilometre EFs zoomed into the southwestern corner of the province, because this is where most BC Ferries routes are operated.

Table 4.7: Passenger-kilometre EFs on BC Ferries routes

Rank	**Route and number**	**Vessel**	**Passenger-kilometre EF ($g\ CO_2$/pkm)**
1	Chemainus–Theis Island–Penelakut Is (20)	*MV Kuper*	261
2	Tsawwassen–Swartz Bay (1)	*Spirit of British Columbia*	288
3	Horseshoe Bay–Departure Bay (2)	*Queen of Oak Bay*	334
4	Salt Spring/Long Harbour–Tsawwassen (9)	*Queen of Nanaimo*	369
5	Pender–Tsawwassen (9)	*Queen of Nanaimo*	369
…			
45	Langdale–Keats–New Brighton–Langdale (13)	*Tenaka*	1,007
46	Langdale–New Brighton–Eastbourne–Keats–Langdale (13)	*Tenaka*	1,007
47	Quadra Is–Cortes Is (24)	*Tenaka*	1,012
48	Haida Gwaii (11)	*Northern Adventure*	1,118
49	Earls Cove–Saltery Bay (7)	*MV Island Sky*	1,781

Figure 4.7: Geographic distribution of BC Ferries passenger-kilometre EFs (province)

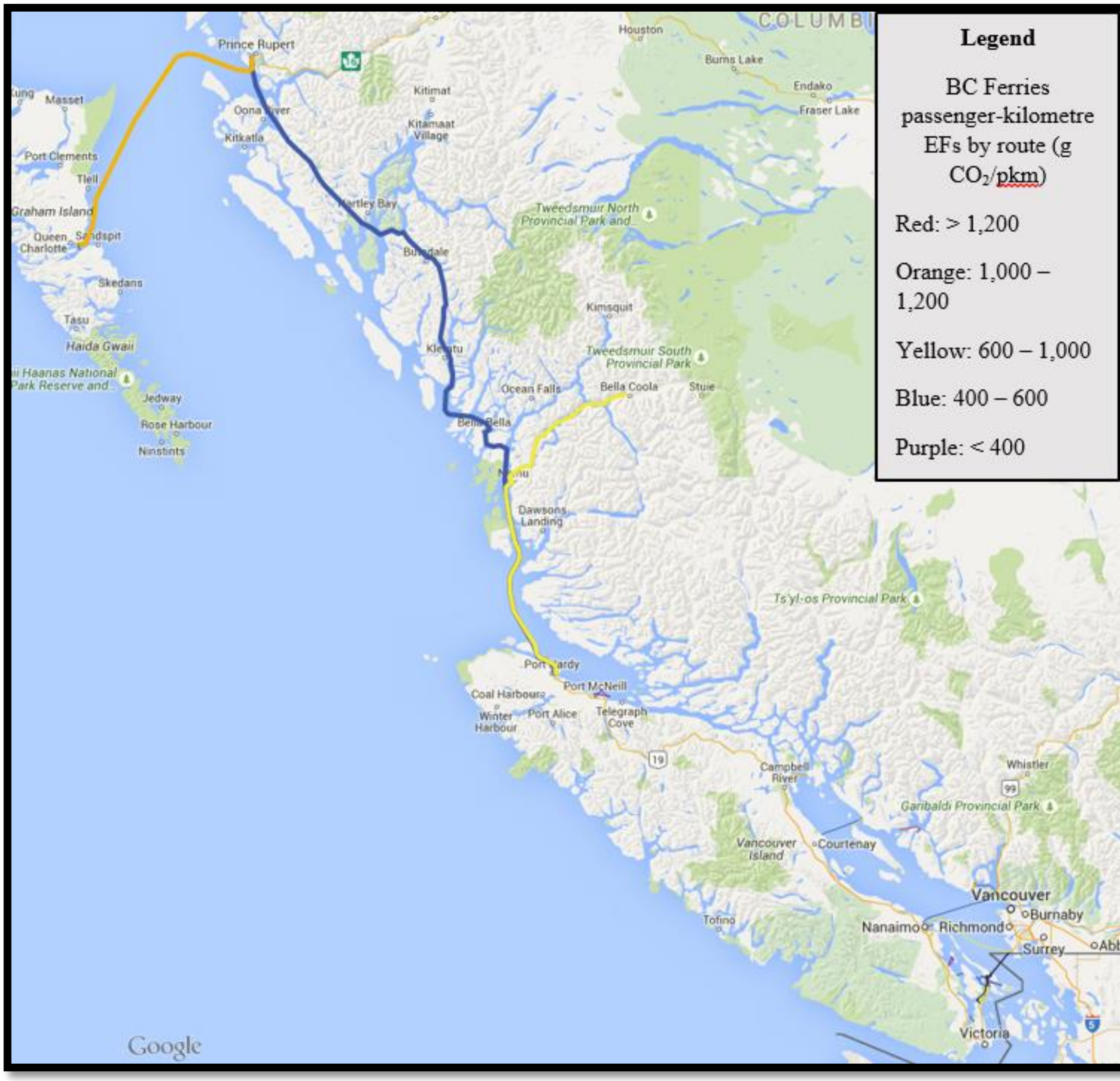


Figure 4.8: Geographic distribution of BC Ferries passenger-kilometre EFs (southwestern BC)

The route with the lowest passenger-kilometre EF is Chemainus–Thetis Island–Penelakut Island on *MV Kuper* with 261 g CO_2 /pkm, followed by Tsawwassen–Swartz Bay on the *Spirit of British Columbia* with 288 g CO_2 /pkm. *MV Kuper* (built in 1985) can carry 32 vehicles and 269 passengers (BC Ferries 2014), making it one of BC Ferries' smallest vessels, while *Spirit of British Columbia* (built in 1993) can carry 410 vehicles and 2,100 passengers (BC Ferries 2014), making it one of BC Ferries' largest vessels. This would seem to indicate that neither the age nor the size of a ferry are directly related to the passenger-kilometre EF. The three remaining routes of the five low-emission routes are all comparatively long for BC Ferries routes, and are operated by mid-sized vessels with capacities for 200-400 vehicles and 1,000-1,500 passengers.

By contrast, the highest passenger-kilometre EFs routes have emissions per passenger-kilometre more than threefold those of *MV Kuper*. Three of these routes are all sailed by the same vessel, *Tenaka*, and all are assigned the same generic LF. It is this low LF, both for vehicles and passengers, coupled with an apparently fuel-inefficient vessel, that led to a very high value. *Northern Adventure* travels to Haida Gwaii with very high vehicle loads and approximately double the average system-wide passenger LF, which indicates that the vessel itself appears to be very fuel-inefficient. The Earls Cove–Saltery Bay route has the highest passenger-kilometre EF of all BC Ferries routes with 1,781 grams of CO_2 per passenger-kilometre, which is almost sevenfold that of the the lowest passenger-kilometre EF route. This route has extremely high emissions because of the apparent fuel inefficiency of the *MV Island Sky*, compounded by extremely low LFs (23.6% for vehicles and 12.6% for passengers).

Discussion

Ferries are an essential part of transportation in BC between mainland BC, Vancouver Island, and the islands that lie in between. However, according to SMITE calculations, BC Ferries accounts for a significant share of BC transportation emissions (approximately 15% of interurban passenger emissions). The low to very low LFs indicate that BC Ferries has excessive capacity.

DEFRA's average passenger-kilometre EF for a ferry is 115 g CO_2 /pkm (DEFRA 2011). *MV Island Sky's* passenger-kilometre EF is approximately fifteen-fold this value, while *Northern Adventure*'s is nearly ten-fold and *Tenaka*'s nearly nine-fold. Even the vessel with the lowest passenger-kilometre EF used by BC Ferries has a value 126% higher than DEFRA's average value. Passenger-kilometre EFs do not seem to depend strongly on the size or age of the vessel. *MV Island Sky* is a mid-size vessel built in 2008; *Northern Adventure* a large vessel built in 2004; *Tenaka* a small vessel built in 1964; *Spirit of British Columbia* a large vessel built in 1993, and *MV Kuper* a small vessel built in 1985 (BC Ferries 2014). Rather, passenger-kilometre EFs seem to depend on the vessel's engine and operating characteristics as well as the LF on a specific sailing.

The Provincial Government pays BC Ferries a defined annual subsidy in return for making a specified number of ferry sailings on specific routes, with a maximum total value of about $106 million per year (British Columbia Ferry Commission 2014). This is because ferries are the only way to access many islands and areas along the Sunshine Coast. Thus, the province obligates BC Ferries to provide service to certain communities at a certain frequency. The three main routes between Vancouver and Vancouver Island are self-supporting; however, the others are subsidized. My calculations confirm that the three main routes have LFs significantly higher than the BC Ferries average for passengers, which may be high enough for them to be financially viable. While BC Ferries could likely reduce its operating cost by introducing more fuel efficient vessels (high per-passenger EFs inevitably are linked to high per-passenger fuel consumption), there may not be enough of a financial incentive because of the guaranteed operating income from the province.

4.2.3 Passenger aviation

This section provides a detailed overview of the CO_2 emissions associated with BC's civil aviation system around the year 2013. Passenger aviation produced 166,867 tonnes of CO_2, which is 1.5% of total interurban transportation emissions and 6.8% of passenger transportation emissions. The emissions of flights within BC were analyzed by airline, flight route, and city-pair. The following order is used to discuss calculations: (1) total CO_2 emissions from civil aviation in BC, (2) CO_2 emissions by airline, (3) CO_2 emissions by route for a given airline, (4) city-pair CO_2 emissions, (5) passenger-flight EFs, and (6) passenger-kilometre EFs.

Total CO_2 emissions of civil aviation in BC

The total CO_2 emissions for BC-internal civil aviation in 2013 of approximately 167,000 tonnes CO_2 were produced on 99 scheduled airline routes in BC by approximately 180,000 annual flights operated by 15 airlines that traveled almost 38,000,000 km within the province. This value amounts to less than 10% of the province's estimate for domestic aviation emissions (British Columbia Ministry of Environment 2012). However, the province's estimate includes in their "domestic flight" category all flights that depart from BC to destinations either within BC or within the rest of Canada (e.g., from Vancouver to Toronto), whereas the inventory for my research included only those flights that remain entirely within BC.

CO_2 emissions by airline

In total, 15 airlines were considered in this study. For each airline, the total number of flights internal within BC (Table 4.8) and the total emissions generated by those flights (Table 4.9) were calculated for the year 2013, and ranked by airline.

Table 4.8: Ranking of airlines by annual BC-internal flights

Rank	**Airline**	**Number of BC-internal flights per year**	**% of total number of flights**
1	Air Canada	44,720	24.82
2	Harbour Air	36,608	20.32
3	Pacific Coastal Airlines	22,932	12.73
4	Seair	17,992	9.99
5	Central Mountain Air	16,900	9.38
6	Westjet	10,192	5.66
7	Helijet	9,152	5.08
8	Salt Spring Air	4,576	2.54
9	Tofino Air	4,368	2.42
10	Hawkair	4,004	2.22
11	KD Air	3,952	2.19
12	Orca Air	3,328	1.85
13	Northern Thunderbird Air	832	0.46
14	Air Nootka	312	0.17
15	Vancouver Island Air	312	0.17
TOTAL		180,180	100

Table 4.9: Ranking of airlines by annual CO_2 emissions

Rank	**Airline**	**Annual CO_2 emissions (tonnes of CO_2)**	**% of total emissions**
1	Air Canada	69,498	41.65
2	Westjet	26,478	15.87
3	Pacific Coastal Airlines	25,034	15.00
4	Central Mountain Air	24,555	14.72
5	Hawkair	12,494	7.49
6	Harbour Air	3,103	1.86
7	Helijet	2,804	1.68
8	Northern Thunderbird Air	1,873	1.12
9	Seair	448	0.27

10	Orca Air	195	0.12
11	KD Air	141	0.08
12	Salt Spring Air	104	0.06
13	Tofino Air	88	0.05
14	Vancouver Island Air	35	0.02
15	Air Nootka	17.8	0.01
TOTAL		166,868	100

Within BC, Air Canada operated the most flights and had the highest total emissions in 2013: 44,720 annual flights or 24.8% of total flights, and 69,500 tonnes of CO_2 or 41.7% of total emissions. Harbour Air ranked second in terms of flights with 36,608 flights (20.3% of total flights), but ranked sixth in terms of emissions with 3,103 tonnes of CO_2 (1.86% of total emissions). Pacific Coastal Airlines ranked third in terms of flights with 22,932 flights (12.7% of total flights), and also ranked third in terms of emissions with 25,034 tonnes of CO_2 (15.0% of total emissions). While Westjet only ranked sixth in terms of flights with 10,192 flights (5.7% of total flights), it ranked second in terms of emissions with 26,478 tonnes of CO_2 (15.9% of total emissions). This is in large part attributable to Westjet's use of Boeing 737 aircraft, which are the largest aircraft in operation on BC-internal routes. Because of Air Canada's large number of flights and Westjet's use of large aircraft, these two airlines have the largest total annual emissions of all airlines on BC-internal flights.

CO_2 emissions by route by airline

The emissions by route by airline in 2013 for all 99 internal routes in BC are contained in Table A2.8 in Appendix 2. To illustrate these results, Table 4.10 below contains the top 20 route emissions ranked by total CO_2 emissions. For these 20, emissions ranged from 11,300 to 2,800 tonnes CO_2. Those routes not included in Table 4.10 range from 2,600 tonnes CO_2 for rank #21, to 18 tonnes CO_2 for rank #99.

Table 4.10: CO_2 emission rank by airline route

Rank	Airline	Route and aircraft used	Annual distance with diversion factor (km)	Annual emissions (tonnes CO_2)	% of total emissions
1	AC Express	Vancouver–Fort St. John DH4	2,086,157	11,290	6.82
2	AC Express	Vancouver–Prince George DH4	1,877,476	9,904	5.99
3	AC Express	Vancouver–Terrace DH3	2,037,344	9,463	5.72
4	Hawkair	Vancouver–Terrace DH3	1,848,701	8,101	4.90
5	Westjet	Vancouver–Prince George 73W	796,505	7,177	4.34
6	AC Express	Vancouver–Kamloops DH3	1,301,009	5,763	3.48
7	AC Express	Vancouver–Prince Rupert DH3	1,067,539	4,991	3.02
8	Westjet Encore	Vancouver–Terrace DH4	905,486	4,909	2.97
9	AC Express	Vancouver–Kelowna DH3	1,030,630	4,579	2.77
10	AC Express	Vancouver–Smithers DH3	891,072	4,134	2.50
11	Pacific Coastal Airlines	Vancouver–Cranbrook BE1	728,910	4,030	2.44
12	AC Express	Vancouver–Castlegar DH3	829,920	3,734	2.26
13	AC Express	Vancouver–Victoria DH3	851,136	3,688	2.23
14	Westjet Encore	Vancouver–Prince George DH4	682,718	3,644	2.20
15	Central Mountain Air	Vancouver–Dawson Creek DH1	990,662	3,578	2.16
16	AC Express	Vancouver–Cranbrook DH3	75,806	3,462	2.09
17	Westjet Encore	Vancouver–Fort St. John DH4	60,846	3,331	2.01
18	Westjet	Vancouver–Kelowna 73W	374,774	3,317	2.00
19	Pacific Coastal Airlines	Vancouver–Williams Lake BE1	593,393	3,049	1.84
20	Helijet	Vancouver–Victoria Sikorsky S76	986,586	2,804	1.69

Civil aviation within BC is dominated by Air Canada. Air Canada and its subsidiary Air Canada Express operate 10 of the 20 most emission-intensive routes in BC. Westjet and its subsidiary Westjet Encore, despite having only a relatively small number of flights, occupy five of the 20 most emission-intensive routes (#5, #8, #14, #17, #18). The fact that airlines in BC employ a hub-and-spoke system in which most traffic is routed via Vancouver is clearly reflected in the emission results. Every route in the above table is to or from Vancouver. Rather than connecting smaller cities directly, the vast majority if traffic is routed from spokes (the smaller cities) to the hub (Vancouver) and then connected to other spokes (smaller destination cities). Consequently, emissions are concentrated geographically between the hub and the spokes which receive the most frequent service by the largest airplanes.

The ranking clearly illustrates the factors that contribute to high annual emissions: a long flight distance, the use of medium to large aircraft, and a high frequency of flights. The top five most emission-intensive routes in the above table all have long flight distance, use large or medium aircraft, and have high flight frequency.

CO_2 emissions of routes by city-pairs

In order to obtain a deeper understanding of the geographical distribution of passenger aviation emissions in BC, city-pairs were considered. A city-pair includes all airlines serving a route between two cities and all airports within the two cities. For example, the Vancouver–Prince George route is served by Air Canada Express and Westjet, so the city-pair includes all Air Canada Express and Westjet flights between the cities. Also, the Greater Vancouver–Greater Victoria route includes in Greater Vancouver the airports of Vancouver International Airport, Vancouver Heliport, Vancouver Coal Harbour, and Langley, and in Greater Victoria the airports of Victoria International Airport, Victoria Downtown

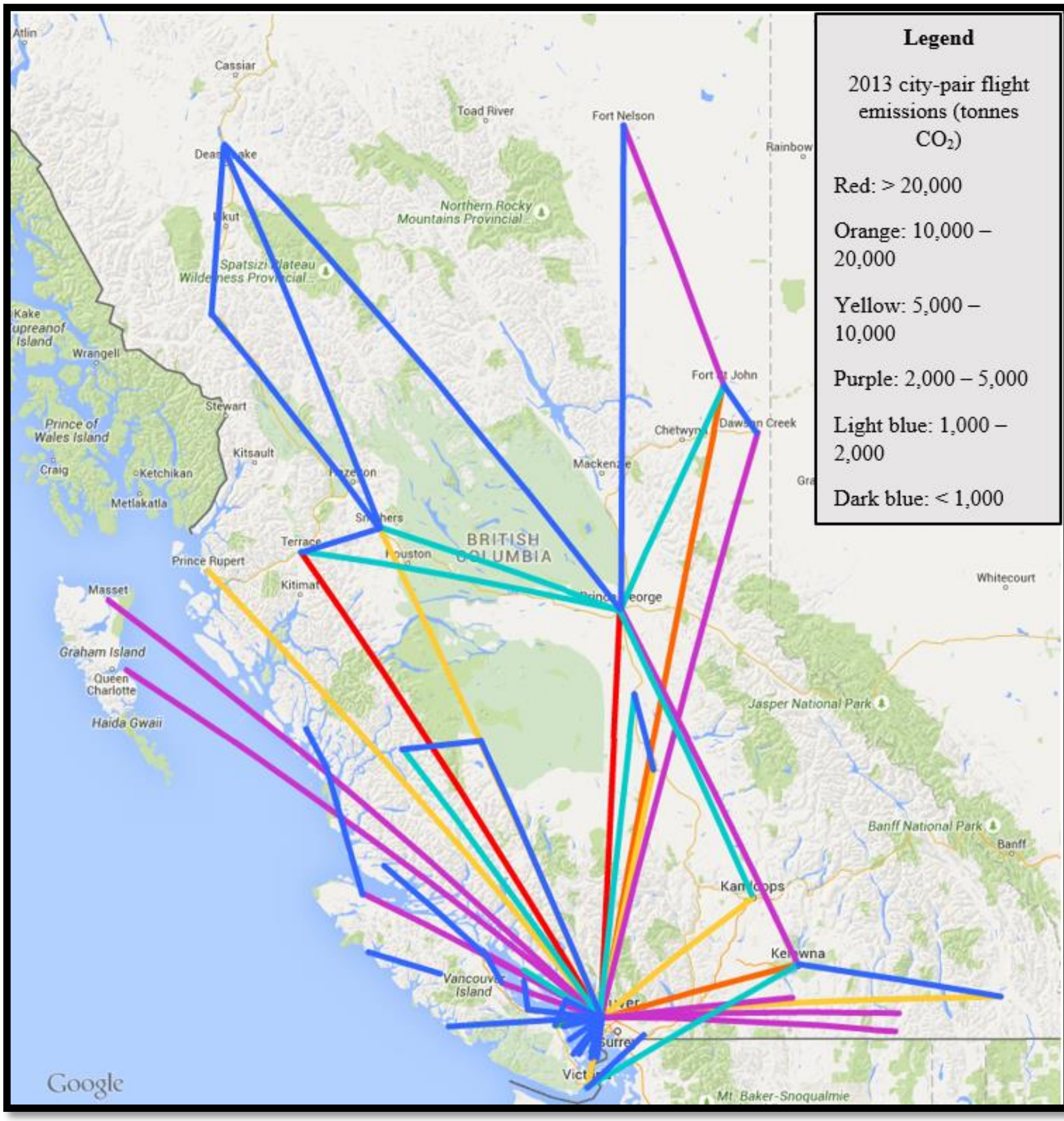
Heliport, and Victoria Inner Harbour; thus the city-pair includes all flights by all airlines that operate between any of these airports. In total, there are 60 city-pairs.

The emissions for all 60 city-pairs are contained in Table A2.9 in Appendix 2. To illustrate these results, Table 4.11 below contains the top ten city-pairs and their annual CO_2 emissions. Emissions for the top 10 city-pairs range from approximately 22,500 to 5,500 tonnes CO_2. None of the remaining city-pairs account for more than 3% of total emissions. Figure 4.9 displays the geographic distribution of city-pair aviation emissions.

Table 4.11: City-pair CO_2 emissions for top 10 city-pairs

Rank	**City pair**	**Annual flights**	**Annual emissions (tonnes CO_2)**	**% of total emissions**
1	Vancouver–Terrace	6,604	22,474	13.47
2	Vancouver–Prince George	6,136	20,724	12.42
3	Vancouver–Fort St. John	3,224	14,621	8.76
4	Vancouver–Kelowna	6,968	11,493	6.89
5	Vancouver–Victoria	41,808	9,778	5.86
6	Vancouver–Prince Rupert	2,080	7,528	4.51
7	Vancouver–Cranbrook	2,652	7,492	4.49
8	Vancouver–Kamloops	5,408	6,646	3.98
9	Vancouver–Smithers	1,820	5,922	3.55
10	Vancouver–Williams Lake	3,276	5,489	3.29

Figure 4.9: Geographic distribution of city-pair CO_2 emissions for all 60 city-pairs



High city-pair emissions are attributable to the same factors as high emissions of individual routes: long flight distances, use of medium or large aircraft, and high flight frequencies. More than half of the top 10 city-pairs, including the three with the highest values, have the longest flights. Moreover, these flights use medium to large aircraft, which means that the individual flights of which the city-pairs' emissions are comprised have high CO_2 emissions. The only route among the top 10 city-pairs that is short is Vancouver–Victoria, which is only about 62 km. However, because of the extremely high flight frequency (an average of 57 flights per day per direction), its emissions are high. As seen in Figure 4.9, city-pair emissions are highest between Vancouver and the province's other larger cities, since these receive the most frequent service flown by larger airplanes.

Flight emission factors

Two types of BC-specific emission factors were calculated: (1) emissions to carry one passenger on one flight (referred to as passenger-flight EF), and (2) emissions to carry one passenger one kilometre travelled on a flight (referred to as passenger-kilometre EF). The passenger-flight EF is used for two comparison purposes: to compare emissions between different airlines on the same route, and to compare emissions from other passenger transportation modes that serve the same two destination points as the flights (e.g, comparison of flights between Vancouver and Prince George to use of a private vehicle or bus between these cities).

The passenger-flight EF for all 99 flights are contained in Table A2.10 in Appendix 2, ranked in order from highest to lowest emissions. To illustrate these results, Table 4.12 below contains the 10 flights with the highest passenger-flight EFs and the 10 flights with the lowest passenger-flight EFs. These 20 routes have emissions per passenger per flight of between 269 and 3.1 kg CO_2. All values were calculated assuming a LF of 80%.

Table 4.12: Passenger-flight EFs of BC aviation

Rank	**Airline**	**Route**	**Aircraft**	**Stage length including diversion factor (km)**	**Passenger-flight EF (kg CO_2)**
1	NTA	Prince George–Dease Lake	Beech 1900	711	269.1
2	CMA	Prince George–Fort Nelson	Beech 1900	574	221.6
3	PCA	Vancouver–Cranbrook	Beech 1900	561	203.9
4	CMA	Prince George–Kelowna	Beech 1900	517	196.3
5	PCA	Vancouver–Masset	Saab 340	860	173.5
6	NTA	Dease Lake–Smithers	Beech 1900	457	168.7
7	CMA	Vancouver–Quesnel	Beech 1900	452	168.6
8	PCA	Vancouver–Bella Coola	Beech 1900	452	159.4
9	PCA	Vancouver–Trail	Beech 1900	427	149.8
10	CMA	Prince George–Kamloops	Beech 1900	405	149.5

90	Harbour Air	Nanaimo–Sechelt	DHC-3 Otter	53	5.4
91	Seair	Vancouver–Saturna Is.	Cessna, Beaver	51	5.0
92	Seair	Vancouver–Salt Spring Is.	Cessna, Beaver	50	4.9
93	Seair	Vancouver–Pender Is.	Cessna, Beaver	47	4.7
94	Seair	Vancouver–Thetis Is.	Cessna, Beaver	46	4.6
95	Seair	Vancouver–Galiano Is.	Cessna, Beaver	44	4.3
96	KD Air	Qualicum Beach–Gillies Bay	Piper PA31, Cessna	44	4.1
97	Seair	Vancouver–Mayne Is.	Cessna, Beaver	41	4.0
98	Tofino Air	Nanaimo–Sechelt	Otter, Beaver, Cessna	41	3.2
99	Tofino Air	Vancouver–Gabriola Is.	Otter, Beaver, Cessna	39	3.1

Table 4.12 Legend:
CMA = Central Mountain Air
NTA = Northern Thunderbird Air
PCA = Pacific Coastal Airlines

The information in Table 4.12 clearly illustrates that passenger-flight EFs depend primarily on two factors: (1) the length of the flight, and (2) aircraft type used. Out of the 10 flights with the highest passenger-flight EFs, nine use Beech 1900 aircraft, which, as is also discussed in the following section in more detail, are the least fuel efficient aircraft operated commercially in BC. The flight with the highest passenger-flight EF (Prince George–Dease Lake) has an extremely high value because it is operated by Beech 1900 aircraft and because it is one of the longest BC-internal routes. The next three flights are also comparatively long and operated by Beech 1900 aircraft, leading to high passenger-flight EFs. By contrast, the route ranked #15 (not displayed in the table), from Vancouver to Prince Rupert, is longer than the #1 route, but has less than half the passenger-flight EF because it does not use Beech 1900 aircraft but instead a Dash 8-300, which is much more fuel efficient. The Dash 8-300 is an older airplane and has been superseded by the more fuel efficient Dash 8-400. As an example, Westjet operates Dash 8-400s on the Vancouver–Fort St. John route, which is longer than both routes discussed above but yields a passenger-flight EF of only 74.1 kg CO_2, less than a quarter the passenger-flight EF of the Beech 1900 route and 37% lower than its predecessor, the Dash 8-300, on a flight of comparable distance.

The routes with the lowest passenger-flight EFs are generally those that are very short (such as floatplane trips between Vancouver and the islands that lie between the BC Mainland and Vancouver Island), which are operated by small to very small aircraft.

The passenger-flight EFs can be used to compare with other modes serving the same origin-destination points. Table 4.13 compares passenger-flight EFs and passenger-sailing EFs of five routes.

Table 4.13: Comparison of passenger-flight EFs and passenger-sailing EFs on BC routes

Route	Passenger-flight EF (kg CO_2)	Passenger-sailing EF (kg CO_2)
Vancouver–Victoria	5.6-7.0	–
Tsawwassen (Vancouver) – Swartz Bay (Victoria)	–	17.2-21.4
Vancouver–Nanaimo	5.8-6.6	–
Tsawwassen (Vancouver) – Duke Point (Nanaimo)	–	54.8-62.1
Horseshoe Bay (Vancouver) –Departure Bay (Nanaimo)	–	18.6-25.9

For both routes, emissions per passenger travelling by ferry are much higher than those of a passenger travelling by air, especially considering that the ferry distance is shorter than the flight distance because the ferry only sails from coast to coast whereas the airports are a little further inland. Passenger-sailing EFs are especially high on the Tsawwassen–Duke Point route because of an extremely low LF of 17.8%.

Passenger-kilometre EF

BC-specific passenger-kilometre aviation EFs are useful to compare emissions between different aircraft types and between other transportation modes in a format that is independent of actual trip routings and distances.

The BC passenger-kilometre EFs for all 99 flights are contained in Table A2.11 in Appendix 2, ranked in order from highest EF to lowest EF. To illustrate these results, Table 4.13 below contains the 10 highest emission flights and 10 lowest emission flights per passenger-kilometre. These 20 routes have passenger-kilometre EFs ranging from 386 g CO_2/pkm to 74.5 g CO_2/pkm. All values were calculated using a LF of 80%.

Table 4.14: Passenger-kilometre EFs of BC aviation

Rank	Airline	Route	Aircraft	Passenger-kilometre EF (g CO_2/pkm
1	CMA	Prince George–Fort Nelson	Beech 1900	385.9
2	CMA	Prince George– Kelowna	Beech 1900	380.1
3	NTA	Prince George– Dease Lake	Beech 1900	378.5
4	CMA	Vancouver–Quesnel	Beech 1900	373.5
5	NTA	Dease Lake–Smithers	Beech 1900	369.4
6	CMA	Prince George–Kamloops	Beech 1900	368.8
7	CMA	Vancouver–Williams Lake	Beech 1900	364.1
8	PCA	Vancouver– Cranbrook	Beech 1900	363.7
9	CMA	Fort Nelson–Fort St. John	Beech 1900	360.9
10	CMA	Prince George–Smithers	Beech 1900	360.7

89	Westjet Encore	Vancouver–Kelowna	Dash 8-400	84.5
90	Westjet Encore	Vancouver–Kamloops	Dash 8-400	84.3
91	Westjet Encore	Vancouver–Victoria	Dash 8-400	82.7
92	Vancouver Island Air	Campbell River–Seymour Inlet	Otter, Beaver, Beech 18	81.1
93	Tofino Air	Nanaimo–Sechelt	Otter, Beaver, Cessna	79.5
94	Tofino Air	Vancouver– Gabriola Is	Otter, Beaver, Cessna	79.4
95	Orca Airways	Vancouver–Tofino	Piper Navajo Chieftain	75.8
96	Westjet	Vancouver–Prince George	Boeing 737 Next-Generation	75.8
97	Orca Airways	Vancouver–Qualicum Beach	Piper Navajo Chieftain	75.2
98	Orca Airways	Abbotsford–Victoria	Piper Navajo Chieftain	75.2
99	Westjet	Vancouver–Kelowna	Boeing 737 Next-Generation	74.5

Table 4.13 *Legend:*
CMA = Central Mountain Air
NTA = Northern Thunderbird Air
PCA = Pacific Coastal Airlines

The flights with the highest passenger-kilometre EFs have one similarity: all are operated by Beech 1900 aircraft. Values vary slightly but this is due to different initial aircraft weights based on the amount of fuel that is needed for the specific flight. In fact, out of the 30 highest passenger-kilometre EFs, all but one are for flights operated by Beech 1900 aircraft. By contrast, the flights with the lowest passenger-kilometre EFs are served by very small aircraft or by large, modern aircraft. Dash 8-400 and Boeing 737 Next-Generation aircraft have passenger-kilometre EFs that are only approximately 20% those of Beech 1900 aircraft. This suggests that while Westjet's use of large aircraft does result in high aggregate emissions, using these aircraft is a low-emissions way of carrying people by plane in the province. If other aircraft, such as the Beech 1900, were used to carry the same number of passengers, aggregate emissions would be much higher.

DEFRA, the de-facto authority on EFs, publishes a passenger-kilometre EF for domestic flights (with a distance of up to 463 km) of 158.6 g CO_2/pkm, and a passenger-kilometre EF for short-haul flights (with a distance between 464 and 1108 km) of 94.0 g CO_2/pkm (DEFRA 2011). Beech 1900 aircraft have a passenger-kilometre EFs that are up to 135% greater than the DEFRA domestic EF and up to 311% greater than the DEFRA short-haul EF. In total, 37 routes within BC have higher passenger-kilometre EFs than DEFRA's value for the equivalent distance category, out of which 29 are operated by Beech 1900 aircraft, one by Dornier 38 aircraft, one by Sikorsky S-76 helicopters, and six by Saab 340 aircraft. By contrast, Dash 8-400 aircraft have passenger-kilometre EFs that are below DEFRA's value for the equivalent distance category, as do Westjet's Boeing 737 jets. The Boeing 737 jets rank 96th and 99th out of 99 routes with values that are approximately 20% lower than DEFRA's average passenger-kilometre EF.

Discussion

Aviation is only a small contributor to BC's overall and passenger transportation emissions at 167,000 tonnes CO_2 per year. Large airplanes, such as Westjet's Boeing 737 jets, create some of the highest emissions per flight but they are among the lowest in terms of passenger-kilometre EFs based on SMITE calculations. Because the passenger aviation system in BC is based on a hub and spoke system in which most flights originate from or arrive in Vancouver, emissions also radiate out from Vancouver, so to speak. They are highest on those routes to larger cities which receive the most frequent service by the largest airplanes. The hub-and-spoke system also means that travel within the province often results in higher emissions because it is routed via Vancouver, compared to what emissions would be if direct flights existed. The city-pairs with the highest aggregate emissions are those with the most flights and the greatest distance from Vancouver. The only exception is Vancouver–Victoria, which is a very short route but with a very high volume of flights. The least 'emissions-friendly' aircraft used in BC are Beech 1900 series planes, which have passenger-kilometre EFs of up to 386 g CO_2/pkm. By contrast, Dash 8-400 airplanes, Boeing 737 Next-Generation jets, and several small propeller airplanes have passenger-kilometre EFs between 75 g CO_2/pkm and 85 g CO_2/pkm, or only one-fifth those of the 'emissions-unfriendly' airplanes.

4.2.4 Long-distance bus

Introduction

Only Greyhound Canada offers scheduled, interurban bus transportation within BC, on 31 routes throughout the province. Frequency of service is moderate. In total, Greyhound produced approximately 12,800 tonnes of CO_2 in 2013, which is 0.1% of total interurban transportation emissions and 0.5% of passenger transportation emissions. In this section, calculations are discussed in the following order: (1) total CO_2 emissions of interurban bus travel in BC, and (2) passenger-kilometre EF of interurban bus travel in BC.

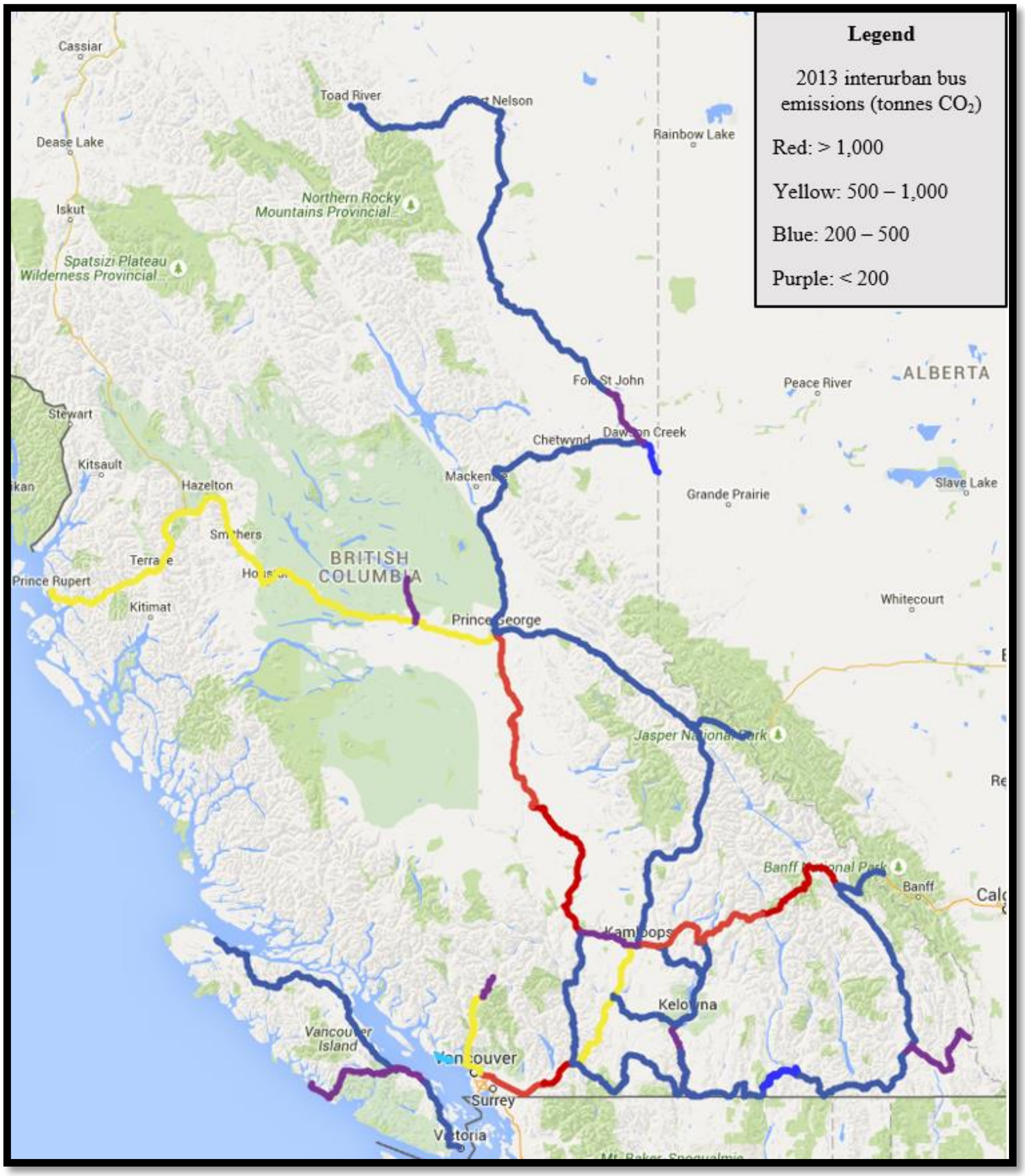
Total CO_2 emissions of long-distance bus travel in BC

Emissions for all 31 Greyhound bus routes internal to BC are contained in Table A2.12 in Appendix 2, ranked in order from highest to lowest annual emissions. To illustrate these results, Table 4.15 below lists the top 10 emission-intensive bus routes. For these, annual CO_2 emissions range from 1,500 to 400 tonnes of CO_2. None of the remaining 21 routes have annual emissions that are greater than 400 tonnes CO_2. Figure 4.10 displays the geographical distribution of bus emissions across the province.

Table 4.15: Emissions of bus routes within BC

Rank	**Route**	**Distance (km)**	**Daily one-way trips**	**Annual CO_2 emissions (tonnes CO_2)**
1	Kamloops–Golden	360	4	1,534
2	Cache Creek–Prince George	443	3	1,416
3	Vancouver–Hope	155	8	1,321
4	Vancouver–Whistler	125	6	799
5	Prince George–Prince Rupert	718	1	765
6	Merritt –Kamloops	87	6	556
7	Hope–Merritt	124	4	529
8	Victoria–Nanaimo	111	4	474
9	Prince George–Dawson Creek	404	1	430
10	Fort St. John–Fort Nelson	380	1	405

Figure 4.10: Geographic distribution of Greyhound emissions



High annual emissions for a specific route are linearly related to the frequency of service and the distance between origin and destination. Therefore emissions of Greyhound routes are highest in BC's interior, which are long, and for those leading to Vancouver, which have high frequencies. Greyhound has a relatively uniform bus fleet (i.e., most coaches are either identical or very similar). Therefore, the type of equipment used to service the route, unlike aviation, is only of marginal importance.

Passenger-kilometre EF of interurban bus travel in BC

Since the entire bus fleet has virtually identical emission performance, the only factor influencing emissions per passenger carried is the LF, or percentage of seats occupied on an average trip. It was not possible to find substantive statistics in this regard; Greyhound does not seem to publish them. However, according to Bradley (2007), they reported North American system-wide LFs of approximately 50% in 2007. Bertrand (2012) states that LFs on some routes in BC are as low as 21%. If Greyhound buses were assumed to be equivalent to the 'average bus' used in the DEFRA database, and if the average Greyhound bus was indeed about 50% occupied, then the passenger-kilometre EF for Canada would be approximately 57 g CO_2/pkm (i.e., double the average DEFRA EF since DEFRA assumes full occupancy (DEFRA 2011)). However, if occupancy on a bus was as low as 21%, the passenger-kilometre EF would be approximately 137 g CO_2/pkm (or approximately five-fold the generic DEFRA bus EF), making it no more efficient a means of conveyance than traveling on an average airplane.

Discussion

Bus travel is not a widely-used means of transportation in BC for reasons that likely include the large distances in the province and the slow speed of bus travel compared to airplanes or private cars. Interurban buses only contribute 13,000 tonnes CO_2, or 0.1% of

BC's total interurban transportation emissions, generated mostly on the busy corridor east of Vancouver and several long routes in BC's interior. Despite the potential for a bus to be an efficient means of transport when it is fully or nearly fully occupied with a passenger-kilometre EF of approximately 28 g CO2/pkm (DEFRA 2011), it appears that low LFs (with estimates ranging between 21% and 50%) mean that the bus is ultimately not as low emissions as it could be.

4.2.5 Passenger trains

Introduction

The use of passenger trains to travel within BC is rare. There are only two scheduled routes that passengers can travel on: from the Alberta Border to Prince Rupert or from the Alberta Border to Vancouver on the *Canadian*, a train that travels from Toronto to Vancouver. Trains on both services do not travel daily and take significantly longer to travel from origin to destination than alternative modes of transportation. Passenger trains in 2013 produced approximately 4,500 tonnes of CO_2, which is less than 0.1% of total interurban transportation emissions and approximately 0.2% of passenger transportation emissions. In this section, calculations are discussed in the following order: (1) total CO_2 emissions of passenger rail travel in BC, and (2) passenger-kilometre EF of passenger rail travel in BC.

Total CO_2 emissions of passenger rail travel in BC

VIA Rails's operations within BC produced approximately 4,525 tonnes of CO_2 in 2013, of which 2,044 tonnes were attributable to Alberta Border–Prince Rupert operations, and 2,480 tonnes were attributable to Alberta Border–Vancouver operations. For these calculations, passenger numbers had to be assumed because detailed information is not available from VIA Rails's annual reports. VIA Rail's Annual Report (VIA Rail 2015) states that there were approximately 344 passengers per week in 2014 on the Alberta Border–

Prince Rupert route, on which there are about three trains per direction per week. The number of passengers is higher for the Alberta Border–Vancouver route, but considering that this train runs all the way to Toronto, more than 3,000 km east of Vancouver, it is unclear how many passengers travel the entire voyage and how many only travel a segment of it. Therefore, I assumed there to be approximately 50 passengers on average on each train on both BC routes as opposed to estimating a LF.[11]

Passenger-kilometre EF of passenger train travel in BC

At an average 117 g CO_2/pkm for VIA Rail (Wikipedia 2014)[12] the train is, per passenger-kilometre, as emission intensive as a modern airplane. However, compared to high-speed electric trains in Asia and Europe, which can have passenger-kilometre EFs as low as 15 g CO_2/pkm (DEFRA 2011), it is much higher. Moreover, the figure of 117 g CO_2/pkm for VIA Rail is presumably system-wide, including VIA's busier routes in Eastern Canada. Based on my work in the tourism industry, I would guess that VIA's LF in western Canada is lower than in Eastern Canada; consequently, the average passenger-kilometre EF in Western Canada is likely somewhat higher than the 117 g CO_2/pkm value.

Discussion

Train travel in BC produced merely 4,500 tonnes CO2, which were approximately evenly split between the two routes that are operated within BC. Despite the ability for trains to be the most emissions-friendly passenger transportation mode, with a passenger-kilometre EF as low as 15g CO_2/pkm, trains in BC do not realize their full potential.

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[11] Estimating a LF for trains, especially over a one-year period, is difficult because, unlike trains or buses, cars can be added or removed from a train based on demand and thus the number of available seats changes. Based on personal experience working in the tourism industry, the BC trains are always longer in the summer than in the winter. Approximately 50 passengers per train seems a reasonable estimate of its year-round average occupancy.

[12] Wikipedia was the only available source of information for this value. The page cites personal communication as its source. I was unable to obtain a value from a verified source.

4.3 Freight transportation within BC

4.3.1 Freight trucking

Introduction

Freight trucking forms one of the backbones of the BC freight transportation system. Trucks are used to distribute food, deliver goods, and move natural resources such as logs, finished wood products, and mineral ore. There are 23,274 trucking companies in BC, of which 90% operate between one and five vehicles (British Columbia Trucking Association 2012). Trucking produced approximately 5,431,000 tonnes of CO_2 in 2013, which was 48.5% of total interurban transportation emissions and 62.1% of freight transportation emissions. Trucking is the transportation mode with the single highest annual emissions. In this section, freight trucking usage and emissions are discussed in the following order: (1) total interurban trucking distances driven in 2007 and 2013, (2) percentage change of distances driven between 2007 and 2013, (3) trucking emissions per kilometre of road, and (4) emissions produced by interurban trucking.

Total distance driven

According to SMITE calculations, trucks in BC drove a total of 2.92 billion interurban kilometres in 2007 and 3.03 billion interurban kilometres in 2013. The breakdown of these distances driven by passenger vehicles on all 79 interurban routes is contained in Table A2.13 in Appendix 2. To illustrate these results, Table 4.16 below lists the 10 routes from Table A2.13 with the longest distances driven in BC in 2007 and in 2013. For the 69 routes not show in the table below, their distance values range from 84 million kilometres driven for rank #11 to 1.1 million kilometres for rank #79. Figure 4.11 displays the geographical distribution of kilometres driven in 2013. Because the vast majority of the routes considered did not change their category on the map, the map is also illustrative for 2007.

Table 4.16: Ranking of BC routes by truck kilometres driven in 2007 and 2013

Rank	2007 distance driven (km)	Route	2013 distance driven (km)	Route
1	236,931,720	Vancouver–Chilliwack	229,529,155	Vancouver–Chilliwack
2	141,178,613	Hope–Merritt	147,093,529	Hope–Merritt
3	112,141,622	Vernon–Kelowna	119,382,682	Vernon–Kelowna
4	105,587,620	Ladysmith–Victoria	109,344,510	Ladysmith–Victoria
5	103,021,922	Parksville–Nanaimo	107,563,456	Kelowna–Penticton
6	99,898,514	Cache Creek–Williams Lake	105,757,071	Revelstoke–Golden
7	96,637,050	Kelowna–Penticton	104,756,533	Tete Jaune Cache–Kamloops
8	94,907,957	Tete Jaune Cache–Kamloops	102,181,677	Parksville–Nanaimo
9	94,421,996	Hope–Cache Creek	98,130,571	Kamloops–Merritt
10	91,100,314	Revelstoke–Golden	95,164,348	Cache Creek–Williams Lake

Figure 4.11: Geographical distribution of trucking kilometres driven in BC in 2013

The rank of the four highest counting sites in terms of total distances driven annually did not change between 2007 and 2013. The longest distance driven was recorded at the Vedder site (Route 1 between Vancouver and Chilliwack), with approximately 237 million kilometres driven in 2007 and 230 million kilometres in 2013. The second longest distance driven was recorded at the Coquihalla site (Route 5 between Hope and Merritt), with approximately 141 million kilometres in 2007 and 147 million kilometres in 2013. The third longest was at the Oyama site (Route 97 between Vernon and Kelowna), with approximately 112 million kilometres in 2007 and 119 million kilometres in 2013. By contrast, the shortest distance driven was recorded at the Powell River site (Route 101 between Saltery Bay ferry terminal and Powell River), with approximately 1.3 million kilometres in 2007 and 1.1 million kilometres in 2013. The highest percentage of vehicles on a route that were trucks was recorded between Fort Nelson and Liard River, where 65% of vehicles were trucks. The lowest percentage of vehicles on a route that were trucks was recorded between Gibsons and Sechelt, where only 6% of vehicles were trucks.

The geographic distribution of distance driven is, expectedly, linked to population density, with most kilometres driven between large urban areas in BC's southwest, and fewer kilometres driven in the rural northern part of the province.

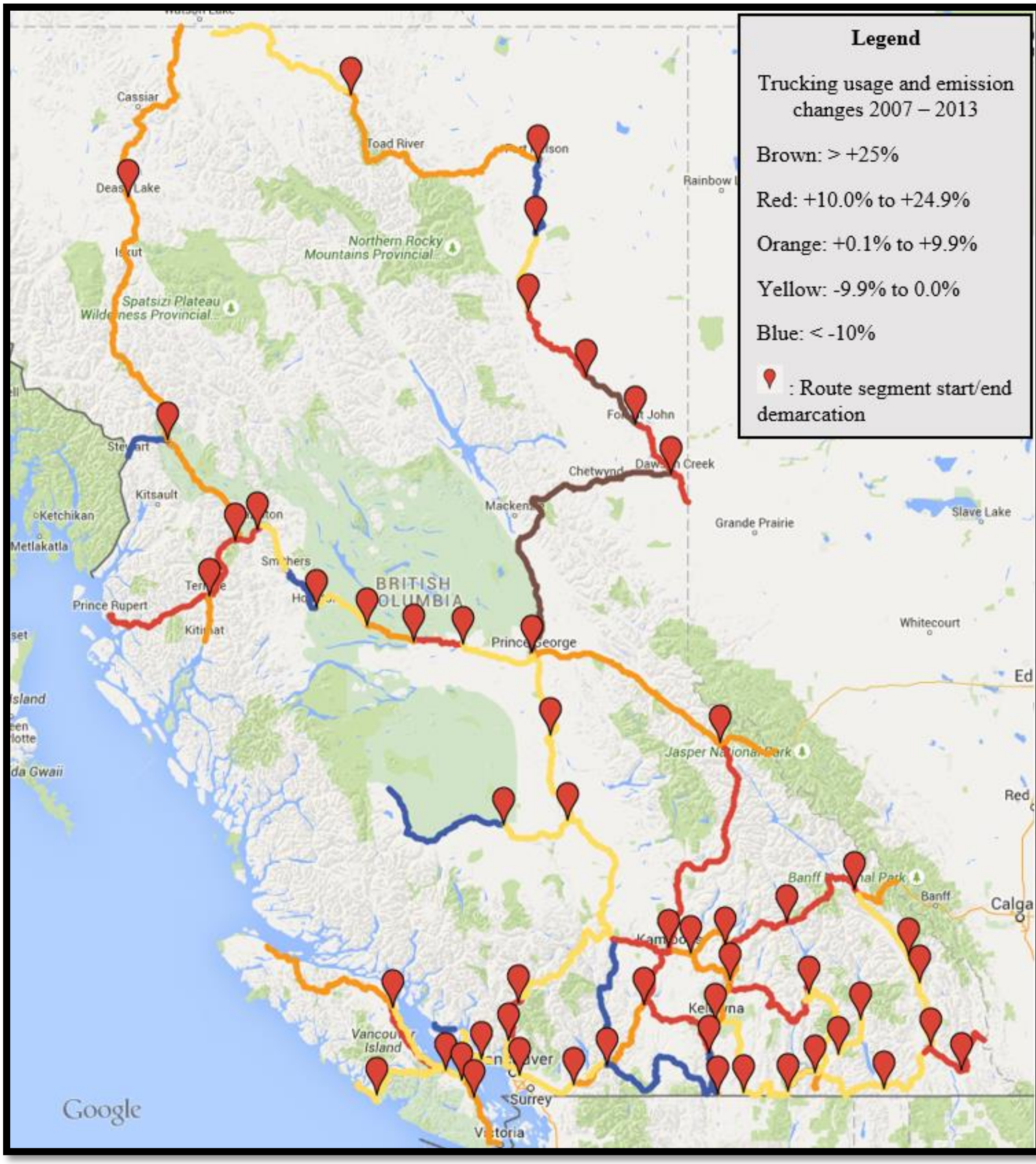
Change in distances driven between 2007 and 2013

Comparison of traffic statistics permitted calculation of changes in traffic volumes between 2007 and 2013. The percentage change in distance driven by trucks is contained in Table A2.14 in Appendix 2. Out of the 79 counting sites considered, 42 sites had increased vehicle numbers, five sites had no change, and 32 sites had decreased vehicle numbers. To illustrate these results, Table 4.17 below contains the three largest and three smallest changes between 2007 and 2013. Figure 4.12 displays on which routes within BC kilometres driven have increased or decreased.

Table 4.17: Percentage changes in trucking distance driven on BC routes 2007-2013

Rank	**Route**	**2007 distance driven (km)**	**2013 distance driven (km)**	**% Change**
1	Dawson Creek–Prince George	56,188,283	80,246,801	42.8
2	Fort St. John–Wonowon	37,048,168	50,790,298	37.1
3	Salmon Arm–Revelstoke	63,759,616	79,337,480	24.4
…				
77	Hope–Cache Creek	94,421,996	75,989,350	-19.5
78	Hope–Penticton	74,030,760	57,450,708	-22.4
79	Alexis Creek–Anahim Lake	5,784,929	3,098,295	-46.4

Figure 4.12: Geographical distribution of percentage change in trucking distance driven 2007-2013



Increases across the province in distances driven by trucks ranged from +42.8% to +0.1%. The largest increase in vehicle numbers was at the Willow Flats counting site, which reports traffic between Dawson Creek and Prince George on Route 97. Between 2007 and 2013, this site had an increase of 42.8%. The second highest increase was at the Inga Lake site, which reports traffic between Fort St. John and Wonowon on Route 97, and which had an increase of 37.1%. The third highest increase was at the Craigellachie site, which reports traffic between Revelstoke and Salmon Arm on Route 1, and which had an increase of 24.4%. The remaining increases across BC range from 20.1% to 0.1%.

Five sites reported no change in traffic counts. Decreases ranged from -0.2% to -36.7%. The third highest decrease was at the China Bar site, which counts traffic between Hope and Cache Creek on Route 1, and which had a decrease of -19.5%. The second highest decrease was at the Nicolum site, which counts traffic between Hope and Penticton on Route 3, and which had a decrease of -22.4%. The largest decrease in vehicle numbers was reported at the Kleena Kleene Bridge site, which counts traffic between Alexis Creek and Anahim Lake on Route 20. Between 2007 and 2013, this site had a decrease in trucks, and hence kilometres driven, of -46.4%.

Emissions per kilometre of road

In addition to total vehicle-kilometres driven, which are directly related to the length of a particular route on which traffic is counted, it is possible to calculate emissions generated per kilometre of road. This illustrates how heavily a given route is travelled which may help in devising mitigation strategies based on the volume of traffic. The emissions per kilometre of road per year on all routes are contained in Table A2.15 in Appendix 2. To illustrate these results, Table 4.18 below contains the three largest and three smallest values for 2007 and 2013, ranked by 2013 values. Figure 4.13 illustrates the emissions per kilometre of road for each route in 2013. Because the map category of nearly all routes has not changed between 2007 and 2013, the map is also illustrative for 2007.

Table 4.18: Trucking emissions per kilometre of road for 2007 and 2013

Rank	**Route**	**2007 emissions per km of road (tonnes CO_2/km)**	**2013 emissions per km of road (tonnes CO_2/km)**
1	Parksville–Nanaimo	4,861	4,821
2	Vancouver–Chilliwack	4,248	4,115
3	Vernon–Kelowna	3,723	3,964
…			
77	Dease Lake–Yukon Border	48	33
78	Meziadin Junction–Dease Lake	31	33
79	Alexis Creek–Anahim Lake	31	26

Figure 4.13: Trucking emissions per kilometre of road on BC routes in 2013

In BC, the route with the highest emissions per kilometer was at the Parksville site, which counts traffic between Parksville and Nanaimo on Route 19, and which had 1,559 tonnes CO_2 per kilometre of road in 2007 and 1,546 tonnes CO_2 per kilometre of road in 2013. The second highest route was at the Vedder site, which counts traffic between Vancouver and Chilliwack on Route 1, and which had 4,248 tonnes CO_2 per kilometre of road in 2007 and 4,115 tonnes CO_2 per kilometre of road in 2013. The third highest route was at the Oyama site, which counts traffic between Vernon and Kelowna on Route 97, and which had approximately 3,723 tonnes CO_2 per kilometre of road in 2007 and 3,964 tonnes CO_2 per kilometre of road in 2013.

The route with the third lowest emissions per kilometre of road was at the Cassiar Junction site, which counts traffic between Dease Lake and the Yukon Border on Route 37, and which had 48 tonnes CO_2 per kilometre of road in 2007 and 33 tonnes of CO_2 per kilometre of road in 2013. The route with the second lowest emissions per kilometre of road was at the Stikine River Bridge site, which counts traffic between Meziadin Junction and Dease Lake on Route 37, and which had 31 tonnes CO_2 per kilometre of road in 2007 and 33 tonnes of CO_2 per kilometre of road in 2013. The lowest emissions per kilometre of road in the province were at the Kleena Kleene Bridge site, which counts traffic between Anahim Lake and Alexis Creek on Route 20, and which had 31 tonnes CO_2 per kilometre of road in 2007 and 26 tonnes of CO_2 per kilometre of road in 2013.

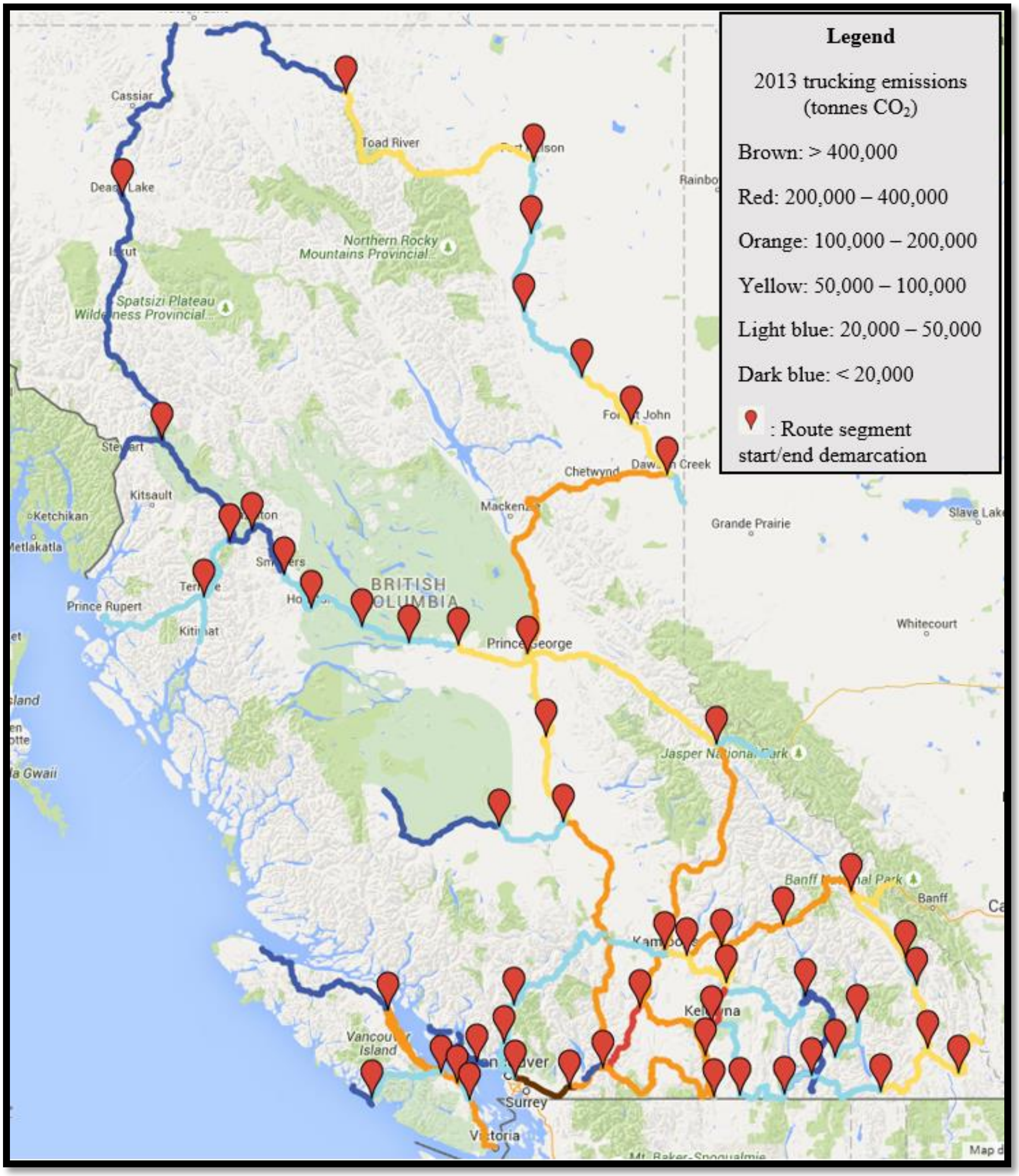
Total CO_2 emissions of trucking travel in BC

Total interurban trucking emissions in 2007 were approximately 5,233,917 tonnes CO_2, while in 2013 they were approximately 5,431,451 tonnes CO_2. The breakdown of these emissions for all 79 interurban routes in BC is contained in Table A2.16 in Appendix 2. To illustrate these results, Table 4.19 below contains the 10 routes from Table A2.16 with the highest CO_2 emissions in 2007 and 2013. The remaining routes range in values from 151,000 tonnes CO_2 for rank #11 to 2,000 tonnes CO_2 for rank #79. Figure 4.14 displays the geographical distribution of the emissions in 2013. Because the map categories of the vast majority of routes have not changed between 2007 and 2013, the map is also illustrative for 2007.

Table 4.19: Trucking interurban CO_2 emissions by route in BC

Rank	**2007 emissions (tonnes CO_2)**	**Route**	**2013 emissions (tonnes CO_2)**	**Route**
1	424,796	Vancouver–Chilliwack	411,523	Vancouver–Chilliwack
2	253,120	Hope–Merritt	263,724	Hope–Merritt
3	201,059	Vernon–Kelowna	214,042	Vernon–Kelowna
4	189,308	Ladysmith–Victoria	196,044	Ladysmith–Victoria
5	184,708	Parksville–Nanaimo	192,851	Kelowna–Penticton
6	179,108	Cache Creek–Williams Lake	189,612	Revelstoke–Golden
7	173,261	Kelowna–Penticton	187,818	Tete Jaune Cache–Kamloops
8	170,161	Tete Jaune Cache–Kamloops	183,202	Parksville–Nanaimo
9	169,289	Hope–Cache Creek	175,939	Kamloops–Merritt
10	163,334	Revelstoke–Golden	170,620	Cache Creek–Williams Lake

Figure 4.14: Trucking interurban CO_2 emissions by route in BC in 2013



Emissions follow the same ranking as those values for distances driven (Table 4.16) because the same EF was used for all trucking calculations. The route with the highest emissions is Vancouver–Chilliwack, with 411,523 tonnes CO_2. This route leads from Vancouver, BC's biggest city, to several of its suburbs, as well as east towards much of the rest of BC via the Trans-Canada-Highway. The route with the second highest emissions is Hope–Merritt, with 263,724 tonnes CO_2. This route is a major part of the transportation network that leads from Vancouver east to the Okanagan area and further towards Alberta. The route with the third-highest emissions is Vernon–Kelowna, with 214,042 tonnes CO_2. This route links two of the biggest cities in BC's Interior, and high emissions result from a high traffic volume because the distance is comparatively short.

Discussion

Trucks form a backbone of the BC interurban transportation system, and are responsible for the highest share of freight transportation emissions. Overall, two factors influence route-specific interurban freight emissions from trucking in SMITE: distance and volume of vehicles. Emissions are a product of the distance of a route and the number of vehicles that travel it. Therefore, a long route with low traffic volume can have similar emissions to a short route with a high traffic volume. Determining route-specific emissions is essential for determining the geographic distribution of emissions, such as illustrated in Figure 4.14. While it was only possible to calculate a trucking tonne-km EF at the national level (as explained in Chapter 3), at 196 g CO_2/tkm, this EF is lower than the average trucking tonne-km EF of 232 g CO_2/tkm published by DEFRA (2009).

4.3.2 Marine freight

Introduction

Marine freight transport in BC is important to move goods to Vancouver Island and other destinations on the BC coast. Information on BC marine freight appears to be very sparse. I relied on data from Statistics Canada, especially the series "Shipping in Canada" (Statistics Canada 2012b). Since this series was discontinued after 2011, the last year of detailed data for marine freight was 2011. Marine freight produced approximately 1,883,000 tonnes of CO_2 in 2011, which was 16.8% of total interurban emissions and 21.5% of interurban freight emissions. In this section, statistics and calculations are discussed in the following order: (1) amount of marine freight transported within BC, (2) total CO_2 emissions of marine freight in BC, and (3) tonne-kilometre EF of marine freight in BC.

Amount of marine freight transported within BC

Twelve of Canada's busiest ports are located in BC, with Metro Vancouver being by far the busiest port in all of Canada. The port of Vancouver is made up of more than one site. For 2007, these sites were listed individually but for 2011 they were listed as one site, "Metro Vancouver", because the sites were amalgamated in name, though not physically, as Port Metro Vancouver in 2008 (Port Metro Vancouver 2014). The values for the individual sites that make up Port Metro Vancouver were added for 2007 to compare with the 2011 values. In 2011, Port Metro Vancouver handled 11,059,000 tonnes of domestic freight and 96,516,000 tonnes of international freight for a total of 107,575,000 tonnes, far ahead of the second-ranked port, Saint John, which handled 31,469,000 tonnes (Statistics Canada 2012a).

Domestic marine freight shipped from BC is almost exclusively destined for other ports in BC, rather than ports in other Canadian provinces because the only way to reach non-BC Canadian ports would be to travel via the Panama Canal, which is likely prohibitive both in terms of cost and time. In 2011, only 4,600 tonnes of machinery, manufactured goods, and fuels and basic chemicals were shipped from BC to ports in eastern Canada, while 12,900 tonnes were shipped from eastern Canada to BC. By contrast, shipments within BC included 3,047,000 tonnes of minerals, 517,000 tonnes of coal, 11,500 tonnes of fuels and basic chemicals, 8,078,000 tonnes of forest and wood products, 47,000 tonnes of pulp and paper products, 500 tonnes of machinery and transportation equipment, and 572,000 tonnes of manufactured and miscellaneous goods (Statistics Canada 2012a).

In 2007, Port Metro Vancouver handled 11,138,000 tonnes of domestic freight, mainly comprised of stone, sand, gravel and crushed stone, salt, logs, and wood chips (Statistics Canada 2010). In 2011, it handled 11,059,000 tonnes of domestic freight (0.7% decrease from 2007), mainly comprised of limestone, stone, sand, gravel and crushed stone, salt, non-metallic metals, coal, logs and other wood in the rough, wood chips, lumber, newsprint, cement, and non-metallic waste and scrap. By contrast, BC's second largest international harbour, Prince Rupert, handled no domestic marine freight at all (Statistics Canada 2012a).

Overall, ports in BC handled 25,591,000 tonnes of domestic freight in 2007 (Statistics Canada 2010), while they handled 24,524,000 tonnes of domestic freight in 2011, a 4.2% decrease. Of this amount, the five busiest ports in 2007, in decreasing order, were: (1) Metro Vancouver with 11,138,000 tonnes, (2) East Coast Vancouver Island with 4,577,000 tonnes, (3) Howe Sound with 3,713,000 tonnes, (4) Crofton with 1,697,000 tonnes, and (5) Beale Cove with 1,053,000 tonnes (Statistics Canada 2010). The five busiest ports in 2011, in decreasing order, were: (1) Metro Vancouver with 11,059,000 tonnes, (2) East Coast Vancouver Island with 4,422,000 tonnes, (3) Howe Sound with 3,472,000 tonnes, (4) Crofton with 1,192,000 tonnes, and (5) Texada Island with 1,091,000 tonnes (Statistics Canada 2012a).

Total CO_2 emissions of marine freight in BC

Based on SMITE calculations, which were based on fuel consumption, BC marine emissions in 2013 were 1,883,007 tonnes CO_2.

Discussion

Marine freight is an important part of the economy, and also a very large contributor to CO_2 emissions, more than five-fold those of BC Ferries. However, the paucity of information and statistics on BC marine freight makes is exceedingly difficult to calculate marine freight emissions. Moreover, because no appropriate statistics on BC-internal marine shipping could be found, it was not possible to calculate a BC-specific EF of marine freight transportation. Data on fuel consumption, shipping distances, and frequency of shipping would be needed to calculate an EF. It was not possible to locate these data, and DEFRA also does not provide a generic marine freight EF. The inability to calculate an EF also makes it impossible to compare the sector's tonne-kilometre EF with other freight transportation modes.

4.3.3 Freight trains

Introduction

Rail freight transportation is significant in BC. Rail is used to transport exports to the ports in Vancouver and Prince Rupert for shipping to Asia, to distribute imports from Asia to the rest of BC and the rest of the country, and to move goods, including natural resources such as coal, grain, and mineral ore, around the province. In this section, calculations are discussed in the following order: (1) total CO_2 emissions of rail freight in BC, and (2) tonne-km EF of rail freight in BC.

Total CO_2 emissions of rail freight in BC

Rail freight statistics are scarce, both at the provincial and federal levels. According to SMITE calculations based on Statistics Canada (2014c) data, emissions in 2007 were 1,361,000 tonnes CO_2, and emissions in 2012 were 1,428,000 tonnes CO_2. Freight trains thus accounted for approximately 12.8% of total interurban transportation emissions and 16.3 % of interurban freight transportation emissions.

Tonne-km EF of rail freight in BC

It was only possible to calculate a per-tonne EF of rail freight on a national level, although the value for BC should be quite similar. According to SMITE calculations, the per-tonne-km EF of rail freight in BC was 16 g CO_2/tonne-km in 2007 and 15 g CO_2/tonne-km in 2012. Based on these calculations, the emissions of trucking per tonne-kilometre are approximately 12 times higher than those of freight trains.

Discussion

Determining total emissions and a tonne-km EF of rail freight was difficult because of sparse statistics. There are no published schedules for freight trains, nor are there extensive, BC-specific statistics such as weight carried by trains and distances over which it is carried, which can be used to calculate a tonne-km EF. Because of this, a broader approach had to be taken, which was made more difficult by two incompatible data sources (British Columbia Ministry of Environment 2012, Statistics Canada 2014c) and no obvious indications as to why they differ substantially.

4.3.4 Aviation freight

Introduction

Aviation freight plays a important but limited role in BC's economy, for example by linking BC to Canada and the rest of the world in terms of courier services or transport of perishable items. Within BC, dedicated aviation freight services play only a small role in the aviation market, with 7,228 annual flights within BC on 11 routes in 2014 operated by three cargo airlines, compared to over 180,000 annual passenger flights within BC. The relatively low number of cargo operations can likely be explained in part by the high cost of aviation freight, especially compared to trucking. CO_2 emissions associated with BC's aviation freight system are discussed in the following order: (1) total CO_2 of aviation freight in BC, and (2) a per-tonne-km EF of BC aviation freight.

Total CO_2 emissions of aviation freight in BC

Total BC-internal aviation freight emissions in 2014 were 8,882 tonnes CO_2. Freight aviation accounted for approximately 0.1% of total interurban transportation emissions and 0.1% of interurban freight transportation emissions. Table 4.20 contains a list of all 11 dedicated aviation freight services in BC in 2014 and their annual emissions.

Table 4.20: BC-internal aviation freight services and annual CO_2 emissions

Rank	Route	Operator	Flights per year	Distance with diversion factor (km)	Aircraft	Annual emissions (tonnes CO_2)
1	Kamloops–Prince George	Kelowna Flightcraft	520	405.3	Convair CV-580	2,677
2	Kelowna–Vancouver	Kelowna Flightcraft	572	302.4	Convair CV-580	2,140
3	Kamloops–Vancouver	Kelowna Flightcraft	520	270.9	Convair CV-580	1,728
4	Kelowna–Vancouver	Skylink Express	520	302.4	Beech 1900C	760
5	Vancouver–Victoria	Kelowna Flightcraft	520	69.3	Boeing 727-200	515
6	Kamloops–Vancouver	Skylink Express	520	270.9	Cessna Caravan	310
7	Kamloops–Kelowna	Skylink Express	520	120.4	Beech 1900C	285
8	Vancouver–Victoria	Skylink Express	1,352	69.3	Cessna Caravan	189

9	Vancouver–Victoria	Morningstar	1,144	69.3	Cessna Caravan	160
10	Vancouver–Nanaimo	Skylink Express	520	57.2	Cessna Caravan	60
11	Vancouver–Nanaimo	Morningstar	520	57.2	Cessna Caravan	60

Annual emissions for aviation freight, similar to passenger aviation, depend largely on the size of aircraft used, the distance of flights, and the frequency of flights. The highest-ranking flights in the table above are all comparatively long and operated by relatively large aircraft. The Boeing 727 employed by Kelowna Flightcraft is by far the biggest all-cargo airplane in use in BC, but because it only flies on the short Vancouver–Victoria route, its annual emissions are comparatively low. On the other hand, the Convair CV-580 is a mid-size airplane that travels on the longest all-cargo routes within BC, which explains why the routes that use this plane have the highest aggregate emissions.

Tonne-km EF of aviation freight in BC

Table 4.21 contains a list of the per-tonne EFs or all 11 dedicated aviation freight services in BC in 2014.

Table 4.21: Tonne-Km EF for BC aviation freight

Rank	Route	Operator	Aircraft	Tonne-km EF (g CO_2 /tkm)
1	Kamloops–Vancouver	Skylink Express	Cessna Caravan	6,810
2	Vancouver–Victoria	Skylink Express	Cessna Caravan	6,240
3	Vancouver–Victoria	Morningstar	Cessna Caravan	6,240
4	Vancouver–Nanaimo	Skylink Express	Cessna Caravan	6,200
5	Vancouver–Nanaimo	Morningstar	Cessna Caravan	6,200
6	Kelowna–Vancouver	Skylink Express	Beech 1900C	6,200
7	Kamloops–Kelowna	Skylink Express	Beech 1900C	5,120
8	Kamloops–Prince George	Kelowna Flightcraft	Convair CV-580	4,660
9	Kelowna–Vancouver	Kelowna Flightcraft	Convair CV-580	4,540
10	Kamloops–Vancouver	Kelowna Flightcraft	Convair CV-580	4,500
11	Vancouver–Victoria	Kelowna Flightcraft	Boeing 727-200	940

For BC-internal flights, tonne-kilometre EFs vary widely, varying largely by aircraft type. The five highest tonne-km EFs are for flights operated by small Cessna Caravan aircraft, followed by those operated by Beech aircraft, then Convair aircraft, and lastly flights operated by Boeing 727 aircraft. The tonne-km EFs of the Cessna aircraft are more than six times higher than those of the Boeing 727, indicating that while the aggregate emissions of a flight operated by Boeing 727 aircraft are much higher than those of a Cessna Caravan, the Boeing 727 can operate such a flight at much lower emissions per unit of freight carried than the Cessna.

Aircraft fuel efficiency, and with it the tonne-km EFs, have improved with time (Peeters and Schouten 2006). Cargo airplanes, however, have a tendency to be old. In fact, many cargo airplanes start their flying careers as passenger airplanes and are later converted for freighter operations. For instance, Kelowna Flightcraft's Convair 580 was manufactured in 1956, while their Boeing 727s were built between 1969 and 1979 (Contrails Photography n.d.). Given this state of affairs, it is likely that cargo aircraft emission factors will only slowly improve.

Discussion

Aviation freight accounts for only a small share of overall emissions in BC but its emissions are high considering the very limited extent of aviation freight transportation within the province. High emissions are largely related to aircraft size, distance flown, and frequency of service. Moreover, tonne-km EFs for BC aviation freight are very high, and subject to a significant range, from 940 to 6,810 g CO_2/tkm, with the tonne-km EF depending largely on the type of aircraft.

4.4 Comparison of modelling results to results from the literature

A comparison of my modelling results was possible to different degrees for the different transportation modes. These comparisons are discussed here in the same order in which the modes were presented in this chapter.

Passenger: private vehicles

SMITE interurban private vehicle emissions were compared to emissions derived from fuel sale statistics. However, while there are statistics on how much fuel is sold at gas stations in BC, how much of this fuel is used for interurban driving is not available. The overall (urban and interurban) private vehicle emission value in the BC PIR (British Columbia Ministry of Environment 2012) is approximately 8.0 million tonnes CO_2, compared to the SMITE interurban value of approximately 1.9 million tonnes CO_2. If these numbers are correct, it would mean there is an approximately 75/25 split between urban and interurban driving. It was not possible to independently confirm if this split holds.

Passenger: ferries

BC Ferries emissions were compared to fuel consumption data. Based on its annual report, BC Ferries spent $121 million on diesel fuel in 2013 (BC Ferries 2013). Assuming the average diesel price in Vancouver in 2013 was $1.41 per litre (Statistics Canada 2015a), the amount that BC Ferries spent would have purchased approximately 85 million litres of diesel fuel, which in turn would have resulted in approximately 229,000 tonnes of CO_2. This value is about 33% less than the SMITE value of 342,000 tonnes of CO_2. However, it is quite likely that BC Ferries pays substantially less than the average Vancouver diesel price because it purchases large quantities of fuel, which is likely discounted. Consequently, the same amount of money would allow BC Ferries to purchase more fuel, which would have resulted in higher emissions, which would bring the value closer to my calculated value.

Passenger: aviation

For passenger aviation, comparison is difficult because (1) most airlines do not compile BC-internal data for their operations, and (2) most airlines operating in BC are small and private, and as such do not publish annual reports. The only comparison I was able to pursue was to compare the small BC airline Harbour Air's emissions to those I calculated for the airline. Harbour Air is a carbon-neutral company and publishes how much it offsets. According to the company (Harbour Air 2015), it offsets approximately 7,500 tonnes CO_2 per year. This is significantly larger than the value of 3,100 tonnes calculated in this research; however, Harbour Air is a completely carbon neutral company, meaning all aspects of its operation, including employee commuting, building heating, etc., are offset. There is no breakdown of emissions between flights and non-flight operations, though. It might be reasonable to expect that roughly one-half of emissions were due to flights and one-half to non-flight operations, which would suggest that the SMITE calculations for this airline are in the right ball park.

Passenger: bus

Interurban bus emissions could not be compared with other results. Greyhound, the operator of interurban buses in BC, was sold in 2007 to the First Group of Great Britain, who no longer publish a stand-alone annual report. Their report (First Group 2015) mentions only financials not operating statistics or fuel expenditures, and does so only on a Canada-wide scale.

Passenger: rail

For passenger trains, VIA Rail's annual report does not explicitly state the emissions associated with the company's operations. The average 2014 diesel price was $1.41 per litre (Statistics Canada 2015a). VIA Rail, according to its annual report (VIA Rail 2015), spent

$125.6 million on train operating costs system-wide in Canada, which would have bought approximately 89 million litres of diesel fuel assuming, for simplicity, that fuel is the only operating cost. With this fuel, VIA Rail operated 9.856 million train-kilometres (VIA Rail 2015), of which 465,500 train-kilometres were in BC according to my calculations. Assuming that the split of train-kilometres between Canada and BC also holds for fuel consumption between Canada and BC, this would have resulted in 4.2 million litres of fuel used in BC, which in turn would have produced 11,200 tonnes CO_2, compared to the SMITE value of 4,500 tonnes CO_2. While there is no specific breakdown of operating cost categories in the annual reports, fuel is, naturally, not the only operating cost. Consequently, the actual amount of money spent on fuel, and fuel purchased and emissions generated, would be less, bringing the value closer to my calculated value. Moreover, trains in BC, especially from the Alberta border to Prince Rupert, are generally short and slow. As such, they may use less fuel than longer trains operating on higher-speed routes in eastern Canada, which would further reduce the emission value and bring it closer to the 4,500 tonnes of CO_2 figure, which would suggest that the SMITE calculations for passenger rail are credible.

Freight: trucking

My method was to compare SMITE values to values from the BC PIR (Government of British Columbia 2014) for total (urban and interurban) heavy-duty gasoline and heavy-duty diesel vehicle emissions. According to the PIR, these emissions were 6,473,000 tonnes CO_2 in 2007 and 7,209,000 tonnes CO_2 in 2013. The province's inventory contains a large value for heavy-duty gasoline usage, but most trucks are fuelled by diesel and there are very few heavy-duty gasoline vehicles in use in North America (United States Environmental Protection Agency 2012). The large value for heavy-duty gasoline in the BC inventory may be mistakenly assigned or not refer to freight vehicles, but it was assumed for this study that all heavy-duty vehicles are involved in the transportation of freight. Comparing the PIR value to my value, there was an approximate 75/25 split between interurban and urban trucking emissions in 2013, which I was not able to verify.

Freight: marine

There are very few statistics related to marine cargo in BC, which makes comparisons difficult. According to the province's GHG inventory (British Columbia Ministry of Environment 2012), total marine emissions (passenger and freight) in 2012 were 2,643,518 tonnes CO_2. Data for 2013 are not yet available. Using the compound growth rate of 1.0013% between the GHG inventory values for 2007 and 2012 for one additional year leads to an estimate of approximately 2,646,897 tonnes CO_2 for BC marine transportation in 2013. Subtracting BC Ferries passenger emissions of 341,563 tonnes CO_2 from the GHG inventory's value yields total annual marine freight emissions of 2,305,334 tonnes CO_2. This value is larger than the 1.9 million tonnes CO_2 derived from my calculations, but it likely includes licensed as well as registered vessels. While pleasure boats are usually licensed, there is no need to register them (Transport Canada 2015). Since pleasure boating cannot be considered interurban transportation, it should not be included in the calculations for this research, which means that the lower value I calculated based on fuel consumption of registered vessels (1,883,007 tonnes CO_2) should be more representative of the actual emissions. However, since registered vessels also include fishing boats which also cannot be considered interurban transportation, the value presented in this research should be seen as an upper limit for marine freight emissions.

Freight: rail

According to BC's GHG inventory, emissions were 676,000 tonnes CO_2 in 2011, and 689,000 tonnes CO_2 in 2012 (British Columbia Ministry of Environment 2012). By contrast, SMITE calculations resulted in 1,361,000 tonnes CO_2 in 2007 and 1,428,000 tonnes CO_2 in 2012. The (lower) provincial value is based on data that is provided by refineries on how much fuel they sold to which sectors, while my calculation resulting in the higher value is based on operating statistics provided by railway operators (Ng 2015b). While at first it may not seem logical that emissions could be higher than emissions based on the amount of fuel sold by refineries to rail companies, it is necessary to keep in mind that BC is not a closed system. Given that fuel tends to be cheaper in Alberta and Washington State than in BC, it would make financial sense for railway operators to fuel their trains in those jurisdictions before proceeding into BC whenever possible. This would appear to explain why railway operators would report higher fuel consumption values than what is provided by refineries within the province. Consequently, the value obtained through my calculation is likely more representative of rail freight emissions.

Freight: aviation

Comparing aviation freight emissions to other results was not possible because none of the aviation freight operators in BC publish information on their fuel consumption or emissions.

4.5 Summary

In this chapter, a detailed portrait of the CO_2 emissions associated with interurban transportation around the year 2013 in BC was presented. Total interurban transportation emissions are displayed in Table 4.22 in order of total annual emissions. Figure 4.15 illustrates how each mode contributes to total interurban transportation emissions, Figure 4.16 illustrates how passenger transportation modes contribute to interurban passenger transportation emissions, and Figure 4.17 illustrates how freight transportation modes contribute to interurban freight transportation emissions.

Table 4.22: Total annual BC interurban transportation emission

Mode	**Total annual emissions (tonnes CO_2)**	**Percent of total transport-ation emissions**	**Passenger-kilometre EF (passenger transportation), or tonne-kilometre EF (freight transportation)**
Freight: Trucking	5,431,000	48.5	196 g CO_2/tkm
Passenger: Private vehicles	1,916,000	17.1	202 g CO_2/pkm
Freight: Marine	1,883,000	16.8	---
Freight: Rail	1,428,000	12.8	15 g CO_2/tkm
Passenger: Ferries	342,000	3.1	260 g CO_2/pkm -1,781 g CO_2/pkm
Passenger: Aviation	167,000	1.5	75g CO_2/pkm – 386 g CO_2/pkm
Passenger: Buses	13,000	0.1	56 g CO_2/pkm* – 137 g CO_2/pkm*
Freight: Aviation	9,000	0.1	940 g CO_2/tkm – 6,810 g CO_2/tkm
Passenger: Rail	5,000	<0.1	117 g CO_2/pkm*
TOTAL	11,194,000	100	

Table 4.22 Legend:
Pkm = Passenger-kilometre
Tkm = Tonne-kilometre
* = Value obtained from alternative sources and not calculated as part of this research

Figure 4.15: Total interurban transportation emission percentages

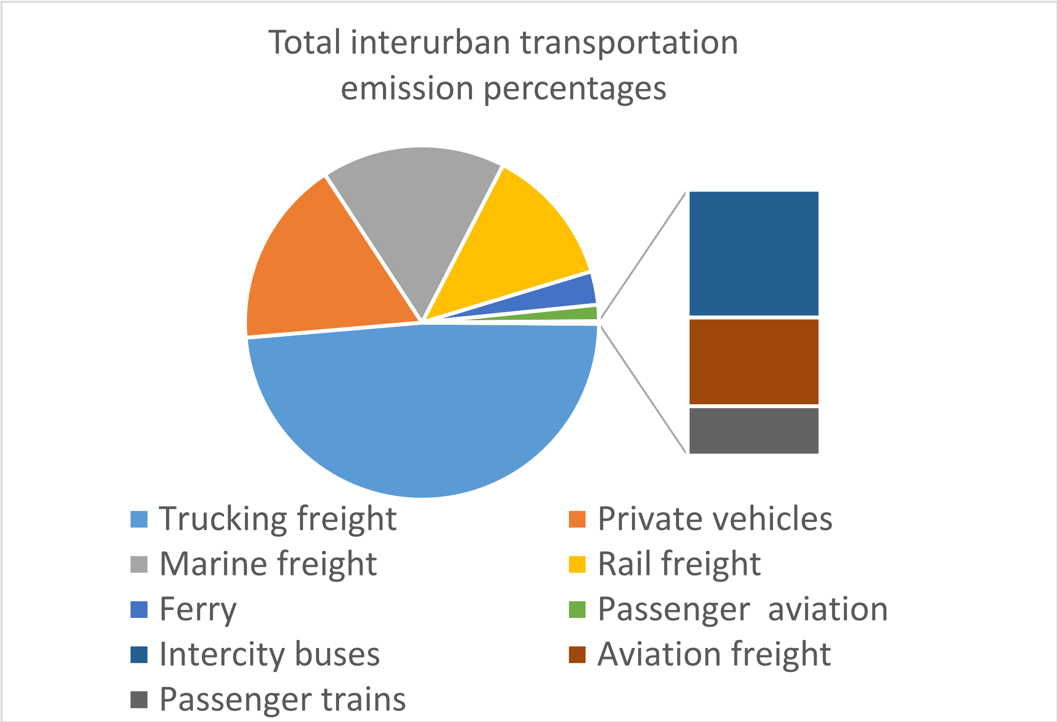


Figure 4.16: Passenger interurban transportation emission percentages

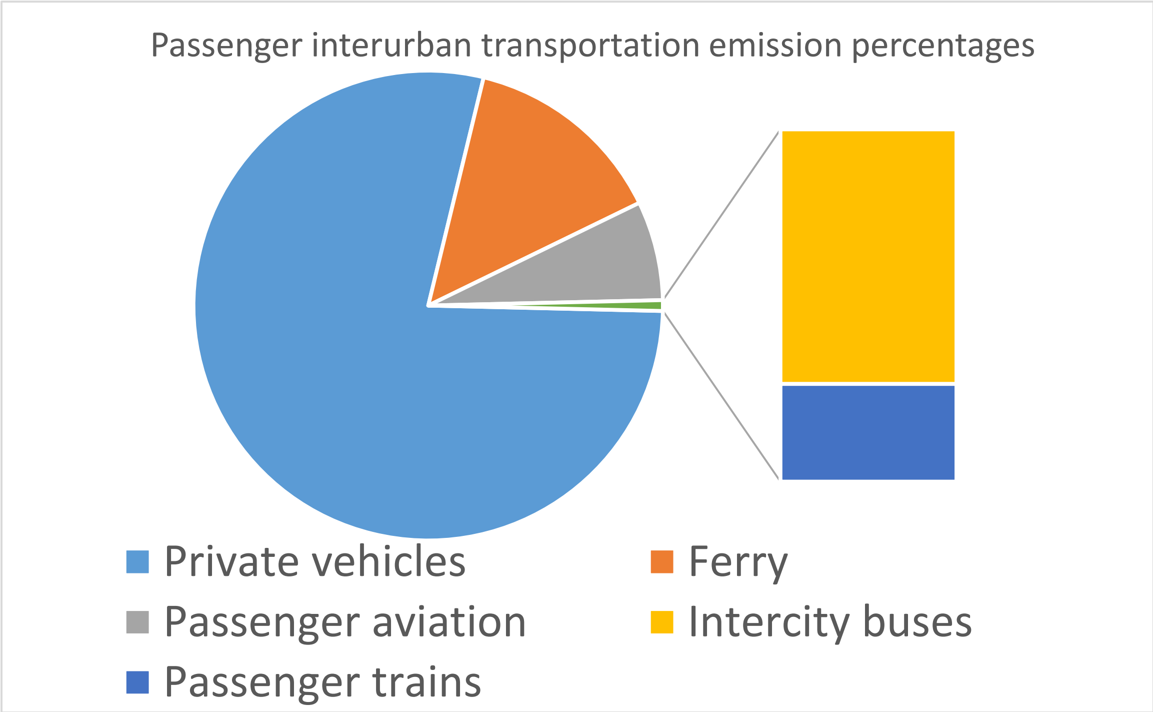
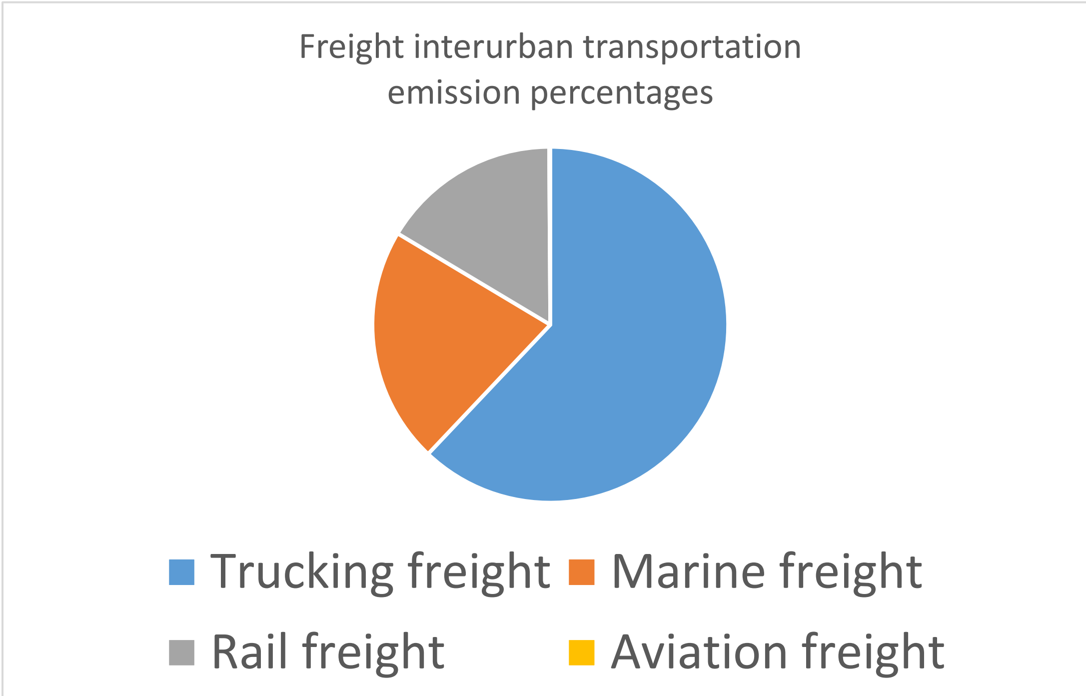


Figure 4.17: Freight interurban transportation emission percentages



**Aviation freight is not visible because the value is too small.*

Total interurban passenger and freight CO_2 emissions in BC in 2013 were estimated to be 11,194,000 tonnes CO_2. Out of this, 48.5% were contributed by freight trucking, 17.1% by private vehicles, 16.8% by marine freight, 12.8% by rail freight, 3.1% by ferries, 1.5% by passenger aviation, 0.1% by buses, 0.1% by aviation freight, and less than 0.1% by passenger trains. Total interurban transportation emissions produced by passenger transportation accounted for 21.8%, while the remaining 78.2% of emissions were produced by freight transportation. Freight transportation emissions were thus almost four times larger than passenger transportation emissions.

Freight trucking is the largest contributor both to BC interurban freight emissions and to overall BC interurban transportation emissions, emitting more than 5.4 million tonnes CO_2, which is nearly 184% greater than the next largest sector, private vehicles. Calculating a trucking EF was only possible at the national scale, and it is approximately 196 CO_2/tkm.

The geographical distribution of trucking emissions is linked to population levels; emissions are highest between dense-populated cities and lowest in rural areas.

The second largest contributor to BC's interurban transportation emissions is private passenger vehicles emitting more than 1.9 million tonnes CO_2, which accounts for nearly one-fifth of BC interurban transportation emissions. Car usage increased between 2007 and 2013. The vehicle passenger-kilometre EF is 202 CO_2/pkm, calculated specifically for Canada to provide a more accurate value for BC car usage. Private vehicles account for approximately 78% of all passenger transportation emissions, and emissions are 460% greater than those of the next highest passenger transportation mode, ferries. Private vehicle emissions correlate with population levels and densities, with aggregate emissions concentrated around the densely-populated Vancouver, Lower Mainland, southern Vancouver Island, and Okanagan areas.

The third largest contributor to BC's interurban transportation emissions is marine freight emitting approximately 1.9 million tonnes CO_2. It was not possible to calculate its tonne-km EF. Determining the geographical distribution of marine freight emissions also was not possible with existing data.

It was not possible to obtain detailed information on rail freight, but based on the available material, the tonne-km rail EF is approximately 15 g CO_2/tkm, or much lower than freight trucking. Trains are the third-largest contributor to BC freight transport emissions. Emissions from rail freight are much higher than those of passenger rail services, but are lower than marine freight or trucking emissions. It was not possible to determine the geographical distribution of rail freight emissions with existing data.

Ferries accounted for 342,000 tonnes CO_2. Ferries in BC operate with passenger-kilometre EFs between 260 g CO_2/pkm and 1,781 g CO_2/pkm, depending on the vessel. This means that any trip on BC Ferries, even on its lowest EF vessel, is less emissions-friendly than a trip with the average BC car. The value of 1,781 g CO_2/pkm is the highest passenger-kilometre EF in BC across all passenger modes. BC Ferries emissions are concentrated on the three main routes between Greater Vancouver and southern Vancouver Island as well as the routes to various islands between the BC Mainland and Vancouver Island.

Passenger aviation accounted for 167,000 tonnes CO_2, and operated with passenger-kilometre EFs between 75 g CO_2/pkm and 386 g CO_2/pkm, depending on the route and aircraft. The aggregate annual emissions value was low considering the importance of aviation for the passenger transportation system and that aviation is often considered one of the prime examples of a form of transportation that is harming the environment. Moreover, the results of this research indicate that on a passenger-kilometre basis, and depending on the aircraft used, aviation can more efficient than other transportation modes, such as ferries. Additionally, airplanes benefit from being independent (for the most part) of terrain in how they travel from origin to destination, so can often travel shorter distances than land-based transportation modes and thus further reduce the emissions per person per trip. Passenger aviation emissions follow a hub and spoke pattern that radiates out of Vancouver, since this is where most routes depart from. Routes to cities with higher population levels tend to have higher emissions because they receive more frequent service and by larger airplanes.

While buses have only very small aggregate emissions, their passenger-kilometre EF of 57 g CO_2/pkm makes them the most efficient means of transporting passengers in BC. This passenger-kilometre EF varies significantly with average occupancy, however, which was difficult to determine for BC. Bus emissions are concentrated on the route leading eastwards from Vancouver because it has a high bus traffic volume, and on several stretches in BC's interior because of long distances.

Aviation freight is also only responsible for very small aggregate emissions, and has tonne-kilometre EFs between 940 g CO_2/tkm to 6,810 g CO_2/tkm. It is by far the most emissions-intensive way of carrying freight in BC, with between 4.8 and 35 times higher tonne-kilometre EFs than trucking and between 63 and 454 times higher tonne-kilometre EFs than rail freight.

Finally, passenger trains account for the smallest aggregate amount of BC interurban transportation emissions, and operate with a passenger-kilometre EF of 117 g CO_2/pkm. At this value, passenger trains are more efficient than some airplanes, all ferries, and most cars, but less efficient than buses; however, since there are only two routes, substituting travel by rail is not possible for most destinations in the province.

For seven out of the nine interurban transportation modes included in my research, I was able to validate my results to varying degrees. Because statistics compiled by the government on activities such as fuel sales do not distinguish between fuel being used for urban or interurban transportation, comparing SMITE results to other results from the literature was a challenge. However, I was able to establish that my numbers seem comparable to results obtained by other methods for the whole or portions of the various modes of BC interurban transportation.

CHAPTER 5: FUTURE EMISSION SCENARIOS

5.1 Introduction

The purpose of this chapter is to provide answers to Research Question Two, *What changes to BC interurban transportation can help the province to achieve its legislated 2020 and 2050 emission reduction targets, and how far above target values will projected values be if reduction rates are insufficient?* Answers are provided through the development and analysis of scenarios representing changes to the BC interurban transportation system.

These scenarios were modelled using the SMITE tool (explained in Chapter 3), and are based on percentage changes (increases or decreases) to annual emissions from the various transportation modes starting from current year emissions. There are essentially an infinite number of possible changes that could be made to BC's interurban transportation system that would alter its GHG emissions. For this study, two main types of scenarios were modelled: (1) emission reduction scenarios, and (2) emission increase scenarios. Emission reduction scenarios for this study were defined to incorporate structured, systematic annual emission reductions that move BC's transportation system towards or beyond the target levels. Emission increase scenarios were defined to incorporate emission increases for part or all of the period of time modelled. The changes incorporated in each scenario were modelled to begin in the year 2014. The emissions resulting from both decrease and increase scenarios were compared with target values. If emission increases occurred, the discrepancy between these emissions and the target values was used to estimate costs to offset the discrepancy assuming progressively increasing carbon offset prices. This approach may be valuable to policymakers and the general public as a proxy for demonstrating potential (financial) consequences of various future transportation paths in BC. If emission decreases occurred, excess carbon credits were calculated assuming that the province could sell these credits at market value. Again, this is a proxy for demonstrating potential (financial) benefits of meeting the targets. A spreadsheet-based approach was chosen over a formulaic approach because it facilitated having different starting years for different emission increase or decrease scenarios, as well as the ability to vary increase or decrease rates for individual modes for any given year, for instance to model the impact of a given technology projected to become available by a certain year. Thus, while a spreadsheet-based approach may be more complex than a formulaic approach, it may ultimately be better suited to deal with the varying timelines and emission change patterns involved in this research.

The scenarios developed for this research incorporated 'plausible' changes to the interurban transportation system. Plausible in this case means that scenarios have annual emission increases or decreases no larger than 5% because such large changes (particularly reductions) seem unlikely on a sustained basis given past experience and current estimates of the rate of change to transportation systems in general. There are several exceptions to my five-percent rule. One exception was one scenario in which targets are exactly met, and others were select scenarios based on a business-as-usual (BAU) approach. BAU is based on each mode's 2007-2013 emissions trends, where for instance a BAU rate of -1% combined with a -5% per annum (pa) reduction would result in a -6% pa reduction for a given mode. Examples of systemic changes to the transportation system included efficiency improvements for new Canadian cars, which are expected to be approximately 3.46% pa between 2011 and 2025 (Environment Canada 2013). Also, the aviation industry is aiming for an annual fuel consumption reduction of 2% pa between 2005 and 2020 (Transport Canada 2012). Plausible changes for my scenario development also included 'sudden' reductions for some scenarios in which all or some of the modes reduce their emissions significantly at one point in time. This may be caused, for instance, by revolutionary technological developments, which are more likely to occur within the next 35 years (i.e., by the time of the 2050 target) than within the next five years (i.e., by the time of the 2020 target), which is why these kinds of changes were only modelled to take place in or after 2020. Literature reviewed in Chapter 2 indicates that for many transportation modes, increases in emissions are expected, which led me to also consider emission increase scenarios as plausible developments. Originally, in order to develop my future scenarios, I had hoped to use results from surveys I had sent to transportation providers and vehicle manufacturers asking them for their expert opinion on likely future technological and other improvements in the transportation sector. However, none of my surveys were returned, so I had to abandon that approach.[13] The templates for the surveys can be found in Appendix 1.

My technique for developing the scenarios was, for a given scenario, to change the annual emissions of each transportation mode by a fixed percentage over a fixed period of time. For example, one scenario might model a 1% pa emissions reduction for all transportation modes. Another scenario might model an emissions reduction of 2% pa for some transportation modes while only a 1% pa emission reduction for other modes. Yet another scenario might model an increase to the year 2020 for some modes and then model a decrease to 2050. The percentage change values ranged from -5% to +5%, in 1% increments. The exceptions to this approach were several scenarios involving BAU where an already negative BAU rate combined with a high annual reduction resulted in reduction rates in excess of -5%, and scenario number 6, which modelled that emission targets would be

[13] I submitted surveys and interview requests to BC Ferries, Via Rail, Greyhound, 16 airlines, and 29 vehicle manufacturers. Only BC Ferries responded, and they only provided me with details about its operations rather than completing my survey.

exactly met. For this scenario, which employed backcasting, annual reduction rates depended on the initial and target values for each mode and the compound annual reduction rates required to meet the targets (which resulted in required annual reduction rates of up to -8.58%). Scenarios with emission reduction values were assumed to represent technological, regulatory policy, and/or social behaviour changes related to BC's interurban transportation system.

I modelled 106 scenarios. This number of scenarios, while not exhaustive, permitted me to bracket a wide range of emission results from those that were excessively negative (10s of times higher than the target values) to unrealistically positive (dramatically under the target values, which might represent, for instance, radical changes in transportation technology). This wide range of scenarios may be beneficial to policymakers and the general public to enhance their perspective on the effect of various emissions changes to BC's transportation system.

In the following sections, a limited and representative number of the 106 scenarios are discussed, as follows. First, a select number of scenarios (a total of 65) that failed to meet both the 2020 and 2050 reduction targets are presented. These are used to illustrate common characteristics for why scenarios failed to meet the targets. Second, scenarios that achieved the 2050 emission reduction target but not the 2020 target are presented (a total of 15). (Note: In this study, there were no scenarios that met the 2020 target but not the 2050 target.) Lastly, scenarios that achieved both the 2020 and 2050 emission reduction targets are presented (a total of two). Table A3.1, in Appendix 3, contains a listing of all scenarios, parameters changed in each scenario, discrepancies between actual (calculated) emissions and the 2020 and 2050 target values, and offset costs for those scenarios that overshot the target values as well as credit values for those scenarios that exceeded the target values.

5.2 Scenarios that do not meet 2020 or 2050 emission reduction targets

5.2.1 Introduction

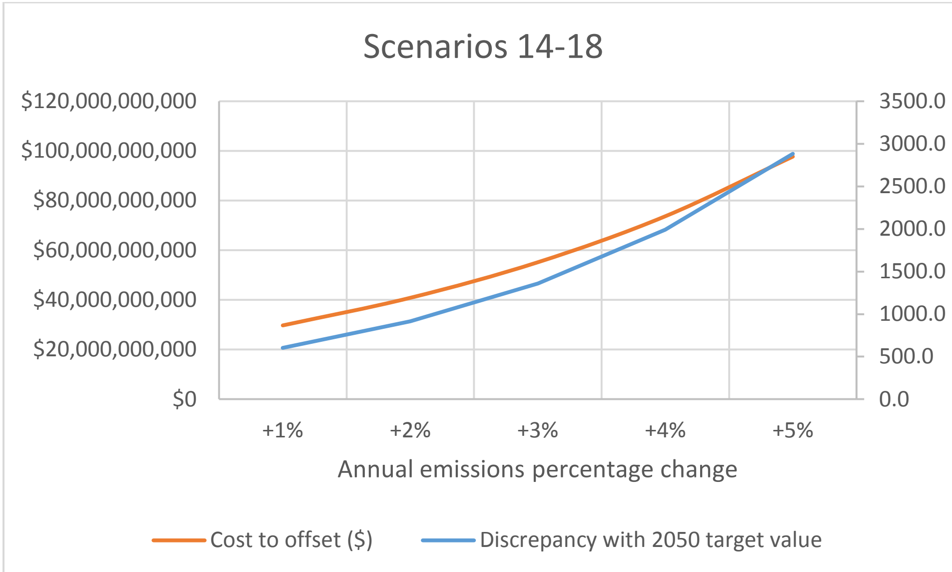
Most of the scenarios that were modelled in my sample of 106 scenarios met neither the 2020 nor the 2050 emission reduction targets. Such scenarios demonstrate the consequences if little or no action is taken to reduce interurban transportation emissions. In this section, four categories of scenarios that failed to meet target values are discussed (increasing emissions, scenarios involving BAU, waiting too long to make changes, and reduction rates that are too small). All scenarios discussed in this section can be found in Table A3.1 in Appendix 3.

Scenario with increasing emissions

Scenarios were calculated to show the variance with the 2020 and 2050 reduction targets when there are increases in the emissions of any or all of the transportation modes (for reasons such as population growth, for example). No scenario with increases in emissions, whether for the whole period to 2050 or parts of it, achieved either the 2020 or the 2050 emission reduction target. These scenarios, while undesirable in their quantitive outcomes, are nevertheless useful in illustrating just how far above the target value transportation emissions could be if they are not reduced systematically and in a sustained manner.

Scenarios 14-18 modelled increases in emissions for all modes from 1% pa to 5% pa. Their cost to offset and discrepancy with target values is plotted in Figure 5.1.

Figure 5.1: Graphic illustration of Scenarios 14-18



Increases of 1% pa yield a 2050 value that is six-fold above target; increases of 2% pa yield a value that is more than nine-fold above target; increases of 3% pa yield a value that is nearly 14-fold above target; increases of 4% pa yield a value that is nearly 20-fold above target; and, finally, increases of 5% pa yield a 2050 value that is nearly 30-fold above target. Offsetting the excess emissions to meet the legislated emission reduction targets would cost, between 2007 and 2050, $29.7 billion for Scenario 14 to $97.3 billion for Scenario 18. Scenario 18 had the costliest results of all scenarios that were modelled. Figure 5.1 illustrates that the cost of offsetting relative to the discrepancy with target values decreases the higher the discrepancy with target values becomes. Though not modelled, if this correlation continued above 5% annual emission increases, it would imply that small annual increases are relatively more costly to offset than larger annual increases relative to the target values.

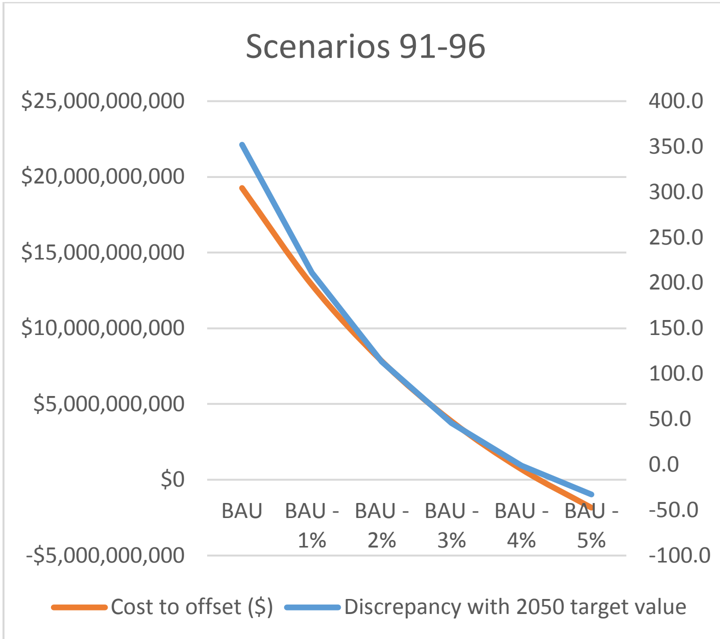
Scenarios 40 and 77-90 modelled an emissions increase of 1% to 5% pa for each mode, up to a given point in time (2020, 2025, or 2030), after which they would decrease at the same rate (1% to 5% pa). None of these scenarios met the 2050 targets. Scenario 85 came closest, which modelled a 5% pa increase across all modes until 2020, from which point forward there would be a 5% pa reduction for all modes. This yielded a 2050 value that was 48% above target. All other scenarios in this group yielded 2050 values that were between 89% and 372% above target. Offsetting the excess emissions would cost, between 2007 and 2050, a total of $12.2 billion for Scenario 85 to $24.2 billion for Scenario 40.

In Scenarios 97-100, each mode follows its 2007-2013 emission trend, plus an increase of between 1% and 4% pa, depending on the scenario, for each mode. For those modes with a negative trend from 2007-2013, their shrinkage rate would reduce or potentially turn it into growth. Thus, for those modes that grew between 2007 and 2013, it would make their growth stronger. The result of Scenarios 97-100 were 2050 values that were between six and 19 times above target, resulting in total offset costs between 2007 and 2050 from $27.4 billion for Scenario 97 to $68.9 billion for Scenario 100.

Scenarios involving BAU

The vast majority of scenarios that involved maintaining the 2007-2013 BAU trend, for either part or all of the time up to 2050, were unable to reach the emission targets. Scenarios based on BAU incorporate the large inertia in the transportation system which makes radical changes difficult from both a technological and social perspective. Figure 5.2 provides a graphic illustration of the cost to offset and discrepancy with 2050 values for Scenarios 91-96.

Figure 5.2: Graphic illustration of Scenarios 91-96



In Scenario 91, all modes follow their BAU trend up to the year 2050. For some modes, this entailed reductions, especially for aviation, whose emissions declined significantly between 2007 and 2013. For others, it entailed growth. Scenario 91 yielded a 2020 value that was 42% above target, and a 2050 value that was 211% above target, resulting in total offset costs of $15.8 billion. Scenario 91 clearly indicates that following a BAU approach, even if it was perhaps slightly skewed in favour of reductions because of the abnormally large aviation reduction rate, cannot achieve the reduction targets and cannot be considered a realistic choice if the reduction targets are taken seriously.

In Scenarios 92-96, all modes would follow their BAU trend up the year 2050, minus a rate of between 1% and 5% for all modes, depending on the scenario. For modes whose emissions already shrunk, such as aviation, this further increased the reduction rate. For modes with growth, it either reduced the growth rate or turned it into a shrinking rate. Out of the scenarios, only scenarios 95 (BAU minus 4% pa) and 96 (BAU minus 5% pa) achieved the 2050 target. The other scenarios, up to BAU -3% pa, failed to meet the targets and yielded 2050 values between 46 % and 211% above target, resulting in total offset costs between 2007 and 2050 from $3.8 billion for Scenario 94 to $12.9 billion for Scenario 92.

Figure 5.2 illustrates that the cost to offset nearly directly correlates with the discrepancy with 2050 targets. This may indicate that in terms of selecting scenarios based on BAU minus a reduction rate, choosing a higher reduction scenario is not inherently cheaper or more expensive in terms of offsetting excess emissions, although the cost of implementing the scenarios may vary.

Waiting too long to make changes

Waiting too long before implementing serious and sustained emission reduction rates means that targets cannot be met. For Scenarios 21-25 and 30-39, there are no changes in emissions until 2020, 2030, or 2040 (i.e., the emissions remain steady at their 2013 values), after which all modes would reduce emissions at rates between 1% pa and 5% pa, depending on the scenario. None of the scenarios were able to achieve the reduction targets. If no changes are made until 2020, the 2050 values are between 4.6% and 260% above target, resulting in offset costs from $4.6 billion for Scenario 34 to $16.4 billion for Scenario 30. If no changes are made until 2030, the 2050 values are between 75% and 299% above target, resulting in offset costs from $12.5 billion for Scenario 25 to $18.9 billion for Scenario 21. If no changes are made until 2040, the 2050 values are between 192% and 341% above target, resulting in offset costs from $18.4 billion for Scenario 39 to $20.5 billion for Scenario 35.

Allowing modes to continue their 2007-2013 BAU trends until 2020, 2025, or 2030 before achieving reductions of 1% pa and 5% pa for each mode also failed to meet target values. These are modelled in Scenarios 41-55. If BAU trends are followed until 2020, the 2050 values are between 4.3% and 253% above target, resulting in offset costs between $4.4

billion for Scenario 55 to $15.8 billion for Scenario 51. If BAU trends are followed until 2025, the 2050 values are between 33% and 266% above target, resulting in offset costs between $8.2 billion for Scenario 50 to $16.7 billion for Scenario 46. If BAU trends are followed until 2030, the 2050 values are between 69% and 280% above targets, resulting in offset costs between $11.6 billion for Scenario 45 to $17.5 billion for Scenario 41.

The scenarios above indicate that an approach of continuing what is currently done before significantly reducing emissions will not allow the 2050 target to be met unless the change resulting in reductions comes within the next few years and is then implemented at a rate of approximately -5% pa.

Reduction rates too small

Reduction rates lower than 4% pa are too small to meet the 80% emission reduction target for 2050. A reduction of 80% over the span of 43 years requires a compound annual reduction rate of -3.67%. Therefore, all scenarios which modelled reductions between 1% and 3% pa were unable to meet the 2050 reduction targets. Even Scenario 4, which modelled a reduction of 4% pa, yielded a 2050 value that was 7.0% above target. This is because the annual 4% reduction would have had to start in 2007, but since the calculations started with the year 2014, up to which reduction rates of 4% pa had not been achieved for most modes, the 2050 value still could not be met.

All scenarios that involve reduction rates between 1% and 3% pa require some form of ‘sudden’ or radical changes to meet the targets. These changes could include technologies that allow for zero emission transportation, wide-sweeping modal shift, or revolutionary technologies that allow emissions for certain modes to be cut by high rates such as 50%. As examples of such sudden change, Scenarios 103-105 modelled huge reductions in trucking emissions. Freight trucking is by far the largest contributor to present-day emissions as calculated by SMITE. In these scenarios, all sectors except trucking would reduce emissions by 1% pa. Trucking emissions would reduce by 1% pa until 2025, at which point 25% of trucking emissions would be eliminated 'suddenly' in Scenario 103 (for example because of modal shift to trains), 50% of trucking emissions in Scenario 104, and 75% of trucking emissions in Scenario 105. For simplicity's sake, it was assumed that freight train emissions would not increase despite the additional freight carried. Projected 2050 total interurban transportation emissions were between 125% and 208% above target values, resulting in total offset costs from $7.2 billion for Scenario 105 to $12.8 billion for Scenario 103.

5.2.2 Discussion of scenarios

Most scenarios in my sample of 106 scenarios were unable to meet the 2020 and 2050 emission reduction targets. In those that were modelled, the four main characteristics that lead to failure were having increases in emissions, continuing with BAU trends too long, waiting too long before implementing radical changes, and having reduction rates that are too small. The results of the scenarios discussed in this section reinforce not only that increases in emissions from current levels will result in values that are significantly above the target values, but also that small to moderate reduction rates may ultimately not be able to achieve the reduction targets.

5.3 Scenarios that meet 2050, but not 2020, emission reduction targets

5.3.1 Introduction

In this section, the scenarios that meet only the 2050 emission reduction targets are discussed. This selection of scenarios illustrates that even strong initial and sustained reduction rates cannot meet the 2020 emission reduction targets, and that if 2020 targets are not met, meeting 2050 emission reduction targets will generally require significant and 'sudden' reductions for at least some sectors on top of strict and sustained reduction rates. However, the requirements to achieve only the 2050 reduction targets are less stringent than those to achieve both the 2020 and 2050 emission reduction targets, which are discussed in the next section. A total of 15 scenarios in my sample of 106 scenarios met the 2050 but not the 2020 emission reduction targets. Table 5.1 lists these scenarios, their overall projected emissions and discrepancy with the 2050 target value, changes that were modelled in each scenario, and estimated value of excess carbon credits. Scenarios are listed in order of increasing total projected 2050 emissions (i.e., the scenario with the lowest overall projected emissions is discussed first).

Table 5.1: Scenarios that meet only 2050 emission reduction targets

Scen	2020	2050	Passenger transportation parameters (% pa)	Freight transportation parameters (% pa)	Offset (bn $)
29	35.4	-100.0	• All modes: • -1% pa through 2030, then all modes 0 emissions	• All modes: • -1% pa through 2030, then all modes 0 emissions	2.41
76	0.9	-69.0	• Aviation: -5% pa • Bus: -5% pa • Cars: -5% pa 2020, then instant 50% reduction, then -5% pa • Ferries: -5% pa • Trains: -5% pa to 2030, then 0 emissions because of electric trains	• Aviation: -5% pa • Marine: -5% pa • Train: -5% pa to 2030, then 0 emissions because of electric trains • Truck: -5% pa to 2025, then 75% reduction, then -5% pa	5.84
71	0.9	-66.3	• Aviation: -5% pa • Bus: -5% pa • Cars: -5% pa to 2020, then instant 30% reduction, then -5% pa • Ferries: -5% pa • Trains: -5% pa to 2030, then 0 emissions because of electric trains	• Aviation: -5% pa • Marine: -5% pa • Train: -5% pa to 2030, then 0 emissions because of electric trains • Truck: -5% pa to 2025, then 75% reduction, then -5% pa	5.42
65	0.9	-61.8	• All modes: • -5% pa to 2030, then	• All modes: • -5% pa to 2030, then	3.88

			halved, then -5% pa	halved, then -5% pa	
75	8.7	-54.6	• Aviation: -4% pa • Bus: -4% pa • Cars: -4% pa to 2020, then 50% reduction, then -4% pa • Ferries: -4% pa • Trains: -4% pa to 2030, then 0 emissions because of electric trains	• Aviation: -4% pa • Marine: -4% pa • Train: -4% pa to 2030, then 0 emissions because of electric trains • Truck: -4% pa to 2025, then 75% reduction, then -4% pa	4.42
70	8.7	-50.7	• Aviation: -4% pa • Bus: -4% pa • Cars: -4% pa to 2020, then 30% reduction, then -4% pa • Ferries: -4% pa • Trains: -4% pa to 2030, then 0 emissions because of electric trains	• Aviation: -4% pa • Marine: -4% pa • Train: -4% pa efficiency to 2030, then 0 emissions because of electric trains • Truck: -4% pa to 2025, then 75% reduction, then -4% pa	3.92
64	8.7	-44.3	• All modes: • -4% pa to 2030, then halved, then -4% pa	• All modes: • -4% pa to 2030, then halved, then -4% pa	2.07
74	17.1	-33.7	• Aviation: -3% pa • Bus: -3% pa • Cars: -3% pa to 2020, then 50%, then -3% pa • Ferries: -3% pa • Trains: -3% pa to 2030, then 0 emissions because of electric trains	• Aviation: -3% pa • Marine: -3% pa • Train: -3% pa to 2030, then 0 emissions because of electric trains • Truck: -3% pa to 2025, then 75% reduction, then -3% pa	2.71
69	17.1	-28.1	• Aviation: -3% pa • Bus: -3% pa • Cars: -3% pa to 2020, then 30%, then -3% pa • Ferries: -3% pa • Trains: -3% pa to 2030, then 0 emissions because of electric trains	• Aviation: -3% pa • Marine: -3% pa • Train: -3% pa to 2030, then 0 emissions because of electric trains • Truck: -3% pa to 2025, then 75% reduction, then -3% pa	2.09
5	0.9	-27.4	• All modes: -5% pa	• All modes: -5% pa	1.23
58	4.7	-26.3	• All modes: • 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	• All modes: • 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	0.51
63	17.1	-18.9	• All modes: • -3% pa to 2030, then halved, then -3% pa	• All modes: • -3% pa to 2030, then halved, then -3% pa	0.11

73	25.9	-3.6	• Aviation: -2% pa • Buses: -2% pa • Cars: -2% pa to 2020, then instant 50% reduction, then -2% pa • Ferries: -2% pa • Trains: -2% pa to 2030, then 0 emissions because of electric trains	• Aviation: -2% pa • Marine: -2% pa • Train: -2% pa to 2030, then 0 emissions because of electric trains • Trucks: -2% pa to 2025, then instant 75% reduction, then -2% pa	0.62
95	6.3	-1.0	• All modes: BAU – 4% pa	• All modes: BAU – 4% pa	0.69
26	0.9	-0.8	• All modes: • -5% pa to 2030, then -4% pa to 2040, then -3% pa to 2050.	• All modes: • -5% pa to 2030, then -4% pa to 2040, then -3% pa to 2050.	0.55

Table 5.2 Legend

Scen = Scenario number in Table A3.1 in Appendix 3
2020 = Discrepancy with 2020 target (%), where a negative value represents the percent by which the scenario emissions are under the 2020 target
2050 = Discrepancy with 2050 target (%), where a negative value represents the percent by which the scenario emissions are under the 2050 target
Offset = Value of excess offset credits ($ billions)
BAU = Business-as-usual (no changes made to current emission trends of mode)

5.3.2 Discussion of scenarios

Strong and sustained annual emission reductions alone are not sufficient for meeting the 2020 emission reduction targets, but they may be able to meet the 2050 targets. Even scenarios involving 5% pa reductions (76, 71, 65, 5, and 26), which are the highest annual reductions modelled apart from the backcasting scenario and certain BAU-based scenarios, failed to meet the 2020 emission reduction target, even though the projected values are only minimally above the target value.

Eleven of the 15 scenarios in this section modelled some kind of dramatic and ‘sudden’ change to part or all of the transportation system at some point beyond 2020 that would significantly reduce emissions and after which emissions would either be zero for one or all modes, or after which modes would continue reducing their emissions at an annual rate.

These changes may be caused, for example, by various kinds of modal shift, for example from trucks to trains, by shifts within a mode (such as to smaller and more efficient private vehicles), or by the wide-scale adoption of revolutionary technologies such as electric vehicles. The scenarios show that varying degrees of such changes (for example, both a sudden 30% and 50% reduction of car emissions) can meet the target values. Because these scenarios resulted in emissions that are below the target value, sellable credits ranged from a total of $111 million to $5.8 billion. (Note: As previously stated the development and implementation costs of such sudden changes are not incorporated into SMITE. These may well be more than the amounts gained by selling credits.)

Because the required annual reduction rate is higher than -4%, Scenario 5, modelling -5% pa reductions, was able to meet the 2050 emission reduction target. Scenario 4 (not listed in the table above), was not able to meet the target even though its reduction rate of -4% pa was above the required annual compound rate because it requires that these reductions begin in 2007 and not 2013, which was the base year for the future scenario calculations.

Scenario 58 modelled a 10% reduction of 2007 values by 2015, 20% reduction of 2015 values by 2020, 30% reduction of 2020 values by 2030, 40% reduction of 2030 values by 2040, and 50% reduction of 2040 values by 2050. This yielded a 2020 value 4.7 % above target, and a 2050 value 26.3% below target without a change in the modal composition of emissions. Because the scenario results in emissions that are below target, sellable credits are approximately $510 million. To achieve the reduction rates in this scenario, revolutionary developments of some sort would have to occur. However, unlike the ‘sudden’ reduction scenarios discussed above, this scenario’s reductions do not occur all at once, meaning that there is more time for changes to be planned and implemented (for example, through successive cycles of product development). As well, a slight failure to accomplish one ‘step’ may be balanced out by overachieving on one of the previous or following steps.

Scenario 95 modelled that all modes reduce their emissions by a rate equal to their BAU trend from 2012 to 2013 minus 4%. This resulted in higher reduction rates for those modes which already reduced their emissions between 2007 and 2013, while it meant that if a mode’s BAU trend was between 0% and +4%, this rate would change from growth to shrinkage. Although this scenario may not be feasible to implement, especially for those modes which already experienced emission reductions and would thus have to decrease their emissions even further annually, it may be a feasible option in that it allows the province to just meet its 2050 targets.

Scenario 26 modelled that all modes reduce their emissions by 5% pa until 2030, then by 4% pa between 2030 and 2040, and by 3% pa between 2040 and 2050. The slowing reduction rate may be caused, for example, by increased transportation usage because of population growth. This scenario illustrates that easing reduction rates can still meet the 2050 target (even if just), but that reductions must start at a high annual reduction rate and can then only gradually decrease after 2030.

While 15 scenarios were able to meet or exceed the 2050 emission reduction targets, none of these scenarios would likely be easy to implement. Focusing on 2050, instead of 2020, does however have the advantage that there is a much greater chance of the development of revolutionary technologies or other radical changes, for some or all of the modes in question, within the next 35 years rather than within the next five years. These revolutionary developments may then contribute to achieving the required annual emission reductions.

5.4 Scenarios that meet 2020 and 2050 emission reduction targets

5.4.1 Introduction

In this section, the scenarios that met both the 2020 and 2050 emission reduction targets are presented. Only two scenarios out of 106 were able to meet both reduction targets, which illustrates the magnitude of changes required to meet the targets. These two scenarios are listed in Table 5.2 along with their overall projected emissions and discrepancy with the 2020 and 2050 target values, changes that were modelled in each scenario, and estimated value of excess carbon credits. Scenarios are discussed in order of decreasing 2050 emission reductions (i.e., the scenario with the lowest overall projected emissions is introduced first).

Table 5.2: Scenarios that meet both 2020 and 2050 emission reduction targets

Scen	2020 (%)	2050 (%)	Passenger transportation parameters (% pa)	Freight transportation parameters (% pa)	Offset (bn $)
96	-1.4	-33.0	• All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	• All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	1.85
6	-2.3	-2.3	• Aviation: +0.54% pa to 2020, then -3.95% pa • Bus: -8.58% to 2020, then -3.95% pa • Cars: -6.33% to 2020, then -3.95% pa • Ferries: -4.35% to 2020, then -3.95% pa • Trains: -5.56% to 2020, then -3.95% pa	• Aviation: -6.46% to 2020, then -3.95% pa • Marine: -3.10% to 2020, then -3.95% pa • Train: -5.45% to 2020, then -3.95% pa • Truck: -6.05% to 2020, then -3.95% pa	0.06

Table 5.1 Legend

Scen = Scenario number in Table A3.1 in Appendix 3

2020 = Discrepancy with 2020 target (%), where a negative value represents the percent by which the scenario emissions are under the 2020 target

2050 = Discrepancy with 2050 target (%), where a negative value represents the percent by which the scenario emissions are under the 2050 target

Offset = Value of excess offset credits ($ billions)

BAU = Business-as-usual (no changes made to current emission trends of mode)

5.4.2 Discussion of scenarios

Scenario 96 modelled that all modes reduce their emissions by a rate equal to their BAU rate from 2007 to 2013, minus 5%. For the three modes that already reduced their emissions between 2007 and 2013 (passenger aviation, ferries, and marine freight), this would mean that even more stringent annual reductions need to occur. For the remaining six modes which had increases in their emissions between 2007 and 2013 or whose emissions were steady, it turned them into shrinkage rates. This scenario shows that it is possible to meet both the 2020 and 2050 reduction targets, but it would require significant changes soon, for example rapid deployment of new technologies such as hydrogen-powered cars and/or sweeping behavioural changes such as widespread use of public transportation. For modes which have already reduced their emissions from 2007 to 2013, reducing emissions by an additional 5% pa would likely be difficult because some aspects that may help achieve these rates, such as technological changes, may have already been taken advantage of. For modes which have not reduced their emissions between 2007 and 2013, reducing emissions by 5% pa may be due to more systemic issues (such as infrastructure investment) that have prevented or discouraged these modes from reducing their emissions so far. As such, accomplishing a BAU -5% pa scenario would likely require a multifaceted approach that pays close attention not only to which modes have reduced their emissions and which have increased theirs, but also to why certain modes have been able to reduce their emissions while others have not. While this scenario is significantly (33%) below the 2050 target value, it is only 1.4% below the 2020 target value. This highlights that accomplishing the 2020 target is very much linked to the point in time at which sustained reductions begin, and that with every year that passes without embarking on systemic reductions to transportation emissions, meeting the 2020 targets and eventually the 2050 targets becomes increasingly difficult. Moreover, the excess offset value of $1.85 billion could very likely by surpassed by the cost of implementing this scenario.

Scenario 6 was the only scenario modelled that utilized backcasting, namely assuming that both 2020 and 2050 targets would be met by each mode individually and calculating the rates that allowed each mode to accomplish these reductions. Passenger aviation was an exceptional case in this scenario because its emissions decreased significantly between 2007 and 2013, to the point where they were below the target value. This may have been caused, in part, by the introduction of newer and more fuel-efficient aircraft in BC or by schedule consolidation. Because passenger aviation emissions decreased at more than 7% pa between 2007 and 2013, meeting the 2020 target value would actually allow passenger aviation to increase its emissions by 0.53% pa between 2013 and 2020. Buses would have to reduce their emissions by -8.58% pa, private vehicles by -6.32% pa, ferries by -4.35% pa, passenger trains by -5.56% pa, aviation freight by -6.46% pa, marine freight by -3.10% pa, freight trains by -5.45% pa, and freight trucks by -6.06% pa. These are some of the highest reduction rates modelled, and for all modes except ferries and marine freight, they exceed my self-imposed maximum modelled value of -5% pa. Between 2020 and 2050, all modes would then, having achieved their 2020 target value, reduce their emissions -3.95% pa to achieve the 80% reduction over 2007 values by 2050. In theory, this scenario should result in just meeting the target values and have a net offset cost/credit value of zero.

Only the most ambitious of scenarios are able to achieve both the 2020 and 2050 emission reduction targets. Scenario 6 is a baseline that illustrates what annual reduction rates are required in order to exactly meet the 2020 and 2050 reduction targets. All other scenarios, ambitious though their reduction rates may be, require some sort of ‘sudden’ change in order to meet the 2050 targets. Since these kinds of changes are not likely to occur within the next five years and were thus not modelled to happen before 2020, only two scenarios were able to meet both targets.

What makes achieving the 2020 targets even more difficult is that more than half of the time from implementation of the law to reduce emissions (2007) to 2020 has already passed, and to date most sectors have achieved little or no emission reductions. Consequently, there are only about six years from 2014 (the starting year for my projections) in which to achieve a 33% emission reduction. Thus, the scenarios illustrate that not only do drastic steps have to be taken in order to meet the 2020 and 2050 emission reductions, but their sustained implementation needs to happen sooner rather than later.

5.5 Summary

In this chapter, a representative sample of the 106 scenarios was presented in order to develop perspective on the ability of British Columbians and the provincial government to meet their legislated emission reduction targets. Analysis of these scenarios for BC’s interurban transportation system demonstrates promising paths for meeting the emission reduction targets, as well as ‘unpromising paths’ that will ensure the targets are not met.

Figure 5.3 illustrates the cost to offset excess emissions relative to annual emission percentage changes ranging from -5% to +5% (not all of these scenarios were discussed individually).

Figure 5.3: Cost to offset relative to annual emission percentage changes.

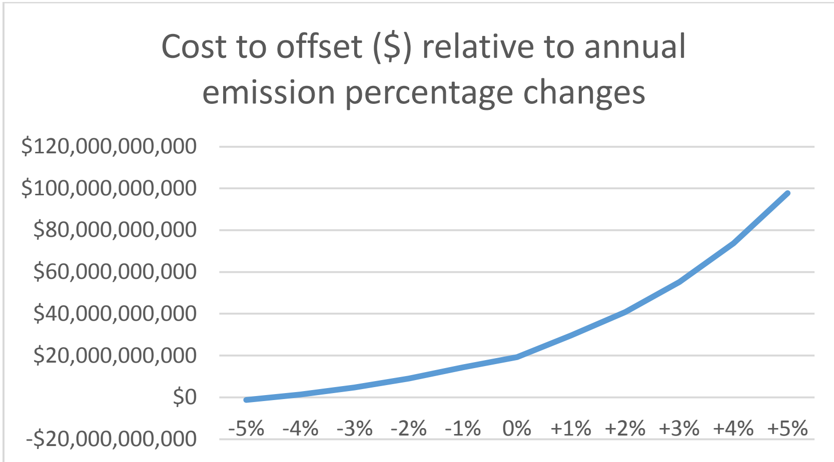


Figure 5.3 indicates that the cost to offset excess emissions increases exponentially the higher the annual emission percentage increase is. This may indicate that while there might only be a limited financial return to larger annual reduction rates (such as from -4% to -5%), the cost of inaction resulting in emission increases rises exponentially the higher the increases are.

The majority of scenarios modelled failed to meet both 2020 and 2050 reduction targets. Scenarios that failed to meet the targets can be broadly grouped into (1) scenarios with emission increases, (2) scenarios involving BAU, (3) waiting too long to make changes, and (4) reduction rates that are too small. Some scenarios were not expected to meet the targets because they modelled increases in emissions, but others, with reductions up to 3% pa, were also unable to achieve significant enough reductions. This indicates the difficulty in achieving BC's legislated GHG reduction goals, since even sustained reductions of 3% pa are, with current technologies, something that would be quite difficult to achieve. However, when it comes to planning for the future, examination of the characteristics of scenarios that failed to meet the reduction targets provides valuable perspective for policymakers and the general public. They illustrate that reductions will have to be substantial and sustained over most or all of the period until 2050 in order for the emission reduction targets to be met.

Meeting only 2050 targets requires strict annual emission reductions for all modes, as well as, in most successful scenarios, ‘sudden’ changes happening at some point beyond the year 2020 that allow one or more modes to significantly reduce their emissions. All of these scenarios would likely be a major challenge to implement. Scenarios focusing on 2050 have the advantage of having time on their side in terms of the development of revolutionary technological, political, or behavioural change. Scenario 58 (mandated 10% reduction over 2007 emissions by 2015, 20% over 2015 emissions by 2020, 30% over 2020 emissions by 2030, 40% over 2030 emissions by 2040, and 50% over 2040 emissions by 2050) and Scenario 74 (-3% pa for all modes, then ‘sudden’ emission reductions for cars and trucks in the 2020s) are among the most promising options in this category. Scenario 58 is promising because it requires that reduction rates are gradually increased. This means that there is time for ways of achieving these reduction rates. Scenario 74 is promising in that it requires only a moderate -3% pa reduction, but it also requires a ‘sudden’ reduction in the near future, for example a modal shift in freight transport and rail electrification. Modal shift and rail electrification are steps that can already be implemented, but modal shift would require systemic changes to transportation while rail electrification is hindered mostly by the extremely high cost.

In this chapter, a variety of scenarios that modelled changes to BC’s transportation system have been discussed. My research points to the fact that only scenarios with the most drastic changes (i.e., the strictest reductions) were able to achieve both the 2020 and 2050 emission reduction targets. These would, in all probability, be very difficult to implement because they require significant and sustained reduction rates that would, most likely, involve revolutionary technological developments, overcoming social inertia, and high costs. My research indicates not only that drastic changes are required but also that they have to occur sooner rather than later. Delaying change will only mean that it will then need to be all the more radical. To end on an optimistic note, there seem to be a variety of paths the province could choose to set BC on a course towards achieving the emission reduction targets; the caveat is that none seem to be easy to implement.

CHAPTER 6: CONCLUSION

The purpose of this final chapter is multifold. First, results of the research are summarized. Next, examples of how BC may be able to achieve significant emission reductions for various transportation modes are discussed. After this, the contribution of this research to existing knowledge as well as limitations of this research are highlighted. Next, suggestions for future research are discussed, which is followed by final thoughts about this research project.

6.1 Summary of results

The goal of this research was to try to provide answers to two main research questions. The first question is: *What are the present-day total CO_2 emissions and EFs of interurban passenger and freight transportation in BC?* Subsidiary questions include: What did each mode contribute towards its sectoral (passenger or freight) emissions totals? How do transportation modes compare to each other in terms of EFs to carry one passenger or one unit of freight over one unit of distance? To provide answers to these questions, the Simulator for Multimodal Interurban Transportation Emissions (SMITE) tool was developed, which is a spreadsheet-based inventory and scenario calculation tool. The inventory function was used to compile emission inventories of BC interurban passenger and freight transportation for each of nine modes (private vehicles, ferries, passenger aviation, interurban buses, passenger trains, trucking freight, marine freight, train freight, and aviation freight). Emission totals and BC-specific per-person or per-tonne EFs were then calculated in the SMITE tool using EFs (specifically calculated for this research if possible, or taken from the literature if not) and usage statistics at the local, provincial, and/or national level. The results were displayed in tables and maps.

The second research question is: *What changes to BC interurban transportation can help the province to achieve its legislated 2020 and 2050 emission reduction targets, and how far above target values will projected values be if reduction rates are insufficient?* Subsidiary questions include: What combinations of changes to the BC interurban transportation system can help the province to achieve its emission reduction targets? What are the costs for offsetting excess emissions in those scenarios that do not meet the reduction targets? To answer these questions, the future scenario function of the SMITE tool was used, which allows users to enter parameters for each mode and then calculate projected future emission values for each transportation mode and the system as a whole, as well as whether 2020 and 2050 targets are met, and the cost of offsetting excess emissions or the value of offset credits. For most scenarios modelled, the rate of change ranged from -5% to +5% per year. The scenarios do not, in most cases, represent specific types of change to the transportation system but rates of change in the modes of the system, which may be affected by, for example, technological, political, and behavioural factors. A total of 106 scenarios, representing a broad spectrum of changes, were modelled and analyzed.

6.1.1 Summary of results for Research Question One

What are the total CO_2 emissions and EFs of interurban passenger and freight transportation in BC? According to the calculations performed using the SMITE tool, the CO_2 emissions of BC interurban transportation around 2013 were 11.19 million tonnes CO_2.

Table 6.1 (identical to Table 1.1 in chapter 1) summarizes the individual interurban transportation modes, their total annual emissions and respective percentage of overall interurban transportation emissions and passenger or freight sector, and their EFs.

Table 6.1: Summary of BC interurban transportation emissions and EFs by mode

Transportation mode	**Emissions by mode (tonnes CO_2)**	**Percentage of *total* interurban trans-portation emissions**	**Percentage of *passenger* interurban trans-portation emissions**	**Percentage of *freight* interurban trans-portation emissions**	**EF (g CO_2/pkm for passengers; g CO_2/tkm for freight) (range where available or average)**
Passenger transportation					
Private vehicles	1,916,000	17.1	78.4		202
Ferry	342,000	3.1	14.0		260 – 1,781
Passenger aviation	167,000	1.5	6.8		75 - 386
Intercity buses	13,000	0.1	0.5		57* - 137*
Passenger trains	5,000	<0.1	0.2		117*
Freight transportation					
Trucking freight	5,431,000	48.5		62.1	196
Marine freight	1,883,000	16.8		21.5	n/a
Rail freight	1,428,000	12.8		16.3	15
Aviation freight	9,000	0.1		0.1	940 – 6,810
Total	11,194,000	100%	100%	100%	

Table 6.1 Legend:
pkm = Passenger-kilometre
tkm = Tonne-kilometre
* = Value could not be calculated independently and was taken from the literature.

Below, each of the nine modes is discussed in order of their contribution to BC interurban transportation emissions.

Trucking freight is the greatest contributor to BC interurban transportation emissions with 5,431,000 tonnes of CO_2, or 48.5% of total emissions. Trucking emissions are concentrated geographically between major urban centres and especially on the busy highways in densely-populated southwestern BC. BC trucking has an EF of 196 g CO_2/tkm. This compares to an EF of 122 g CO_2/tkm by DEFRA (2012), and an EF of between 100 g

CO_2/tkm and 200 g CO_2/tkm by Chapman (2007), where values vary based on the size and weight of the truck.

Passenger vehicles accounted for 1,916,000 tonnes of $CO_{2,}$ or 17.1% of total emissions. The EF of the average Canadian vehicle, based on highway EF information for more than 16,500 individual models sold in Canada between 1995 and 2013, is 202.0 g CO_2/pkm. DEFRA (2012) publishes an EF of 202 g CO_2/km, while Chapman (2007) lists an EF of approximately 240 g CO_2/km. Both of these EFs are a combination of both less efficient city driving and more efficient highway driving. The fact that the car EF calculated in this research is as high as that provided by DEFRA, even though it only includes more efficient highway driving, stands to reason because the average Canadian car tends to be larger than the average car globally. Private vehicle emissions are closely related to population density levels: in BC, they are highest around Vancouver and the densely-populated Lower Mainland, southern Vancouver Island, and Okanagan areas, and lowest in rural and northern areas of BC.

Marine freight is the third greatest contributor to BC interurban transportation emissions with 1,883,000 tonnes of $CO_{2,}$ or 16.5% of total emissions. The geographic distribution of these emissions could not be determined because schedule and routing information were not available. Moreover, a BC-specific EF could not be calculated because of a lack of relevant statistics. Chapman (2007) lists an EF of approximately 40 g CO_2/tkm, but it is unclear whether this EF is for ocean-shipping or domestic shipping, or how EFs for each of these would vary.

Rail freight accounted for 1,428,000 tonnes of CO_2, or 12.8% of total emissions. The EF of rail freight is 15 g CO_2/tkm. Trains therefore have a tonne-kilometre EF 92% lower than trucks. DEFRA (2012) lists a rail freight EF of 28 g CO_2/tkm, while Chapman (2007) lists an EF of approximately 30 g CO_2/tkm. The lower value for BC may be caused by trains in BC generally consisting of many cars (more than an average European train), where carrying more cars may make the train more efficient than a shorter train per unit of freight carried. Determining the geographic distribution of emissions was not possible because statistical information on route usage was not available.

Ferries accounted for only 342,000 tonnes of CO_2 or 3.1% of total emissions, despite high passenger-kilometre EFs and the low LFs observed on many of its routes. BC Ferries operated 155,000 sailings travelling a total of 2.5 million kilometres. Aggregate ferry emissions are concentrated between Greater Vancouver and southern Vancouver Island, since this is where most sailings take place and the largest vessels are used. The geographic distribution of passenger-kilometre EFs depends mostly on the vessel used and its average LF, with the highest EF (1,781 g CO_2/pkm) found on the Sunshine Coast near Vancouver, and the lowest EF (261 g CO_2/pkm) found on a route serving several small islands off Vancouver Island. At an average 696 g CO_2/pkm, the BC passenger-kilometre ferry EF is more than 3.5 times higher than that of driving the average BC vehicle as a single occupant. DEFRA (2012) lists a ferry EF of 115 g CO_2/pkm. This significantly lower value may be due to ferries in Europe generally carrying higher percentages of foot passengers. Ferries in BC also have the ability to carry these foot passengers, but more difficult public transit access to many ports may mean that less people choose to travel as foot passengers, which increases the per-passenger EF of those passengers who do travel.

Passenger aviation accounted for 167,000 tonnes CO_2, or 1.5% of total emissions. A total of 15 airlines operated 180,000 flights that travelled 38 million kilometres within BC.

The geographic distribution is mostly between Vancouver and the other, larger cities around the province, since these receive the most frequent air service by the largest airplanes. Passenger-kilometre EFs of passenger aviation in BC range from 74.5 g CO_2/pkm on Westjet's Boeing 737 jets to 385.9 g CO_2/pkm using CMA's Beech 1900 series airplanes. On certain flights, Westjet thus achieves lower passenger-kilometre EFs than what is, according to my calculations, the most fuel-efficient vehicle for sale in BC, the Toyota Prius, which achieves a highway passenger-kilometre EF of 92 g CO_2/pkm assuming single occupancy. At an average 184.5 g CO_2/pkm, passenger aviation has a slightly lower passenger-kilometre EF than using the average BC vehicle as a single occupant, and less than one-third that of ferries. DEFRA (2012) lists an EF of approximately 167 g CO_2/pkm. This value, although only somewhat lower than that calculated in this research, may be explained by more efficient aircraft or higher LFs.

Buses accounted for approximately 13,000 tonnes of CO_2 or 0.1% of total emissions. Emissions are geographically centred on longer routes in BC's interior and in the area around Vancouver which sees the highest service frequencies. Estimates for a bus passenger-kilometre EF range from 57g CO_2/pkm to 137 g CO_2/pkm, depending on average occupancy. Thus, bus emissions could be the lowest of available interurban transportation modes in BC. However, when occupancy numbers are low, they may be only somewhat lower than averages for aviation and private vehicles. The bus EF can be compared to a bus EF of 28 g CO_2/pkm provided by DEFRA (2012), which may be lower because of higher LFs in Europe.

Aviation freight accounted for approximately 9,000 tonnes CO_2, or 0.1% of total emissions. These emissions are generated on the select few routes that see regular all-freight flights, such as Vancouver to Victoria, Prince George, and Kelowna. The tonne-kilometre EF of aviation freight is, depending on the airplane type used, between 940 g CO_2/tkm and 6,810 g CO_2/tkm. Aviation freight thus has, by far, the highest tonne-kilometre EFs within BC, with EFs that are 4.8 to 35 times higher than trucking and 63 to 454 times higher than rail freight. DEFRA (2012) provides an aviation freight EF of 2,044 g CO_2/tkm, while Chapman (2007) provides an EF of approximately 1,430 g CO_2/tkm. These lower values as averages are comparable with the results of this research, especially considering that Cessna aircraft, which had the highest EFs of aviation freight in BC, are so small that they may not be used for aviation freight in other parts of the world, such as Europe.

Passenger trains accounted for approximately 5,000 tonnes CO_2, or less than 0.1% of total emissions. It has the lowest aggregate emissions because only two routes are operated, and these have low traffic volumes. The passenger-kilometre EF of passenger trains in BC is approximately 117 g CO_2/pkm. This means that while BC trains have higher EFs than their electric, high-speed counterparts, they still have lower passenger-kilometre EFs than cars, airplanes, and ferries. Chapman (2007) provides a passenger train EF of approximately 50 g CO_2/pkm, while DEFRA (2012) lists an EF of 55 g CO_2/pkm. These lower values can likely be explained by much higher train LFs in Europe, along with at least partial electrification resulting in lower emissions.

6.1.2 Summary of results for Research Question Two

A total of 106 scenarios of changes to the BC interurban transportation system were modelled using the SMITE tool. The parameters in each scenario were chosen to reflect ‘plausible’ changes to each transportation mode.

The majority of the scenarios modelled were unable to meet either the 2020 or 2050 emission reduction targets. Scenarios that failed to meet the targets could be slotted into four categories: (1) scenarios that incorporated increases in emissions for either all or part of the time studied, (2) scenarios that continued business-as-usual trends for too long before making systemic changes to reduce emissions, (3) scenarios that kept emissions steady too long before making systemic changes to reduce emissions, and (4) scenarios that incorporated reduction rates that were too small.

A total of 15 of the 106 scenarios met the 2050 target but not the 2020 target. Apart from requiring significant annual reduction rates from all modes (either sustained or increasing with time), 11 out of the 15 scenarios also required 'sudden' or drastic reductions to take place at some point beyond 2020, that would allow one or more modes to significantly reduce their emissions in a single step. Since all of these scenarios exceeded the 2050 reduction target, sellable offsets ranged from $111 million to $5.84 billion. Only two scenarios meet or exceed both the 2020 and 2050 reduction targets. One of these modelled reductions of the 2007-2013 BAU rates minus 5%, while the other used backcasting to calculate the exact rates that allow each mode to meet its emission targets. Although both scenarios featured some of the highest reduction rates modelled, they both only just managed to meet the 2020 targets, which highlighted that meeting the 2020 targets in particular critically depends on sustained and significant annual reduction rates to be implemented sooner than later. Sellable offsets ranged from $60 million to $1.85 billion.

6.2 Examples of changes that may help accomplish CO_2 reductions

Based on my analysis of the current aggregate CO_2 emissions and EFs of BC interurban transportation, as well as the scenarios of future changes, I put forth six concrete examples of how emission reductions in the BC interurban transportation system may be achieved. These examples also serve to illustrate the policy value or capability of the SMITE model. They are ordered more or less according to their importance for achieving the 2020 and 2050 emission reduction targets.

Example 1: Reducing trucking emissions through modal shift to freight trains and through small-scale truck efficiency improvements

Freight trucking has the highest total CO_2 emissions of all interurban transportation in BC, and at 196 g CO_2/tonne-km, its tonne-kilometre EF is more than 13 times higher than the 15 g CO_2/tonne-km produced by rail freight. Some of the 'sudden' reductions to trucking emissions which were modelled in various scenarios discussed in Chapter 5 could be delivered by a modal shift for freight from trucks to trains. In scenarios where all modes reduce their emissions by 1% per year, reducing trucking emissions 25% through modal shift to trains by 2025 (and assuming that railway emissions would not increase because of their higher efficiency and that there is at least partial railway electrification) results in 2050 emissions that are 208% above target values; reducing trucking emissions 50% results in 2050 emissions that are 166% above target values; and reducing trucking emissions 75% results in 2050 emissions that are 125% above target values. This compares to 2050 emissions that are 237% above target values if there is no sudden reduction of trucking emissions and all modes reduce their emissions 1% per year, in which case total projected 2050 emissions are 7.6 Mt CO_2. By comparison, total projected emissions are 7.0 Mt CO_2 in the 25% reduction scenario, 6.0 Mt CO_2 in the 50% reduction scenario, and 5.1 Mt CO_2 in the 75% reduction scenario. In the 75% trucking emission reduction scenario, the cost of offsetting excess emissions is $7.2 billion below that of the non-modal shift scenario (the cost is halved). In short, SMITE shows significant emission reductions could result from a modal shift from truck to rail.

This shift may be particularly attractive because the technology and infrastructure needed already exist. Rail freight is, however, not a perfect substitute for freight trucking, because trains are naturally bound by the limitations of the rail network and are unable to travel to as many places are freight trucks, especially in rural and remote parts of the province where building rail access if it is currently not available may not be feasible. Thus, there are positives and negatives of a truck-to-rail modal shift; however, the SMITE model demonstrates that climate benefits are one of the positives.

Modal shift to freight trains is not the only way in which BC could reduce its freight trucking emissions, though. Small-scale efficiency improvements to trucks, such as to their aerodynamics and the use of low-friction lubricants, may reduce fuel consumption in trucks by as much as 33.2% (Ang-Olson and Schroeer 2002). If through such measures BC's tonne-kilometre EF was reduced by 33.2% from 196 g CO_2/tkm to 131 g CO_2/tkm by 2020, emissions would be 3,630,000 tonnes CO_2, assuming 2013 trucking usage (kilometres and route driven). This value is only 3.5% larger than the 2020 trucking target value of 3,507,000 tonnes CO_2, meaning that wide-scale adoption of small-scale efficiency improvements to trucks may allow BC to nearly meet its 2020 trucking emission reduction target without any reduction in trucking usage.

Example 2: Reduce passenger-kilometre EFs of private vehicles below 100 g CO_2/km

Private vehicles generate by far the highest emissions of interurban passenger transportation in BC. As such, accomplishing any reductions in this mode is vital to reducing overall transportation emissions. Private cars account for nearly one-fifth of all interurban transportation emissions in BC, which are directly related to the distances traveled each year and to the EFs of the vehicles used. Emissions from private cars can be reduced substantially by switching to vehicles with lower passenger-kilometre EFs, even without reducing travel usage. In my research, I calculated a Canada-specific car EF of 202 g CO_2/km. Based on an analysis of the vehicles available for sale in Canada in 2013 (Natural Resources Canada 2014), the vehicle with the lowest EF was the Toyota Prius, with an EF of 92 g CO_2/km. Of the more than 1,000 vehicle models available in 2013, more than 100 have EFs below 130 g CO_2/km. If by 2020 all vehicles were replaced by models that had the EF of the 2013 Prius, and assuming that car usage (kilometres and routes driven) remain at 2013 levels, private vehicle emissions in 2020 would be 873,000 tonnes CO_2. The 2020 target value for private vehicles is 1,212,000 tonnes CO_2, meaning that emissions would be 339,000 tonnes CO_2 or 28.0% below target. The 2050 emission target value for private vehicles is 362,000 tonnes CO_2, which means that maintaining a fleet-wide EF of a 2013 Prius will not be sufficient to meet the 2050 target value, as the emissions of 873,000 tonnes CO_2 would be 141% above target, assuming 2013 usage (kilometres and routes driven). Thus, converting all vehicles by 2020 to an average EF that is equivalent to the 2013 Prius EF means BC's 2020 private vehicle target could be met but its 2050 target could not. The private vehicle target and the 'Prius EF' total emissions value become identical in 2028 (at approximately 878,000 tonnes CO_2). Therefore, if all cars were switched to 2013 Prius models by 2020, it would allow eight years for new vehicle technologies to be developed with even lower EFs that could then lead to reducing emissions below target values between 2028 and 2050. The example in this section illustrates two key points. First, it illustrates the significant degree of improvement required in the automobile fleet to meet the 2020 target (for private vehicles)—a drop in EF of about 100 g CO_2/km, or approximately 50%. Second, it illustrates the value of lowering vehicle EFs sooner rather than later.

Example 3: Reduce private vehicle emissions through modal shift

Promoting modal shift of passenger transportation from private vehicles to trains and buses could be viable in those areas of BC that have the highest population densities and passenger vehicle traffic volumes. Two areas are of especial interest: the Lower Mainland east of Vancouver, and the region between Victoria and Nanaimo.

For private vehicles, the Vancouver to Chilliwack route currently has the highest emissions of all BC roads, with 226,000 tonnes CO_2 in 2013. We can compare emission reductions if light rail or bus replaces private vehicles on this route. In the Lower Mainland, the West Coast Express rail service links Vancouver to Mission (Translink 2015), a distance of approximately 65 km. Assume it is extended approximately 40 km to Chilliwack, the last of the large cities in the Lower Mainland east of Vancouver. Light rail has a passenger-kilometre EF of 67 g (DEFRA 2012), which is 67% smaller than the private vehicle EF of 202 g CO_2/km calculated in this research. If (unrealistically) all private vehicle traffic on this route were replaced by trains with an EF of 67 g CO_2/pkm, emissions could be reduced to as little as 75,000 tonnes CO_2. This is a 151,000 tonnes CO_2 drop, which equals approximately 7.9% of all 2013 interurban private vehicle emissions.

Alternatively, express buses, which perhaps could use the dedicated high-occupancy-vehicle lanes, could also be used at little initial expense to reduce congestion and emissions. Assuming a coach EF as low as 28 g CO_2/pkm (DEFRA 2012) and full occupancy (the EF is 86% smaller than that for cars), then (unrealistically) switching all private vehicle traffic on this route to buses could reduce emissions to as little as 32,000 tonnes CO_2. This 194,000 tonnes CO_2 reduction equals approximately 10.1% of all 2013 interurban private vehicle emissions. Modal replacement from private vehicles to rail and/or bus service may be feasible on other high emission private vehicle routes such as Victoria–Nanaimo (a distance of 100 km), or the Vancouver–Hope–Kamloops/Kelowna loop routes.

There are two main take-home lessons from this example of private vehicle-to-rail/bus modal shifts. First, the SMITE model calculations demonstrate significant emission reductions from a modal shift, thus indicating such modal shifts are a worthwhile topic of policy discussion. Second, the calculations are an example of the value of developing a localized model such as SMITE. SMITE determines the geographic distribution of usage and emissions that can be put to use for making calculations and comparisons on a route by route basis. This illustrates the policy value of a localized model.

Example 4: Reductions of rail freight emissions

Rail freight has a significantly lower tonne-kilometre EF than trucking, but it still produces significant emissions. Currently, it accounts for 12.8% of BC's interurban transportation emissions and, if the province were to engage in large-scale modal shift from truck to rail transport, this percentage would likely rise. Improvements in diesel locomotive technology may allow railway companies to reduce their emissions slightly each year. However, to significantly reduce railway emissions, radical changes, such as electrification of the BC railway system, would be needed. Much of BC's electricity is produced by hydroelectric dams, which means that BC's electricity supply is basically 'clean' and has minimal GHG emissions.

SMITE can be deployed to compare emission reductions and costs in the electrification of BC's rail network. According to SMITE, full electrification of the BC rail network could reduce emissions by up to 1.4 Mt CO_2 from 2013 levels, or approximately 12.8% of total BC interurban transportation emissions in 2013. For SMITE cost calculations, I assumed that offsetting a tonne of CO_2 would cost $100 between 2020 and 2050, and that a credit for an excess tonne of CO_2 reduced could be sold on the offset market for $100. If BC were to electrify its entire rail network by 2020 (and since the electricity would come from hydroelectric power, there are nominally no additional GHGs from electricity generation), between 2020 and 2050 BC would be able to sell offset credits for 16.5 million tonnes CO_2 compared to the target values for that time span, resulting in potential revenues of $1.65 billion.

This can now be compared to the cost of infrastructure investment to build an all-electric rail system. Using data from the UK, the budget for electrifying a mere 300 km of rail from London to Swansea was estimated at approximately $1.85 billion (Railway-Technology.com 2010). This proposal did not include upgrading the railway tracks to accommodate high-speed trains, which is significantly more expensive. Assuming, based on the British case, that the cost of electrification is approximately $6.2 million per kilometre of rail, electrifying nearly all 10,000 km of railway in BC (Statistics Canada 2014b) would cost upwards of $62 billion, or 3,700% more than what BC could, under ideal circumstances, earn by selling excess CO_2 credits. Based on a British study (Railway-Technology.com 2010), the cost savings of electric trains over diesel trains are approximately 82 cents (Canadian) per kilometre. Thus, for electrification to pay for itself (excluding any potential revenue from carbon offsets), trains would have to travel 75.6 billion kilometres. Statistics are only available at the national level on train operating statistics, but since BC accounts for 26.3% of all train fuel consumption in Canada (Statistics Canada 2014c), it should account for a roughly equal percentage of total freight train-kilometres (105,473,695) (Statistics Canada 2014e, f), or approximately 27,340,000 train-kilometres pa. At this rate, electrification would take a staggering 2,725 years to pay for itself. However, it is likely that significant emission reductions could be achieved at much lower cost if only the main railway arteries are electrified, such as Vancouver to Prince George or from the Lower Mainland towards the Alberta border.

This example illustrates two main points. First, electrification of BC's rail system is not a panacea; there are significant financial obstacles to this method of emission reduction. And second, the SMITE model is capable of generating rough cost comparisons that might be beneficial to policymakers and the general public in discussions of financial feasibility.

Example 5: Improve ferry EFs to below 300 g CO_2/pkm

BC Ferries is a vital part of the BC interurban transportation system, but its average passenger-kilometre EF is 696 g CO_2/pkm (the highest value is 1,781 g CO_2/pkm), which is by far the highest average EF of all BC interurban passenger transportation modes. The lowest BC Ferries EF is 261 g CO_2/pkm, which is still higher than the average EFs for all other passenger transportation modes. If the average ferry EF was reduced to 300 g CO_2/pkm by 2020, assuming 2013 usage, emissions in 2020 would be 198,000 tonnes CO_2 instead of 342,000 tonnes CO_2, which equates to a 42% reduction. This would bring emissions 21% below the 2020 target value of 250,000 tonnes CO_2. If by 2020 an average EF of 300 g CO_2/pkm was only achieved on the main routes linking Vancouver to Vancouver Island, emissions in 2020 would still be reduced by 77,000 tonnes CO_2, or 22% of 2013 ferry emissions. This value of 265,000 tonnes CO_2 would then only be 6% above the 2020 target value. Measures to reduce ferry EFs could include buying new and more fuel-efficient vessels, increasing load factors, and dropping or consolidating routes. The case here illustrates, first, that it is difficult to achieve significant emission reductions in BC's ferry service, and second, that the SMITE model again is useful for providing geographically detailed (i.e., route specific) results.

Example 6: Improve airplane passenger-kilometre EFs to below 100 g CO_2/pkm

The average passenger-kilometre EF of airplanes in BC is 184.5 g CO_2/pkm. The results in Chapter 4 show that there are significant differences in the EFs of different aircraft models. In particular, the Beech 1900 series aircraft have the highest EFs in BC, with values of up to 385.9 g CO_2/pkm, which is approximately five-fold those of Boeing 737 jets (which are as low as 74.5 g CO_2/pkm). If by 2020 all planes had the EF of Boeing 737 jets, emissions at 2013 usage levels would be 98,000 tonnes CO_2. This results in a 69,000 tonnes CO_2 drop and equates to reducing passenger aviation emissions by 41%, or 43% below the 2020 target value of 173,000 tonnes CO_2. Recognizing that the Boeing 737 is not suitable for all BC routes because of its large size, if by 2020 the average EF was reduced to, say, 100 g CO_2/pkm, emissions at 2013 usage levels would be 132,000 tonnes CO_2. This results in a 37,000 tonnes CO_2 reduction and still equates to an overall passenger aviation emission reduction of 21.0%, or 24% below the 2020 target value of 173,000 tonnes CO_2. While fleet changeovers that result in lower EFs are costly, high passenger-kilometre EFs are directly related to high fuel consumption, so airlines would be able to reduce their operating costs by introducing more efficient aircraft.

This example illustrates two main points: First, significant emission reductions can be achieved in the passenger aviation sector if EFs are lowered across the fleet to be closer to those of the planes with the lowest passenger-kilometre EFs. Second, it highlights the value of SMITE's high degree of geographical resolution, which identifies usage and emissions by individual routes. This again illustrates SMITE's policy value.

Summary

The six examples discussed above show that there are changes (often requiring only wider adoption of existing technologies rather than revolutionary technologies and systemic changes) that can help various interurban transportation modes in BC to reduce their emissions, in several cases below the 2020 emission target values. The examples also highlight the value of SMITE, which, as a localized, bottom-up model, can analyze usage and emissions for individual routes rather than the entire interurban transportation sector. This makes it an important policymaking tool.

6.3 Contribution of research

In brief, for my research, I devised a novel inventorying and scenario projection methodology, and applied it to British Columbia. My study is a contribution to existing knowledge both on a practical and theoretical level. On the practical level, it contributes a detailed, bottom-up inventory of interurban passenger and freight transportation in BC, along with its geographical distribution where possible. To my knowledge, this is the first such detailed inventory in BC. Furthermore, the results of my future scenario calculations provide perspective on how BC needs to change its interurban transportation system to achieve its mandated emission reduction targets. Together, the inventory and future scenario calculations provide practical data and calculations for policy decisions regarding interurban transportation emissions in BC.

At the theoretical level, my study contributes a more or less novel collection of spreadsheet-based techniques for inventorying transportation emissions and projecting future emissions. This collection of techniques is what I called the SMITE model. It uses place-specific rather than generic EFs to more accurately reflect transportation fleets at a local level; contains fine grain geographical resolution that may make it 'policy-friendly' for local policymakers; addresses only interurban transportation rather than the entirety of the transportation system, thus focusing on a portion of the transportation system that is often overlooked; and is capable of comparing projected emissions to target values and determining (offset) costs of achieving or not achieving the targets. SMITE was developed as a generic tool that can be applied to other jurisdictions or on other geographical scales, even though in my research it was applied only to BC.

6.4 Limitations of research

The CO_2 emissions calculations in Chapter 4 and future emission projections in Chapter 5 are subject to a number of limitations. For the CO_2 emission calculations in Chapter 4, uncertainties such as difficulty in establishing the exact number of services operated on a certain route, or difficulty in calculating representative EFs, were among the main challenges and applied to most transportation modes covered. For other modes (especially marine freight), a dearth of statistical information further complicated research efforts. The limitations applicable to each specific transportation mode were discussed in Chapter 3 following the description of the methodological approach for that mode. However, despite the limitations of my Chapter 4 calculations, I am reasonably confident in my results, as outlined in the comparison section of that chapter. I was able to validate my results to varying degrees for seven of the nine modes covered in my research; the two modes for which comparisons were not possible account for only 0.1% of emissions each.

The future emission scenarios in Chapter 5 are also subject to a number of limitations. The most significant is that the starting values for each scenario, for years between 2007 and 2014, are directly based on the results of Chapter 4. If values in Chapter 4 contain errors, these errors transfer to the future scenario calculations. Moreover, since it was impossible to calculate all possible parameter changes, I limited the number of changes to model. These, depending on the mode, may not accurately reflect realistically achievable values. I had hoped to interview transportation providers and car manufacturers in order to obtain a better understanding of achievable emission reduction values, but because of the lack of participation in my survey, this was not possible.

6.5 Suggestions for further research

There are two main suggested areas for further research: (1) improving SMITE, and (2) expanding the application of SMITE.

First, in terms of improving SMITE, one important step would be to obtain improved transportation usage statistics. For instance, for marine freight, one of the largest contributors to BC interurban transportation emissions in total terms, information on distances travelled or tonnage carried from origins to destinations is very sparse. Compiling the required data should be possible. Companies should be aware of how much cargo they carry over which distances, since this is most likely how they bill their clients. This information could possibly be collected (anonymously if there are competition issues) and aggregated. A reintroduction of some of the data series on marine traffic that have been discontinued would also alleviate some of the paucity of statistical information. Another important step would be to improve the detail of statistical information on BC fleets for most modes (e.g., through surveying transportation companies or vehicle manufacturers). This would allow more accurate and representative EFs to be calculated, which in turn would improve the accuracy of emission calculations. This would also allow more accurate comparisons between transportation modes, and enable comparisons to include those modes which so far could not be compared because of lacking information (such as marine freight).

Second, building on the research in this dissertation, the application of SMITE could be expanded. In its current scope, which addresses only interurban transportation, SMITE could be expanded to the national (e.g., Canada) or even supra-national scale, as the methods developed for this research allow for such an expansion. A second direction to build is to expand SMITE to combine (BC's) urban and interurban transportation systems. Combining both components would facilitate a better understanding of the GHG emission contributions of each part of the system, and how changes can help to reduce emissions. This expanded model could then also be applied at various geographic scales, such as different provinces or the entirety of Canada.

6.6 Final thoughts

Transportation of people and freight has been a cornerstone of societies for millennia, and there are no indications that the importance of transportation will lessen in the future. On the contrary, increasing global interconnectivity has resulted in emissions, of both passenger and freight transportation, steadily rising across the globe. In addition, awareness of the contribution of transportation sector GHG emissions to negative climate impacts has also been increasing globally. As such, there is a distinct need to reconcile the importance of transportation, both interurban and urban, with its climate and environmental impacts.

The first step in reducing GHG emissions, not just from transportation but from other economic sectors as well, is to obtain a clear insight into emissions levels and the activities that generate them, which can be accomplished through detailed usage and emission inventories. Conducting research for this dissertation has illustrated very clearly just how difficult and complex it is to accurately inventory transportation emissions. This complexity is caused not only by the lack of statistical information but also by the difficulty of establishing methodologies. Various approaches to quantify the same aspect of transportation emissions (such as annual emissions) may, depending on their scope and methods, result in entirely different values, as was the case for BC rail freight emissions. Also, there are a multitude of stakeholders involved in the transportation system, who may have divergent interests in terms of transportation's path for the future. Accurately quantifying transportation's environmental impact and plotting paths for the future will require consultation and agreement among its many stakeholders and a streamlining of the inventorying process that is transparent, fair, and accountable.

Finally, the time to start acting on reducing transportation GHG emissions is now. Many of the options for reducing transportation emissions already exist, and simply need to be disseminated more widely and more rapidly. Revolutionary technological developments may make the transition to a lower-carbon transportation system easier, but waiting for such developments to occur distracts from beginning to reduce transportation emissions through those measures already at our disposal. My research has demonstrated that for the BC interurban transportation sector to achieve BC's ambitious GHG reduction targets, systematic changes to the transportation sector are required and that they need to be initiated as soon as possible, otherwise achieving the legislated reduction targets will become more difficult with each passing year.

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APPENDIX 1: Interview Questions

British Columbia Vehicle Manufacturer Questionnaire

Purpose of Questionnaire: The purpose of this questionnaire is to gather information on whether manufacturers of vehicles sold in British Columbia are influenced by environmental considerations and what likely future improvements in vehicle efficiency will be.
For those questions which ask you to rank your opinion, please use the following scale:

- 1: Strong disagree
- 2: Disagree
- 3: Neutral/does not apply
- 4: Agree
- 5: Strongly agree

Company profile

1.	Fuel consumption and greenhouse gas (GHG) emissions are central concerns when we design vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
2.	Our customers demand vehicles that are more fuel efficient.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.	We strive to go above meeting environmental legislation when designing vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
4.	Competition with other vehicle manufacturers has provided a greater incentive for improving vehicle efficiency than environmental legislation.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.	My company produces vehicles for markets other than North America.	Yes ☐			No ☐	
6.	*If you answered "no" to Question 5, please skip this question.* My company's vehicles sold in markets other than North America are generally more fuel-efficient than those sold in North America.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
7.	Customers in North America value vehicle performance over efficiency.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

Diesel engines

8.	My company produces diesel vehicles.	Yes ☐			No ☐	
	If you answered "no" to Question 8, please skip this section.					
9.	Diesel vehicles are more efficient than gasoline vehicles of similar engine size.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
10.	Diesel engines in my company's vehicles are designed to consume a similar amount of fuel as a gasoline engine but provide more performance.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
11.	Diesel engines in my company's vehicles are designed to	1	2	3	4	5

	provide a similar performance to a gasoline engine but use less fuel to do so.	☐	☐	☐	☐	☐
12.	My company is working on building diesel engines that are more efficient than current models.	Yes ☐			No ☐	
13.	If you answered "yes" to Question 12, please elaborate on these measures:	Click here to enter text.				
14.	In your opinion, what is the maximum fuel consumption reduction (as a percentage) that is feasible for diesel engines by 2020 compared to 2013?	Click here to enter text.				
15.	In your opinion, what is the maximum fuel consumption reduction (as a percentage) that is feasible for diesel engines by 2050 compared to 2013?	Click here to enter text.				
16.	Making diesel engines more efficient will significantly increase the cost of the vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

Gasoline engines

17.	My company only produces gasoline engines because there is no demand for diesel vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
18.	My company is considering introducing diesel engines.	Yes ☐			No ☐	
19.	My company is working on building gasoline engines that are more efficient than current models.	Yes ☐			No ☐	
20.	If you answered "yes" to Question 19, please elaborate on these measures:	Click here to enter text.				
21.	In your opinion, what is the maximum fuel consumption reduction (as a percentage) that is feasible for gasoline engines by 2020 compared to 2013?	Click here to enter text.				
22.	In your opinion, what is the maximum fuel consumption reduction (percentage) that is feasible for gasoline engines by 2050 compared to 2013?	Click here to enter text.				
23.	Making gasoline engines more efficient will significantly increase the cost of the vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

Alternative fuel vehicles

24.	My company produces vehicles that are neither gasoline nor diesel powered.	Yes ☐			No ☐	
	If you answered "yes" to Question 24, please complete Questions 26-31. *If you answered "no" to Question 24, please complete Question 25 only.*					
25.	My company is considering building alternative fuel vehicles in the future.	Yes ☐			No ☐	
26.	My company builds the following types of alternative fuel vehicles:	Click here to enter text.				
27.	The performance of alternative-fuel vehicles is comparable to fossil-fuel powered vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
28.	Alternative fuel vehicles are significantly more expensive than fossil-fuel vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

29.	Prices for alternative fuel vehicles will drop and become closer to fossil-fuel vehicles.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
30.	Year by which price of fossil fuel and alternative fuel vehicle could be comparable:	Click here to enter text.				
31.	My company hopes to shift a greater share of its business to alternative fuel vehicles in the future.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

<u>British Columbia Interurban Transportation Provider Questionnaire</u>

Purpose of Questionnaire: The purpose of this questionnaire is to gather information on British Columbia interurban transportation providers, their perceptions regarding the BC Carbon Tax, and fuel usage and emission reduction measures they have engaged in or may engage in in the future.

For those questions which ask you to rank your opinion, please use the following scale:

- 1: Strong disagree
- 2: Disagree
- 3: Neutral/does not apply
- 4: Agree
- 5: Strongly agree

<u>Company profile</u>

1.	Is your company aware of the 2007 BC Greenhouse Gas Reduction Targets Act, which requires emissions to be reduced 33% by 2020 over 2007 levels and to be reduced 80% by 2050 over 2007 levels?	Yes ☐	No ☐
2.	Do you consider the transportation sector to be a strong contributor to overall fuel consumption and greenhouse gas (GHG) emission creation?	Yes ☐	No ☐
3.	Has your company calculated its GHG emissions?	Yes ☐	No ☐
4.	Has your company considered or implemented measures to reduce its fuel consumption and associated GHG emissions?	Yes ☐	No ☐
5.	Transportation is an important part of the BC economy and lifestyle because of the province's size. However, transportation contributes 37% of overall BC GHG emissions, compared to an average of 20% globally. Despite this, do you think exemptions to environmental legislation should be made to BC transportation because of its importance to the province?	Yes ☐	No ☐

BC Carbon Tax

6.	The BC Carbon Tax has had a financial impact on my company.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
7.	The cost burden of the BC Carbon Tax is absorbed by my company.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
8	The cost burden of the BC Carbon Tax is passed on to customers.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
9.	The BC Carbon Tax has created an incentive for my company to change how it operates in order to save fuel.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
10.	If you answered "agree" or "strongly agree" to Question 9, what measures have you taken, and to what reductions in fuel usage have they lead?	Click here to enter text.				
11.	If the BC Carbon Tax was increased further, this would create an incentive/more of an incentive for my company to adjust its operations.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
12.	The BC Carbon Tax is transparent in how it is applied and what the monies collected are used for.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
13.	The BC Carbon Tax is effective in achieving its intended goals.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
14.	If you answered "disagree" or "strongly disagree" to Question 13, how would you, as a transportation provider, prefer to encourage transportation stakeholders to reduce their emissions?	Click here to enter text.				
15.	Other comments regarding the BC Carbon Tax:	Click here to enter text.				

Future fuel usage and emission reductions

16.	Reducing fuel consumption will not only reduce emissions but also save my company money.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
17.	My company is aware of how we can reduce emissions but implementing these measures is too expensive.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
18.	My company knows that reducing fuel consumption and associated emissions would reduce operating expenses but does not have the expertise to carry out such reductions.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
19.	My company will be able to reduce fuel consumption and associated GHG emissions by 33% by the year 2020 and still be able to offer the same level of transportation service	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
20.	If you answered "agree" or "strongly agree" to Question 19, how would this likely be achieved (e.g., energy efficiency measures, alternative fuels, etc.)?	Click here to enter text.				
21.	If you answered "disagree" or "strongly disagree" to Question 19, what kinds of measures would such reductions require (e.g., new technologies etc.)?	Click here to enter text.				
22.	My company will be able to reduce fuel consumption and associated GHG emissions by 80% by the year 2050 and still be able to offer the same level of transportation	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

	service.					
23.	If you answered "agree" or "strongly agree" to Question 19, how would this likely be achieved (e.g., energy efficiency measures, alternative fuels, etc.)?	Click here to enter text.				
24.	If you answered "disagree" or "strongly disagree" to Question 19, what kinds of measures would such reductions require (e.g., new technologies etc.)?	Click here to enter text.				
25.	What do you think are the greatest fuel consumption reductions (as a percentage) that can realistically be achieved by the year 2020?	Click here to enter text.				
26.	What do you think are the greatest fuel consumption reductions (as a percentage) that can realistically be achieved by the year 2050?	Click here to enter text.				
27.	Costs for implementing measures that reduce emissions, such as new technology or infrastructure, should be borne by transportation providers.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
28.	Costs for implementing measures that reduce emissions, such as new technology or infrastructure, should be borne by transportation users.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
29.	Other comments regarding future fuel consumption reductions:	Click here to enter text.				

APPENDIX 2: Calculation Data

Table A2.1: Ranking of BC routes by kilometres driven in 2007 and 2013

Rank	2007 distance driven (km)	Route	2013 distance driven (km)	Route
1	1,156,784,280	Vancouver–Chilliwack	1,120,642,345	Vancouver–Chilliwack
2	598,329,845	Ladysmith–Victoria	619,618,890	Ladysmith–Victoria
3	319,172,308	Vernon–Kelowna	345,182,544	Parksville–Campbell River
4	314,236,267	Hope–Merritt	339,781,478	Vernon–Kelowna
5	305,851,896	Parksville–Campbell River	327,401,726	Hope–Merritt
6	293,216,238	Parksville–Nanaimo	306,142,144	Kelowna–Penticton
7	275,043,910	Kelowna–Penticton	290,824,773	Parksville–Nanaimo
8	259,536,827	Chilliwack–Hope	267,043,271	Chilliwack–Hope
9	245,903,654	Vancouver–Squamish	250,063,982	Tete Jaune Cache–Kamloops
10	234,430,740	Hope–Penticton	245,903,654	Vancouver–Squamish
11	211,246,743	Tete Jaune Cache–Kamloops	208,527,464	Kamloops–Merritt
12	201,294,945	Vernon–Salmon Arm	206,553,573	Vernon–Salmon Arm
13	193,920,646	Cache Creek–Williams Lake	197,410,688	Kelowna–Merritt
14	177,411,374	Kamloops–Merritt	196,405,989	Revelstoke–Golden
15	174,539,700	Monte Creek–Salmon Arm	184,730,792	Cache Creek–Williams Lake
16	169,186,297	Revelstoke–Golden	181,927,242	Hope–Penticton
17	168,922,701	Kelowna–Merritt	181,217,025	Squamish–Whisler
18	163,463,571	Squamish–Whisler	179,440,935	Monte Creek–Salmon Arm
19	161,491,056	Whistler–Cache Creek/Pemberton	154,272,743	Kamloops–Cache Creek
20	141,632,994	Hope–Cache Creek	153,857,081	Whistler–Cache Creek/Pemberton
21	139,723,570	Kamloops–Cache Creek	149,029,774	Dawson Creek–Prince George
22	137,558,718	Parksville–Campbell River	141,044,410	Salmon Arm–Revelstoke
23	127,476,002	Penticton–Osoyoos	136,866,240	Parksville–Campbell River
24	119,098,704	Golden–Radium Hot Springs	127,876,115	Penticton–Osoyoos
25	118,108,014	Nanaimo–Ladysmith	119,134,467	Nanaimo–Ladysmith
26	115,550,897	Prince George–Quesnel	119,098,704	Golden–Radium Hot Springs

27	113,350,429	Salmon Arm–Revelstoke	115,332,700	Prince George–Quesnel
28	105,527,953	Monte Creek–Vernon	113,984,025	Hope–Cache Creek
29	105,461,443	Prince George–Vanderhoof	108,422,345	Monte Creek–Vernon
30	104,548,147	Cranbrook–Fairmont Hot Springs	105,461,443	Prince George–Vanderhoof
31	104,349,668	Dawson Creek–Prince George	104,694,001	Cranbrook–Fairmont Hot Springs
32	93,902,309	Golden–Alberta Border	103,404,179	Alberta/BC Boundary–Highway 93 Junction
33	90,190,398	Alberta/BC Boundary–Highway 93 Junction	99,757,814	Golden–Alberta Border
34	87,169,446	Cranbrook–Creston	96,914,070	Dawson Creek–Ft. St. John
35	86,589,534	Port Hardy–Campbell River	90,415,975	Cranbrook–Highway 93 Junction
36	86,503,306	Kamloops–Monte Creek	88,757,021	Kamloops–Monte Creek
37	84,398,220	Dawson Creek–Ft. St. John	88,388,984	Port Hardy–Campbell River
38	81,381,670	Rock Creek–Castlegar	83,885,760	Cranbrook–Creston
39	81,286,595	Cranbrook–Highway 93 Junction	78,446,216	Quesnel–Williams Lake
40	81,004,538	Quesnel–Williams Lake	73,991,734	Rock Creek–Castlegar
41	75,087,800	Ucluelet Junction–Parksville	73,981,470	Tete Jaune Cache–Prince George
42	73,777,946	Tete Jaune Cache–Prince George	72,077,762	Gibsons–Sechelt
43	73,368,504	Gibsons–Sechelt	68,517,618	Ucluelet Junction–Parksville
44	62,906,290	Kelowna–Rock Creek	59,871,987	Kelowna–Rock Creek
45	62,610,531	Radium Hot Springs–Fairmont Hot Springs	58,906,795	Castlegar–Trail
46	55,284,068	Nelson–Kaslo	57,214,024	Tete Jaune Cache–Alta border
47	55,041,153	Castlegar–Trail	56,464,405	Radium Hot Springs–Fairmont Hot Springs
48	53,777,990	Houston–Smithers	52,826,158	Nelson–Kaslo
49	52,850,723	Tete Jaune Cache–Alta border	50,930,056	Burns Lake–Houston
50	52,738,047	Sechelt–ferry	50,502,933	Sechelt–ferry
51	50,930,056	Burns Lake–Houston	47,269,310	Prince Rupert–Terrace

52	48,105,496	Creston–Castlegar	44,945,180	Vanderhoof–Fraser Lake
53	43,729,920	Castlegar–Christina Lake	44,570,690	Creston–Castlegar
54	42,184,218	Williams Lake–Alexis Creek	44,529,766	Houston–Smithers
55	39,356,928	Prince Rupert–Terrace	42,436,221	Kitwanga–Terrace
56	38,960,845	Vanderhoof–Fraser Lake	41,506,807	Williams Lake–Alexis Creek
57	37,885,993	Nakusp–Castlegar	40,505,693	Castlegar–Christina Lake
58	37,355,640	Kitwanga–Terrace	39,496,723	Fraser Lake–Burns Lake
59	36,320,347	Fraser Lake–Burns Lake	38,356,361	Vernon–Nakusp
60	34,636,003	Vernon–Nakusp	38,029,350	Dawson Creek–Alberta Border
61	34,497,172	Terrace–Kitimat	36,506,716	Terrace–Kitimat
62	33,375,162	Dawson Creek–Alberta Border	35,526,311	Nakusp–Castlegar
63	31,976,599	Smithers–New Hazelton	35,294,953	Fort St. John–Wonowon
64	27,235,661	Fort Nelson–Liard River	31,976,599	Smithers–New Hazelton
65	25,745,337	Fort St. John–Wonowon	29,885,196	Fort Nelson–Liard River
66	22,389,969	Hope–Agassiz	23,380,148	Wonowon–Buckinghorse River
67	21,391,920	Ucluelet Junction–Tofino	20,925,187	Ucluelet Junction–Tofino
68	21,121,309	Wonowon–Buckinghorse River	20,586,471	Hope–Agassiz
69	19,753,493	Kitwanga–Meziadin Junction	19,794,819	Kitwanga–Meziadin Junction
70	18,224,457	Liard River–Lower Post	18,020,262	Liard River–Lower Post
71	16,092,558	Meziadin Junction–Dease Lake	17,344,201	Meziadin Junction–Dease Lake
72	15,563,162	Kitwanga–New Hazelton	17,142,707	Kitwanga–New Hazelton
73	14,875,531	Alexis Creek–Anahim Lake	12,281,987	Dease Lake–Yukon Border
74	11,796,435	1 km north of Prophet River–Fort Nelson	10,988,383	Buckinghorse River–1 km north of Prophet River
75	11,404,702	Dease Lake–Yukon Border	10,513,314	1 km north of Prophet River–Fort Nelson
76	11,089,459	Buckinghorse River–	9,415,598	Alexis Creek–

		1 km north of Prophet River		Anahim Lake
77	9,337,284	Saltery Bay ferry terminal–Powell River	8,325,504	Saltery Bay ferry terminal–Powell River
78	4,889,890	Ucluelet Junction–Ucluelet	4,665,167	Ucluelet Junction–Ucluelet
79	4,646,260	Meziadin Junction–Stewart	3,954,264	Meziadin Junction–Stewart
Total	8,964,072,902		9,491,321,413	

Table A2.2: Percentage changes in distance driven on BC routes 2007-2013

Rank	Route	2007 distance driven (km)	2013 distance driven (km)	% Change
1	Dawson Creek–Prince George	104,349,668	149,029,774	42.8
2	Fort St. John–Wonowon	25,745,337	35,294,953	37.1
3	Salmon Arm–Revelstoke	113,350,429	141,044,410	24.4
4	Prince Rupert–Terrace	39,356,928	47,269,310	20.1
5	Tete Jaune Cache–Kamloops	211,246,743	250,063,982	18.4
6	Kamloops–Merritt	177,411,374	208,527,464	17.5
7	Kelowna–Merritt	168,922,701	197,410,688	16.9
8	Revelstoke–Golden	169,186,297	196,405,989	16.1
9	Vanderhoof–Fraser Lake	38,960,845	44,945,180	15.4
10	Dawson Creek–Ft. St. John	84,398,220	96,914,070	14.8
11	Alberta/BC Boundary–Highway 93 Junction	90,190,398	103,404,179	14.7
12	Dawson Creek–Alberta Border	33,375,162	38,029,350	13.9
13	Kitwanga–Terrace	37,355,640	42,436,221	13.6
14	Parksville–Campbell River	305,851,896	345,182,544	12.9
15	Kelowna–Penticton	275,043,910	306,142,144	11.3
16	Cranbrook–Highway 93 Junction	81,286,595	90,415,975	11.2
17	Squamish–Whistler	163,463,571	181,217,025	10.9
18	Vernon–Nakusp	34,636,003	38,356,361	10.7
19	Wonowon–	21,121,309	23,380,148	10.7

	Buckinghorse River			
20	Kamloops–Cache Creek	139,723,570	154,272,743	10.4
21	Kitwanga–New Hazelton	15,563,162	17,142,707	10.1
22	Fort Nelson–Liard River	27,235,661	29,885,196	9.7
23	Fraser Lake–Burns Lake	36,320,347	39,496,723	8.7
24	Tete Jaune Cache–Alta border	52,850,723	57,214,024	8.3
25	Meziadin Junction–Dease Lake	16,092,558	17,344,201	7.8
26	Dease Lake–Yukon Border	11,404,702	12,281,987	7.7
27	Castlegar–Trail	55,041,153	58,906,795	7.0
28	Vernon–Kelowna	319,172,308	339,781,478	6.5
29	Golden–Alberta Border	93,902,309	99,757,814	6.2
30	Terrace–Kitimat	34,497,172	36,506,716	5.8
31	Hope–Merritt	314,236,267	327,401,726	4.2
32	Ladysmith–Victoria	598,329,845	619,618,890	3.6
33	Chilliwack–Hope	259,536,827	267,043,271	2.9
34	Monte Creek–Salmon Arm	174,539,700	179,440,935	2.8
35	Monte Creek–Vernon	105,527,953	108,422,345	2.7
36	Vernon–Salmon Arm	201,294,945	206,553,573	2.6
37	Kamloops–Monte Creek	86,503,306	88,757,021	2.6
38	Port Hardy–Campbell River	86,589,534	88,388,984	2.1
39	Nanaimo–Ladysmith	118,108,014	119,134,467	0.9
40	Penticton–Osoyoos	127,476,002	127,876,115	0.3
41	Tete Jaune Cache–Prince George	73,777,946	73,981,470	0.3
42	Kitwanga–Meziadin Junction	19,753,493	19,794,819	0.2
43	Cranbrook–Fairmont Hot Springs	104,548,147	104,694,001	0.1
44	Vancouver–Squamish	245,903,654	245,903,654	0.0
45	Prince George–Vanderhoof	105,461,443	105,461,443	0.0
46	Burns Lake–Houston	50,930,056	50,930,056	0.0
47	Smithers–New Hazelton	31,976,599	31,976,599	0.0
48	Golden–Radium Hot Springs	119,098,704	119,098,704	0.0
49	Prince George–Quesnel	115,550,897	115,332,700	-0.2

50	Parksville–Campbell River	137,558,718	136,866,240	-0.5
51	Parksville–Nanaimo	293,216,238	290,824,773	-0.8
52	Buckinghorse River–1 km north of Prophet River	11,089,459	10,988,383	-0.9
53	Liard River–Lower Post	18,224,457	18,020,262	-1.1
54	Williams Lake–Alexis Creek	42,184,218	41,506,807	-1.6
55	Gibsons–Sechelt	73,368,504	72,077,762	-1.8
56	Ucluelet Junction–Tofino	21,391,920	20,925,187	-2.2
57	Vancouver–Chilliwack	1,156,784,280	1,120,642,345	-3.1
58	Quesnel–Williams Lake	81,004,538	78,446,216	-3.2
59	Cranbrook–Creston	87,169,446	83,885,760	-3.8
60	Sechelt–ferry	52,738,047	50,502,933	-4.2
61	Nelson–Kaslo	55,284,068	52,826,158	-4.4
62	Ucluelet Junction–Ucluelet	4,889,890	4,665,167	-4.6
63	Whistler–Cache Creek/Pemberton	161,491,056	153,857,081	-4.7
64	Cache Creek–Williams Lake	193,920,646	184,730,792	-4.7
65	Kelowna–Rock Creek	62,906,290	59,871,987	-4.8
66	Nakusp–Castlegar	37,885,993	35,526,311	-6.2
67	Creston–Castlegar	48,105,496	44,570,690	-7.3
68	Castlegar–Christina Lake	43,729,920	40,505,693	-7.4
69	Hope–Agassiz	22,389,969	20,586,471	-8.1
70	Ucluelet Junction–Parksville	75,087,800	68,517,618	-8.8
71	Rock Creek–Castlegar	81,381,670	73,991,734	-9.1
72	Radium Hot Springs–Fairmont Hot Springs	62,610,531	56,464,405	-9.8
73	Saltery Bay ferry terminal–Powell River	9,337,284	8,325,504	-10.8
74	1 km north of Prophet River–Fort Nelson	11,796,435	10,513,314	-10.9
75	Meziadin Junction–Stewart	4,646,260	3,954,264	-14.9
76	Houston–Smithers	53,777,990	44,529,766	-17.2
77	Hope–Cache Creek	141,632,994	113,984,025	-19.5
78	Hope–Penticton	234,430,740	181,927,242	-22.4
79	Alexis Creek–	14,875,531	9,415,598	-36.7

	Anahim Lake			
Average				2.7

Table A2.3: Emissions per kilometre of road for 2007 and 2013

Rank	Route	2007 emissions per km of road (tonnes CO_2/km)	2013 emissions per km of road (tonnes CO_2/km)
1	Vancouver–Chilliwack	2,337	2,264
2	Nanaimo–Ladysmith	1,591	1,604
3	Parksville–Nanaimo	1,559	1,546
4	Ladysmith–Victoria	1,358	1,406
5	Vernon–Kelowna	1,194	1,271
6	Chilliwack–Hope	953	981
7	Kelowna–Penticton	868	966
8	Vancouver–Squamish	730	730
9	Vernon–Salmon Arm	678	695
10	Gibsons–Sechelt	674	662
11	Kamloops–Monte Creek	624	640
12	Squamish–Whisler	560	620
13	Hope–Merritt	516	581
14	Parksville–Campbell River	515	538
15	Kamloops–Merritt	412	484
16	Monte Creek–Salmon Arm	410	421
17	Penticton–Osoyoos	409	410
18	Castlegar–Trail	383	410
19	Radium Hot Springs–Fairmont Hot Springs	342	375
20	Kamloops–Cache Creek	340	312
21	Kelowna–Merritt	267	308
22	Whistler–Cache Creek/Pemberton	261	281
23	Golden–Alberta Border	260	277
24	Cranbrook–Highway 93 Junction	253	276
25	Golden–Radium Hot Springs	234	266
26	Parksville–Campbell River	232	261
27	Revelstoke–Golden	229	258
28	Dawson Creek–Ft. St. John	227	249
29	Monte Creek–Vernon	227	234
30	Alberta/BC Boundary–Highway 93 Junction	225	233
31	Salmon Arm–Revelstoke	222	230
32	Prince George–Vanderhoof	215	215
33	Sechelt–ferry	197	196
34	Cranbrook–Fairmont Hot Springs	196	192

35	Cache Creek–Williams Lake	192	191
36	Prince George–Quesnel	191	189
37	Hope–Penticton	175	183
38	Houston–Smithers	170	161
39	Dawson Creek–Alberta Border	169	157
40	Cranbrook–Creston	168	154
41	Nelson–Kaslo	160	152
42	Hope–Cache Creek	150	149
43	Tete Jaune Cache–Alta border	142	141
44	Quesnel–Williams Lake	138	136
45	Hope–Agassiz	137	133
46	Vanderhoof –Fraser Lake	136	132
47	Ucluelet Junction–Tofino	135	129
48	Burns Lake–Houston	129	126
49	Tete Jaune Cache–Kamloops	126	121
50	Ucluelet Junction–Ucluelet	123	119
51	Castlegar–Christina Lake	113	118
52	Terrace–Kitimat	112	114
53	Ucluelet Junction–Parksville	109	105
54	Fraser Lake–Burns Lake	105	100
55	Rock Creek–Castlegar	96	95
56	Smithers–New Hazelton	95	88
57	Kelowna–Rock Creek	93	87
58	Creston–Castlegar	78	87
59	Kitwanga–Terrace	76	81
60	Port Hardy–Campbell River	75	80
61	Williams Lake–Alexis Creek	75	77
62	Kitwanga–New Hazelton	73	74
63	Saltery Bay ferry terminal–Powell River	63	74
64	Fort St. John–Wonowon	58	73
65	Prince Rupert–Terrace	55	66
66	Tete Jaune Cache–Prince George	55	56
67	Nakusp–Castlegar	52	55
68	Dawson Creek–Prince George	52	49
69	Wonowon–Buckinghorse River	37	41
70	Vernon–Nakusp	36	40
71	1 km north of Prophet River–Fort Nelson	26	26
72	Kitwanga–Meziadin Junction	26	26
73	Buckinghorse River–1 km north of Prophet River	26	24
74	Liard River–Lower Post	19	20
75	Fort Nelson–Liard River	18	19
76	Meziadin Junction–Stewart	15	13
77	Alexis Creek–Anahim Lake	14	11
78	Dease Lake–Yukon Border	10	11
79	Meziadin Junction–Dease Lake	10	9

Table A2.4: Private vehicle interurban CO_2 emissions by route in BC

Rank	2007 emissions (tonnes CO_2)	Route	2013 emissions (tonnes CO_2)	Route
1	233,670	Vancouver–Chilliwack	226,370	Vancouver–Chilliwack
2	120,863	Ladysmith–Victoria	125,163	Ladysmith–Victoria
3	64,473	Vernon–Kelowna	69,727	Parksville–Campbell River
4	63,476	Hope–Merritt	68,636	Vernon–Kelowna
5	61,782	Parksville–Campbell River	66,135	Hope–Merritt
6	59,230	Parksville–Nanaimo	61,841	Kelowna–Penticton
7	55,559	Kelowna–Penticton	58,747	Parksville–Nanaimo
8	52,426	Chilliwack–Hope	53,943	Chilliwack–Hope
9	49,673	Vancouver–Squamish	50,513	Tete Jaune Cache–Kamloops
10	47,355	Hope–Penticton	49,673	Vancouver–Squamish
11	42,672	Tete Jaune Cache–Kamloops	42,123	Kamloops–Merritt
12	40,662	Vernon–Salmon Arm	41,724	Vernon–Salmon Arm
13	39,172	Cache Creek–Williams Lake	39,877	Kelowna–Merritt
14	35,837	Kamloops–Merritt	39,674	Revelstoke–Golden
15	35,257	Monte Creek–Salmon Arm	37,316	Cache Creek–Williams Lake
16	34,176	Revelstoke–Golden	36,749	Hope–Penticton
17	34,122	Kelowna–Merritt	36,606	Squamish–Whisler
18	33,020	Squamish–Whisler	36,247	Monte Creek–Salmon Arm
19	32,621	Whistler–Cache Creek/Pemberton	31,163	Kamloops–Cache Creek
20	28,610	Hope–Cache Creek	31,079	Whistler–Cache Creek/Pemberton
21	28,224	Kamloops–Cache Creek	30,104	Dawson Creek–Prince George
22	27,787	Parksville–Campbell River	28,491	Salmon Arm–Revelstoke
23	25,750	Penticton–Osoyoos	27,647	Parksville–Campbell River
24	24,058	Golden–Radium Hot Springs	25,831	Penticton–Osoyoos
25	23,858	Nanaimo–Ladysmith	24,065	Nanaimo–Ladysmith
26	23,341	Prince George–Quesnel	24,058	Golden–Radium Hot Springs
27	22,897	Salmon Arm–Revelstoke	23,297	Prince George–Quesnel
28	21,317	Monte Creek–Vernon	23,025	Hope–Cache Creek

29	21,303	Prince George–Vanderhoof	21,901	Monte Creek–Vernon
30	21,119	Cranbrook–Fairmont Hot Springs	21,303	Prince George–Vanderhoof
31	21,079	Dawson Creek–Prince George	21,148	Cranbrook–Fairmont Hot Springs
32	18,968	Golden–Alberta Border	20,888	Alberta/BC Boundary–Highway 93 Junction
33	18,218	Alberta/BC Boundary–Highway 93 Junction	20,151	Golden–Alberta Border
34	17,608	Cranbrook–Creston	19,577	Dawson Creek–Ft. St. John
35	17,491	Port Hardy–Campbell River	18,264	Cranbrook–Highway 93 Junction
36	17,474	Kamloops–Monte Creek	17,929	Kamloops–Monte Creek
37	17,048	Dawson Creek–Ft. St. John	17,855	Port Hardy–Campbell River
38	16,439	Rock Creek–Castlegar	16,945	Cranbrook–Creston
39	16,420	Cranbrook–Highway 93 Junction	15,846	Quesnel–Williams Lake
40	16,363	Quesnel–Williams Lake	14,946	Rock Creek–Castlegar
41	15,168	Ucluelet Junction–Parksville	14,944	Tete Jaune Cache–Prince George
42	14,903	Tete Jaune Cache–Prince George	14,560	Gibsons–Sechelt
43	14,820	Gibsons–Sechelt	13,841	Ucluelet Junction–Parksville
44	12,707	Kelowna–Rock Creek	12,094	Kelowna–Rock Creek
45	12,647	Radium Hot Springs–Fairmont Hot Springs	11,899	Castlegar–Trail
46	11,167	Nelson–Kaslo	11,557	Tete Jaune Cache–Alta border
47	11,118	Castlegar–Trail	11,406	Radium Hot Springs–Fairmont Hot Springs
48	10,863	Houston–Smithers	10,671	Nelson–Kaslo
49	10,676	Tete Jaune Cache–Alta border	10,288	Burns Lake–Houston
50	10,653	Sechelt–ferry	10,202	Sechelt–ferry
51	10,288	Burns Lake–Houston	9,548	Prince Rupert–Terrace
52	9,717	Creston–Castlegar	9,079	Vanderhoof –Fraser Lake

53	8,833	Castlegar–Christina Lake	9,003	Creston–Castlegar
54	8,521	Williams Lake–Alexis Creek	8,995	Houston–Smithers
55	7,950	Prince Rupert–Terrace	8,572	Kitwanga–Terrace
56	7,870	Vanderhoof –Fraser Lake	8,384	Williams Lake–Alexis Creek
57	7,653	Nakusp–Castlegar	8,182	Castlegar–Christina Lake
58	7,546	Kitwanga–Terrace	7,978	Fraser Lake–Burns Lake
59	7,337	Fraser Lake–Burns Lake	7,748	Vernon–Nakusp
60	6,996	Vernon–Nakusp	7,682	Dawson Creek–Alberta Border
61	6,968	Terrace–Kitimat	7,374	Terrace–Kitimat
62	6,742	Dawson Creek–Alberta Border	7,176	Nakusp–Castlegar
63	6,459	Smithers–New Hazelton	7,130	Fort St. John–Wonowon
64	5,502	Fort Nelson–Liard River	6,459	Smithers–New Hazelton
65	5,201	Fort St. John–Wonowon	6,037	Fort Nelson–Liard River
66	4,523	Hope–Agassiz	4,723	Wonowon–Buckinghorse River
67	4,321	Ucluelet Junction–Tofino	4,227	Ucluelet Junction–Tofino
68	4,267	Wonowon–Buckinghorse River	4,158	Hope–Agassiz
69	3,990	Kitwanga–Meziadin Junction	3,999	Kitwanga–Meziadin Junction
70	3,681	Liard River–Lower Post	3,640	Liard River–Lower Post
71	3,251	Meziadin Junction–Dease Lake	3,504	Meziadin Junction–Dease Lake
72	3,144	Kitwanga–New Hazelton	3,463	Kitwanga–New Hazelton
73	3,005	Alexis Creek–Anahim Lake	2,481	Dease Lake–Yukon Border
74	2,383	1 km north of Prophet River–Fort Nelson	2,220	Buckinghorse River–1 km north of Prophet River
75	2,304	Dease Lake–Yukon Border	2,124	1 km north of Prophet River–Fort Nelson
76	2,240	Buckinghorse River–1 km north of Prophet River	1,902	Alexis Creek–Anahim Lake

77	1,886	Saltery Bay ferry terminal–Powell River	1,682	Saltery Bay ferry terminal–Powell River
78	988	Ucluelet Junction–Ucluelet	942	Ucluelet Junction–Ucluelet
79	939	Meziadin Junction–Stewart	799	Meziadin Junction–Stewart
Total	1,860,644		1,917,247	

Table A2.5: Annual emissions of BC Ferries routes

Rank	Route	Annual emissions (tonnes CO_2)
1	Tsawwassen–Duke Point (30)	81,097
2	Tsawwassen–Swartz Bay (1)	80,686
3	Horseshoe Bay–Departure Bay (2)	74,075
4	Horseshoe Bay–Langdale (3)	18,561
5	Inside passage Prince Rupert–Port Hardy (10)	10,966
6	Earls Cove–Saltery Bay (7)	10,396
7	Haida Gwaii (11)	6,893
8	Powell River–Comox (17)	6,229
9	Salt Spring/Fulford–Victoria (4)	5,664
10	Pender–Swartz Bay (5)	5,533
11	Snug Cove–Horseshoe Bay (8)	4,042
12	Mayne–Swartz Bay	3,904
13	Port McNeill–Alert Bay–Sointula (25)	3,208
14	Nanaimo Harbour–Gabriola (19)	2,900
15	Saturna Island–Swartz Bay (5)	2,872
16	Galiano–Tsawwassen (9)	2,544
17	Day trip from Swartz Bay (via Pender, Mayne, Galiano, Pender)	2,261
18	Campbell River–Quadra Island (23)	2,131
19	Galiano–Swartz Bay (5)	1,655
20	Salt Spring/Long Harbour–Tsawwassen (9)	1,600
21	Langdale–Keats/Gambier	1,391
22	Powell River–Texada Island (18)	1,350
23	Port Hardy–Bella Coola Discovery Coast (40)	1,271
24	Salt Spring/Vesuvius–Crofton (6)	1,171
25	Chemainus–Theis Island–Penelakut Is (20)	1,159
26	Quadra Island–Cortes Is (24)	1,126
27	Galiano Island–Mayne Island	1,088
28	Mayne Island–Pender Island	886

29	Mayne–Tsawwassen (9)	837
30	Pender Island–Salt Spring Island Long Harbour	790
31	Buckley Bay–Denman Island (21)	743
32	Galiano Island–Pender Island	602
33	Mayne–Saturna Island Lyall Hrbr	537
34	Pender–Saturna	365
35	Brentwood Bay–Mill Bay (12)	360
36	Haida Gwaii Skidegate–Alliford Bay (26)	271
37	Denman Island–Hornby Island (22)	226
38	Pender–Tsawwassen (9)	148
39	Mayne–Salt Spring IS Long Harbour	28
Total		341,563

Table A2.6: Passenger-sailing EFs on BC Ferries routes

Rank	Route and number	Vessel	Passenger-sailing EF (kg CO_2)
1	Inside passage Prince Rupert–Port Hardy (10)	Northern Expedition	288
2	Haida Gwaii (11)	Northern Adventure	193
3	Port Hardy–Bella Coola Discovery Coast (40)	Queen of Chilliwack	183
4	Tsawwassen–Duke Point (30)	Coastal Inspiration	62
5	Tsawwassen–Duke Point (30)	Queen of Alberni	55
6	Day trip from Swartz Bay (via Pender, Mayne, Galiano, Pender)	Queen of Cumberland	51
7	Earls Cove–Saltery Bay (7)	MV Island Sky	31
8	Saturna Island –Swartz Bay (5)	Queen of Cumberland	30
9	Horseshoe Bay–Departure Bay (2)	Coastal Renaissance	26
10	Galiano–Swartz Bay (5)	Queen of Cumberland	25
11	Langdale–New Brighton–Keats–Eastbourne–Langdale (13)	Tenaka	24
12	Langdale–New Brighton–Eastbourne–Keats–Langdale (13)	Tenaka	22
13	Tsawwassen–Swartz Bay (1)	Queen of New Westminster	21
14	Mayne–Swartz Bay	Queen of Cumberland	20
15	Horseshoe Bay–Departure Bay (2)	Queen of Oak Bay	19
16	Langdale–Eastbourne–Keats–Langdale (13)	Tenaka	18
17	Powell River–Comox (17)	Queen of Burnaby	18

18	Tsawwassen–Swartz Bay (1)	Coastal Celebration	17
19	Langdale–New Brighton–Eastbourne–Langdale (13)	Tenaka	16
20	Port McNeill–Alert Bay–Sointula (25)	Quadra Queen II	15
21	Langdale–Keats–New Brighton–Langdale (13)	Tenaka	14
22	Pender–Swartz Bay (5)	Queen of Cumberland	14
23	Tsawwassen–Swartz Bay (1)	Spirit of British Columbia	13
24	Pender–Tsawwassen (9)	Queen of Nanaimo	12
25	Salt Spring/Long Harbour–Tsawwassen (9)	Queen of Nanaimo	12
26	Quadra Island–Cortes Island (24)	Tenaka	12
27	Langdale–Eastbourne–Langdale (13)	Tenaka	11
28	Mayne–Tsawwassen (9)	Queen of Nanaimo	10
29	Pender–Saturna	Bowen Queen	9
30	Salt Spring/Fulford–Victoria (4)	Skeena Queen	9
31	Powell River–Texada Island (18)	North Island Princess	8
32	Galiano Island–Pender Island	Bowen Queen	8
33	Pender Island–Salt Spring Island Long Harbour	Bowen Queen	8
34	Galiano–Tsawwassen (9)	Queen of Nanaimo	7
35	Horseshoe Bay–Langdale (3)	Queen of Coquitlam	7
36	Mayne–Saturna Island Lyall Hrbr	Bowen Queen	7
37	Langdale–New Brighton–Langdale (13)	Tenaka	6
38	Mayne–Salt Spring Island Long Harbour	Bowen Queen	6
39	Chemainus–Theis Island–Penelakut Island (20)	MV Kuper	5
40	Galiano Island–Mayne Island	Bowen Queen	4
41	Nanaimo Harbour–Gabriola (19)	Quinsam	4
42	Mayne Island–Pender Island	Bowen Queen	4
43	Snug Cove–Horseshoe Bay (8)	Queen of Capilano	4
44	Haida Gwaii Skidegate–Alliford Bay (26)	Kwuna	3
45	Campbell River–Quadra Island (23)	Powell River Queen	3
46	Salt Spring/Vesuvius–Crofton (6)	Howe Sound Queen	2
47	Brentwood Bay–Mill Bay (12)	Klitsa	2
48	Buckley Bay–Denman Island (21)	Quinitsa	2
49	Denman Island–Hornby Island (22)	Kahloke	1

Table A2.7: Passenger-kilometre EFs on BC Ferries routes

Rank	Route and number	Vessel	Passenger-kilometre EF (g CO_2/pkm)
1	Earls Cove–Saltery Bay (7)	MV Island Sky	1,781

2	Haida Gwaii (11)	Northern Adventure	1,118
3	Quadra Island–Cortes Island (24)	Tenaka	1,012
4	Langdale–New Brighton–Eastbourne–Keats–Langdale (13)	Tenaka	1,007
5	Langdale–Keats–New Brighton–Langdale (13)	Tenaka	1,007
6	Langdale–New Brighton–Langdale (13)	Tenaka	1,007
7	Langdale–Eastbourne–Langdale (13)	Tenaka	1,007
8	Langdale–New Brighton–Eastbourne–Langdale (13)	Tenaka	1,007
9	Langdale–Eastbourne–Keats–Langdale (13)	Tenaka	1,007
10	Langdale–New Brighton–Keats–Eastbourne–Langdale (13)	Tenaka	1,007
11	Galiano–Swartz Bay (5)	Queen of Cumberland	982
12	Mayne–Swartz Bay	Queen of Cumberland	982
13	Pender–Swartz Bay (5)	Queen of Cumberland	982
14	Saturna Island–Swartz Bay (5)	Queen of Cumberland	982
15	Day trip from Swartz Bay (via Pender, Mayne, Galiano, Pender)	Queen of Cumberland	982
16	Salt Spring/Fulford–Victoria (4)	Skeena Queen	923
17	Tsawwassen–Duke Point (30)	Coastal Inspiration	883
18	Powell River–Texada Island (18)	North Island Princess	838
19	Campbell River–Quadra Island (23)	Powell River Queen	814
20	Tsawwassen–Duke Point (30)	Queen of Alberni	778
21	Port Hardy–Bella Coola Discovery Coast (40)	Queen of Chilliwack	734
22	Buckley Bay–Denman Island (21)	Quinitsa	721
23	Snug Cove–Horseshoe Bay (8)	Queen of Capilano	642
24	Inside passage Prince Rupert–Port Hardy (10)	Northern Expedition	567
25	Powell River–Comox (17)	Queen of Burnaby	561
26	Galiano Island–Mayne Island	Bowen Queen	551
27	Galiano Island–Pender Island	Bowen Queen	551
28	Mayne Islan–Pender Island	Bowen Queen	551
29	Mayne–Salt Spring Island Long Harbour	Bowen Queen	551
30	Mayne–Saturna Island Lyall Hrbr	Bowen Queen	551
31	Pender Island–Salt Spring Island Long Harbour	Bowen Queen	551
32	Pender–Saturna	Bowen Queen	551

33	Nanaimo Harbour–Gabriola (19)	Quinsam	548
34	Denman Island–Hornby Island (22)	Kahloke	487
35	Tsawwassen–Swartz Bay (1)	Queen of New Westminster	482
36	Haida Gwaii Skidegate–Alliford Bay (26)	Kwuna	479
37	Salt Spring/Vesuvius–Crofton (6)	Howe Sound Queen	472
38	Horseshoe Bay–Departure Bay (2)	Coastal Renaissance	466
39	Brentwood Bay–Mill Bay (12)	Klitsa	420
40	Horseshoe Bay–Langdale (3)	Queen of Coquitlam	413
41	Port McNeill–Alert Bay–Sointula (25)	Quadra Queen II	407
42	Tsawwassen–Swartz Bay (1)	Coastal Celebration	387
43	Galiano–Tsawwassen (9)	Queen of Nanaimo	369
44	Mayne–Tsawwassen (9)	Queen of Nanaimo	369
45	Pender–Tsawwassen (9)	Queen of Nanaimo	369
46	Salt Spring/Long Harbour–Tsawwassen (9)	Queen of Nanaimo	369
47	Horseshoe Bay–Departure Bay (2)	Queen of Oak Bay	334
48	Tsawwassen–Swartz Bay (1)	Spirit of British Columbia	288
49	Chemainus–Theis Island–Penelakut Island (20)	MV Kuper	261
Average			696

Table A2.8: CO_2 emission rank by airline route

Rank	**Airline**	**Route**	**Aircraft**	**Annual kilometres with diversion factor (km)**	**Annual emissions (tonnes CO_2)**	**% of total emissions**
1	AC Express	Vancouver–Fort St. John	DH4	2,086,157	11,290	6.82
2	AC Express	Vancouver–Prince George	DH4	1,877,476	9,904	5.99
3	AC Express	Vancouver–Terrace	DH3	2,037,344	9,463	5.72
4	Hawkair	Vancouver–Terrace	DH3	1,848,701	8,101	4.90
5	Westjet	Vancouver–Prince George	73W	796,505	7,177	4.34
6	AC Express	Vancouver–Kamloops	DH3	1,301,009	5,763	3.48
7	AC Express	Vancouver–Prince Rupert	DH3	1,067,539	4,991	3.02

8	Westjet Encore	Vancouver–Terrace	DH4	905,486	4,909	2.97
9	AC Express	Vancouver–Kelowna	DH3	1,030,630	4,579	2.77
10	AC Express	Vancouver–Smithers	DH3	891,072	4,134	2.50
11	Pacific Coastal Airlines	Vancouver–Cranbrook	BE1	728,910	4,030	2.44
12	AC Express	Vancouver–Castlegar	DH3	829,920	3,734	2.26
13	AC Express	Vancouver–Victoria	DH3	851,136	3,688	2.23
14	Westjet Encore	Vancouver–Prince George	DH4	682,718	3,644	2.20
15	Central Mountain Air	Vancouver–Dawson Creek	DH1	990,662	3,578	2.16
16	AC Express	Vancouver–Cranbrook	DH3	758,066	3,462	2.09
17	Westjet Encore	Vancouver–Fort St. John	DH4	608,462	3,331	2.01
18	Westjet	Vancouver–Kelowna	73W	374,774	3,317	2.00
19	Pacific Coastal Airlines	Vancouver–Williams Lake	BE1	593,393	3,049	1.84
20	Helijet	Vancouver–Victoria	Sikorsky S76	986,586	2,804	1.69
21	Pacific Coastal Airlines	Vancouver–Masset	Saab 340	536,609	2,598	1.57
22	Hawkair	Vancouver–Prince Rupert	DH3	574,829	2,536	1.53
23	Central Mountain Air	Vancouver–Williams Lake	BEH	465,465	2,440	1.47
24	AC Express	Vancouver–Penticton	DH3	537,373	2,380	1.44
25	AC Express	Vancouver–Sandspit	DH3	490,090	2,290	1.38
26	AC Express	Vancouver–Kelowna	DH4	437,237	2,255	1.36
27	Central Mountain Air	Vancouver–Comox	BEH	451,840	2,230	1.35
28	Central Mountain Air	Vancouver–Campbell River	BEH	423,051	2,111	1.28
29	Central Mountain Air	Prince George–Kelowna	BEH	376,085	2,058	1.24
30	Central Mountain Air	Fort Nelson–Fort St. John	D38	237,728	1,950	1.18
31	Hawkair	Vancouver–	DH3	408,408	1,787	1.08

		Smithers				
32	Pacific Coastal Airlines	Vancouver–Port Hardy	BE1	337,100	1,762	1.07
33	Pacific Coastal Airlines	Vancouver–Powell River	BE1	345,909	1,688	1.02
34	Central Mountain Air	Vancouver–Quesnel	BEH	305,214	1,642	0.99
35	Pacific Coastal Airlines	Vancouver–Port Hardy	Saab 340	355,828	1,596	0.96
36	Central Mountain Air	Prince George–Fort St. John	BEH	285,012	1,472	0.89
37	Pacific Coastal Airlines	Vancouver–Trail	BE1	266,666	1,421	0.86
38	Pacific Coastal Airlines	Vancouver–Trail	Saab 340	311,111	1,410	0.85
39	Pacific Coastal Airlines	Vancouver–Bella Coola	BE1	258,258	1,386	0.84
40	Central Mountain Air	Prince George–Kamloops	BEH	252,907	1,343	0.81
41	Westjet Encore	Victoria–Kelowna	DH4	250,723	1,314	0.79
42	Pacific Coastal Airlines	Vancouver–Victoria	BE1	262,434	1,257	0.76
43	AC Express	Vancouver–Nanaimo	DH3	290,347	1,257	0.76
44	Pacific Coastal Airlines	Vancouver–Campbell River	BE1	249,985	1,241	0.75
45	Central Mountain Air	Prince George–Terrace	DH3	256,183	1,148	0.69
46	Westjet Encore	Vancouver–Kelowna	DH4	218,618	1,141	0.69
47	Central Mountain Air	Prince George–Smithers	BEH	202,457	1,051	0.64
48	Pacific Coastal Airlines	Vancouver–Comox	BE1	199,116	977	0.59
49	Central Mountain Air	Fort Nelson–Dawson Creek	DH1	264,755	920	0.56
50	Westjet Encore	Vancouver–Kamloops	DH4	169,697	884	0.53
51	Central Mountain Air	Fort Nelson–Fort St. John	BEH	169,806	882	0.53

52	Harbour Air	Vancouver–Victoria	DHC-3 Otter	702,187	864	0.52
53	Northern Thunderbird Air	Prince George–Dease Lake	Beech 1900	147,857	851	0.51
54	Westjet Encore	Vancouver–Victoria	DH4	148,949	761	0.46
55	Pacific Coastal Airlines	Kelowna–Cranbrook	BE1	142,506	727	0.44
56	Central Mountain Air	Quesnel–Williams Lake	BEH	140,140	684	0.41
57	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	516,402	636	0.38
58	Pacific Coastal Airlines	Port Hardy–Bella Bella	Saab 340	133,825	583	0.35
59	Northern Thunderbird Air	Dease Lake–Smithers	Beech 1900	95,004	505	0.31
60	Central Mountain Air	Prince George–Fort Nelson	BEH	89,599	498	0.30
61	Pacific Coastal Airlines	Vancouver–Comox	Saab 340	91,900	398	0.24
62	Harbour Air	Vancouver–Comox	DHC-3 Otter	291,015	363	0.22
63	Pacific Coastal Airlines	Vancouver–Anahim Lake	BE1	64,373	342	0.21
64	Northern Thunderbird Air	Smithers–Bob Quinn	Beech 1900	66,394	339	0.21
65	Pacific Coastal Airlines	Campbell River–Comox	BE1	71,386	339	0.21
66	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	260,718	320	0.19
67	Central Mountain Air	Fort Nelson–Fort St. John	DH3	67,922	302	0.18
68	Harbour Air	Vancouver–Victoria	DHC-3 Otter	241,155	297	0.18
69	Central Mountain Air	Campbell River–Comox	BEH	51,308	245	0.15
70	Harbour Air	Nanaimo–Sechelt	DHC-3 Otter	181,210	223	0.13
71	AC Express	Vancouver–Kelowna	CRJ	31,231	201	0.12
72	Northern Thunderbird	Bob Quinn–Dease Lake	Beech 1900	36,223	177	0.11

	Air					
73	Harbour Air	Vancouver–Maple Bay	DHC-3 Otter	139,110	171	0.10
74	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	103,074	127	0.08
75	Pacific Coastal Airlines	Campbell River–Comox	Saab 340	26,770	114	0.07
76	KD Air	Vancouver–Qualicum Beach	Piper PA31, Cessna	247,104	112	0.07
77	Seair	Vancouver–Nanaimo	Cessna, Beaver	230,287	109	0.07
78	AC Express	Vancouver–Victoria	DH4	21,278	107	0.06
79	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	83,283	102	0.06
80	Seair	Vancouver–Nanaimo	Cessna, Beaver	169,770	80	0.05
81	Orca Airways	Vancouver–Qualicum Beach	Piper Navajo Chieftain	154,440	74	0.04
82	Pacific Coastal Airlines	Anahim Lake–Bella Coola	BE1	15,101	73	0.04
83	Orca Airways	Vancouver–Tofino	Piper Navajo Chieftain	148,694	72	0.04
84	Hawkair	Smithers–Terrace	DH3	16,817	69	0.04
85	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	120,120	53	0.03
86	Seair	Vancouver–Saturna Is	Cessna, Beaver	110,510	52	0.03
87	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	118,404	52	0.03
88	Seair	Vancouver–Salt Spring Is	Cessna, Beaver	108,108	51	0.03
89	Orca Airways	Abbotsford–Victoria	Piper Navajo Chieftain	101,816	49	0.03
90	Seair	Vancouver–Pender Is	Cessna, Beaver	103,303	49	0.03
91	Seair	Vancouver–Thetis Is	Cessna, Beaver	100,901	48	0.03
92	Tofino Air	Nanaimo–Sechelt	Otter, Beaver, Cessna	88,889	45	0.03
93	Tofino Air	Vancouver–Gabriola Is	Otter, Beaver,	84,084	43	0.03

			Cessna			
94	Pacific Coastal Airlines	Bella Bella–Klemtu	Beaver	92,893	41	0.02
95	Vancouver Island Air	Campbell River–Seymour Inlet	Otter, Beaver, Beech 18	67,080	35	0.02
96	Seair	Vancouver–Galiano Is	Cessna, Beaver	64,064	30	0.02
97	KD Air	Qualicum Beach–Gillies Bay	Piper PA31, Cessna	64,064	29	0.02
98	Seair	Vancouver–Mayne Is	Cessna, Beaver	59,259	28	0.02
99	Air Nootka	Gold River–Kyuquot	Float plane	40,248	18	0.01
Total				37,688,164	166,867	100

Table A2.9: City-pair CO_2 emissions

Rank	City pair	Annual flights	Annual emissions (tonnes CO_2)	% of total emissions
1	Vancouver–Terrace	6,604	22,474	13.47
2	Vancouver–Prince George	6,136	20,724	12.42
3	Vancouver–Fort St. John	3,224	14,621	8.76
4	Vancouver–Kelowna	6,968	11,493	6.89
5	Vancouver–Victoria	41,808	9,778	5.86
6	Vancouver–Prince Rupert	2,080	7,528	4.51
7	Vancouver–Cranbrook	2,652	7,492	4.49
8	Vancouver–Kamloops	5,408	6,646	3.98
9	Vancouver–Smithers	1,820	5,922	3.55
10	Vancouver–Williams Lake	3,276	5,489	3.29
11	Vancouver–Comox	7,020	3,968	2.38
12	Vancouver–Castlegar	1,976	3,734	2.24
13	Vancouver–Dawson Creek	1,248	3,578	2.14
14	Vancouver–Port Hardy	1,924	3,358	2.01
15	Vancouver–Campbell River	3,640	3,353	2.01
16	Fort Nelson–Fort St. John	1,456	3,134	1.88
17	Vancouver–Trail	1,352	2,831	1.70
18	Vancouver–Masset	624	2,598	1.56
19	Vancouver–Nanaimo	20,644	2,395	1.44
20	Vancouver–Penticton	1,976	2,380	1.43
21	Vancouver–Sandspit	624	2,290	1.37
22	Prince George–Kelowna	728	2,058	1.23
23	Vancouver–Powell River	2,704	1,688	1.01

24	Vancouver–Quesnel	676	1,642	0.98
25	Prince George–Fort St. John	936	1,472	0.88
26	Vancouver–Bella Coola	572	1,386	0.83
27	Prince George–Kamloops	624	1,343	0.80
28	Victoria–Kelowna	728	1,314	0.79
29	Prince George–Terrace	624	1,148	0.69
30	Prince George–Smithers	624	1,051	0.63
31	Fort Nelson–Dawson Creek	676	920	0.55
32	Prince George–Dease Lake	208	851	0.51
33	Kelowna–Cranbrook	520	727	0.44
34	Campbell River–Comox	5,356	697	0.42
35	Quesnel–Williams Lake	1,300	684	0.41
36	Port Hardy–Bella Bella	728	583	0.35
37	Dease Lake–Smithers	208	505	0.30
38	Prince George–Fort Nelson	156	498	0.30
39	Vancouver–Anahim Lake	156	342	0.20
40	Smithers–Bob Quinn	208	339	0.20
41	Nanaimo–Sechelt	5,616	268	0.16
42	Vancouver–Sechelt	2,080	216	0.13
43	Vancouver–Qualicum Beach	4,680	207	0.12
44	Bob Quinn–Dease Lake	208	177	0.11
45	Vancouver–Maple Bay	1,976	171	0.10
46	Vancouver–Salt Spring Is	5,408	152	0.09
47	Vancouver–Tofino	1,560	74	0.04
48	Anahim Lake–Bella Coola	728	72	0.04
49	Smithers–Terrace	156	69	0.04
50	Abbotsford–Victoria	2,184	53	0.03
51	Vancouver–Saturna Is	2,392	52	0.03
52	Vancouver–Pender Is	2,184	49	0.03
53	Vancouver–Thetis Is	2,184	48	0.03
54	Vancouver–Gabriola Is	2,184	43	0.03
55	Bella Bella–Klemtu	1,456	41	0.02
56	Campbell River–Seymour Inlet	312	35	0.02
57	Qualicum Beach–Gillies Bay	1,456	30	0.02
58	Vancouver–Galiano Is	1,456	29	0.02
59	Vancouver–Mayne Is	1,456	28	0.02
60	Gold River–Kyuquot	312	18	0.01
Total		180,180	166,867	100

Table A2.10: Passenger-flight EFs of BC aviation

Rank	**Airline**	**Route**	**Aircraft**	**Stage length including diversion factor**	**Passenger-flight EF (kg CO_2)**
1	Northern	Prince George–	Beech 1900	711	269.1

	Thunderbird Air	Dease Lake			
2	Central Mountain Air	Prince George–Fort Nelson	BEH	574	221.6
3	Pacific Coastal Airlines	Vancouver–Cranbrook	BE1	561	203.9
4	Central Mountain Air	Prince George–Kelowna	BEH	517	196.3
5	Pacific Coastal Airlines	Vancouver–Masset	Saab 340	860	173.5
6	Northern Thunderbird Air	Dease Lake–Smithers	Beech 1900	457	168.7
7	Central Mountain Air	Vancouver–Quesnel	BEH	452	168.6
8	Pacific Coastal Airlines	Vancouver–Bella Coola	BE1	452	159.4
9	Pacific Coastal Airlines	Vancouver–Trail	BE1	427	149.8
10	Central Mountain Air	Prince George–Kamloops	BEH	405	149.5
11	Pacific Coastal Airlines	Vancouver–Anahim Lake	BE1	413	144.1
12	Central Mountain Air	Vancouver–Williams Lake	BEH	358	130.4
13	Pacific Coastal Airlines	Vancouver–Port Hardy	BE1	360	123.9
14	Central Mountain Air	Fort Nelson–Fort St. John	BEH	327	117.8
15	Hawkair	Vancouver–Prince Rupert	DH3	790	117.7
16	Central Mountain Air	Prince George–Smithers	BEH	324	117.0
17	Northern Thunderbird Air	Smithers–Bob Quinn	Beech 1900	319	113.3
18	Central Mountain Air	Fort Nelson–Fort St. John	D38	327	111.6
19	Central Mountain Air	Prince George–Fort St. John	BEH	305	109.2
20	Hawkair	Vancouver–Terrace	DH3	726	107.4
21	Hawkair	Vancouver–Smithers	DH3	714	105.6
22	Pacific Coastal Airlines	Vancouver–Williams Lake	BE1	300	101.5
23	Central Mountain Air	Vancouver–Dawson Creek	DH1	794	96.9
24	Pacific Coastal Airlines	Kelowna–Cranbrook	BE1	274	91.9

25	AC Express	Vancouver–Prince Rupert	DH3	790	90.8
26	AC Express	Vancouver–Sandspit	DH3	785	90.3
27	AC Express	Vancouver–Terrace	DH3	726	82.9
28	AC Express	Vancouver–Smithers	DH3	714	81.5
29	Pacific Coastal Airlines	Vancouver–Trail	Saab 340	427	80.7
30	AC Express	Vancouver–Fort St. John	DH4	836	77.3
31	Westjet Encore	Vancouver–Fort St. John	DH4	836	74.1
32	Pacific Coastal Airlines	Vancouver–Port Hardy	Saab 340	360	67.3
33	Central Mountain Air	Vancouver–Campbell River	BEH	185	64.1
34	Westjet Encore	Vancouver–Terrace	DH4	726	63.7
35	AC Express	Vancouver–Cranbrook	DH3	561	63.0
36	Pacific Coastal Airlines	Vancouver–Campbell River	BE1	185	60.4
37	Northern Thunderbird Air	Bob Quinn–Dease Lake	Beech 1900	174	59.2
38	Central Mountain Air	Vancouver–Comox	BEH	147	50.5
39	AC Express	Vancouver–Prince George	DH4	547	49.3
40	Pacific Coastal Airlines	Vancouver–Comox	BE1	147	47.6
41	AC Express	Vancouver–Kelowna	CRJ	300	47.4
42	Westjet Encore	Vancouver–Prince George	DH4	547	47.3
43	AC Express	Vancouver–Castlegar	DH3	420	46.5
44	Central Mountain Air	Prince George–Terrace	DH3	411	46.0
45	Central Mountain Air	Fort Nelson–Dawson Creek	DH1	392	46.0
46	Westjet	Vancouver–Prince George	73W	547	41.5
47	Pacific Coastal Airlines	Vancouver–Powell River	BE1	128	41.1
48	Central Mountain Air	Quesnel–Williams Lake	BEH	108	36.5
49	Central	Fort Nelson–Fort	DH3	327	36.2

	Mountain Air	St. John			
50	Pacific Coastal Airlines	Port Hardy–Bella Bella	Saab 340	184	33.4
51	AC Express	Vancouver–Kelowna	DH3	300	32.8
52	Pacific Coastal Airlines	Anahim Lake–Bella Coola	BE1	97	30.8
53	AC Express	Vancouver–Kamloops	DH3	272	29.6
54	AC Express	Vancouver–Penticton	DH3	272	29.6
55	Westjet Encore	Victoria–Kelowna	DH4	344	29.2
56	Helijet	Vancouver–Victoria	Sikorsky S76	108	27.4
57	Pacific Coastal Airlines	Vancouver–Comox	Saab 340	147	26.6
58	AC Express	Vancouver–Kelowna	DH4	300	26.5
59	Westjet Encore	Vancouver–Kelowna	DH4	300	25.4
60	Westjet Encore	Vancouver–Kamloops	DH4	272	22.9
61	Westjet	Vancouver–Kelowna	73W	300	22.4
62	Pacific Coastal Airlines	Vancouver–Victoria	BE1	68	21.5
63	Air Nootka	Gold River–Kyuquot	Float plane	129	17.8
64	Vancouver Island Air	Campbell River–Seymour Inlet	Otter, Beaver, Beech 18	215	17.4
65	Orca Airways	Vancouver–Tofino	Piper Navajo Chieftain	204	15.5
66	Harbour Air	Vancouver–Comox	DHC-3 Otter	147	15.3
67	Hawkair	Smithers–Terrace	DH3	108	14.9
68	Central Mountain Air	Campbell River–Comox	BEH	43	14.3
69	Pacific Coastal Airlines	Campbell River–Comox	BE1	43	13.4
70	KD Air	Vancouver–Qualicum Beach	Piper PA31, Cessna	99	9.4
71	Pacific Coastal Airlines	Bella Bella–Klemtu	Beaver	64	8.7
72	Pacific Coastal Airlines	Campbell River–Comox	Saab 340	43	7.6
73	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	55	7.5
74	Orca Airways	Vancouver–	Piper Navajo	99	7.4

		Qualicum Beach	Chieftain		
75	Orca Airways	Abbotsford–Victoria	Piper Navajo Chieftain	98	7.4
76	AC Express	Vancouver–Victoria	DH3	68	7.3
77	Harbour Air	Vancouver–Maple Bay	DHC-3 Otter	70	7.2
78	Harbour Air	Vancouver–Victoria	DHC-3 Otter	68	7.0
79	Harbour Air	Vancouver–Victoria	DHC-3 Otter	68	7.0
80	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	67	6.9
81	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	50	6.8
82	Seair	Vancouver–Nanaimo	Cessna, Beaver	67	6.6
83	AC Express	Vancouver–Nanaimo	DH3	59	6.3
84	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	58	6.0
85	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	58	6.0
86	AC Express	Vancouver–Victoria	DH4	68	5.9
87	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	57	5.9
88	Seair	Vancouver–Nanaimo	Cessna, Beaver	58	5.8
89	Westjet Encore	Vancouver–Victoria	DH4	68	5.6
90	Harbour Air	Nanaimo–Sechelt	DHC-3 Otter	53	5.4
91	Seair	Vancouver–Saturna Is	Cessna, Beaver	51	5.0
92	Seair	Vancouver–Salt Spring Is	Cessna, Beaver	50	4.9
93	Seair	Vancouver–Pender Is	Cessna, Beaver	47	4.7
94	Seair	Vancouver–Thetis Is	Cessna, Beaver	46	4.6
95	Seair	Vancouver–Galiano Is	Cessna, Beaver	44	4.3
96	KD Air	Qualicum Beach–Gillies Bay	Piper PA31, Cessna	44	4.1
97	Seair	Vancouver–Mayne Is	Cessna, Beaver	41	4.0
98	Tofino Air	Nanaimo–Sechelt	Otter, Beaver, Cessna	41	3.2
99	Tofino Air	Vancouver–	Otter,	39	3.1

		Gabriola Is	Beaver, Cessna		

Table A2.11: Passenger-kilometre EFs of BC aviation

Rank	Airline	Route	Aircraft	Passenger-kilometre EF(g CO_2/pkm
1	Central Mountain Air	Prince George–Fort Nelson	BEH	385.9
2	Central Mountain Air	Prince George–Kelowna	BEH	380.1
3	Northern Thunderbird Air	Prince George–Dease Lake	Beech 1900	378.5
4	Central Mountain Air	Vancouver–Quesnel	BEH	373.5
5	Northern Thunderbird Air	Dease Lake–Smithers	Beech 1900	369.4
6	Central Mountain Air	Prince George–Kamloops	BEH	368.8
7	Central Mountain Air	Vancouver–Williams Lake	BEH	364.1
8	Pacific Coastal Airlines	Vancouver–Cranbrook	BE1	363.7
9	Central Mountain Air	Fort Nelson–Fort St. John	BEH	360.9
10	Central Mountain Air	Prince George–Smithers	BEH	360.7
11	Central Mountain Air	Prince George–Fort St. John	BEH	358.7
12	Northern Thunderbird Air	Smithers–Bob Quinn	Beech 1900	355.1
13	Pacific Coastal Airlines	Vancouver–Bella Coola	BE1	353.0
14	Pacific Coastal Airlines	Vancouver–Trail	BE1	350.6
15	Pacific Coastal Airlines	Vancouver–Anahim Lake	BE1	349.1
16	Central Mountain Air	Vancouver–Campbell River	BEH	346.6
17	Pacific Coastal Airlines	Vancouver–Port Hardy	BE1	344.0
18	Central Mountain Air	Vancouver–Comox	BEH	342.8
19	Central Mountain Air	Fort Nelson–Fort St. John	D38	341.7
20	Northern Thunderbird Air	Bob Quinn–Dease Lake	Beech 1900	340.0
21	Central Mountain	Quesnel–Williams	BEH	338.8

	Air	Lake		
22	Pacific Coastal Airlines	Vancouver–Williams Lake	BE1	338.1
23	Pacific Coastal Airlines	Kelowna–Cranbrook	BE1	335.5
24	Central Mountain Air	Campbell River–Comox	BEH	332.2
25	Pacific Coastal Airlines	Vancouver–Campbell River	BE1	326.7
26	Pacific Coastal Airlines	Vancouver–Comox	BE1	323.0
27	Pacific Coastal Airlines	Vancouver–Powell River	BE1	321.1
28	Pacific Coastal Airlines	Anahim Lake–Bella Coola	BE1	318.0
29	Pacific Coastal Airlines	Vancouver–Victoria	BE1	315.2
30	Pacific Coastal Airlines	Campbell River–Comox	BE1	312.7
31	Helijet	Vancouver–Victoria	Sikorsky S76	253.7
32	Pacific Coastal Airlines	Vancouver–Masset	Saab 340	201.7
33	Pacific Coastal Airlines	Vancouver–Trail	Saab 340	188.9
34	Pacific Coastal Airlines	Vancouver–Port Hardy	Saab 340	186.9
35	Pacific Coastal Airlines	Port Hardy–Bella Bella	Saab 340	181.7
36	Pacific Coastal Airlines	Vancouver–Comox	Saab 340	180.6
37	Pacific Coastal Airlines	Campbell River–Comox	Saab 340	177.5
38	AC Express	Vancouver–Kelowna	CRJ	158.0
39	Hawkair	Vancouver–Prince Rupert	DH3	149.1
40	Hawkair	Vancouver–Terrace	DH3	148.0
41	Hawkair	Vancouver–Smithers	DH3	147.9
42	Air Nootka	Gold River–Kyuquot	Float plane	138.2
43	Hawkair	Smithers–Terrace	DH3	138.1
44	Pacific Coastal Airlines	Bella Bella–Klemtu	Beaver	136.9
45	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	136.8
46	Salt Spring Air	Vancouver–Salt Spring Is	Float plane	136.7
47	Central Mountain Air	Vancouver–Dawson Creek	DH1	122.0
48	Central Mountain Air	Fort Nelson–Dawson Creek	DH1	117.4
49	AC Express	Vancouver–Prince	DH3	115.0

		Rupert		
50	AC Express	Vancouver–Sandspit	DH3	115.0
51	AC Express	Vancouver–Terrace	DH3	114.3
52	AC Express	Vancouver–Smithers	DH3	114.1
53	AC Express	Vancouver–Cranbrook	DH3	112.3
54	Central Mountain Air	Prince George–Terrace	DH3	112.0
55	Central Mountain Air	Fort Nelson–Fort St. John	DH3	111.0
56	AC Express	Vancouver–Castlegar	DH3	110.7
57	AC Express	Vancouver–Kelowna	DH3	109.3
58	AC Express	Vancouver–Kamloops	DH3	109.0
59	AC Express	Vancouver–Penticton	DH3	109.0
60	AC Express	Vancouver–Victoria	DH3	106.6
61	AC Express	Vancouver–Nanaimo	DH3	106.5
62	Harbour Air	Vancouver–Comox	DHC-3 Otter	103.8
63	Harbour Air	Vancouver–Maple Bay	DHC-3 Otter	102.6
64	Harbour Air	Vancouver–Victoria	DHC-3 Otter	102.6
65	Harbour Air	Vancouver–Victoria	DHC-3 Otter	102.6
66	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	102.6
67	Harbour Air	Vancouver–Nanaimo	DHC-3 Otter	102.4
68	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	102.4
69	Harbour Air	Vancouver–Sechelt	DHC-3 Otter	102.4
70	Harbour Air	Nanaimo–Sechelt	DHC-3 Otter	102.3
71	Seair	Vancouver–Nanaimo	Cessna, Beaver	98.8
72	Seair	Vancouver–Nanaimo	Cessna, Beaver	98.7
73	Seair	Vancouver–Saturna Is	Cessna, Beaver	98.6
74	Seair	Vancouver–Salt Spring Is	Cessna, Beaver	98.6
75	Seair	Vancouver–Pender Is	Cessna, Beaver	98.6
76	Seair	Vancouver–Thetis Is	Cessna, Beaver	98.5
77	Seair	Vancouver–Galiano Is	Cessna, Beaver	98.5
78	Seair	Vancouver–Mayne Is	Cessna, Beaver	98.5
79	KD Air	Vancouver–Qualicum Beach	Piper PA31, Cessna	94.7
80	KD Air	Qualicum Beach–Gillies Bay	Piper PA31, Cessna	94.2
81	AC Express	Vancouver–Fort St. John	DH4	92.5
82	AC Express	Vancouver–Prince George	DH4	90.1
83	Westjet Encore	Vancouver–Fort St. John	DH4	88.6
84	AC Express	Vancouver–Kelowna	DH4	88.1

85	Westjet Encore	Vancouver–Terrace	DH4	87.8
86	Westjet Encore	Vancouver–Prince George	DH4	86.4
87	AC Express	Vancouver–Victoria	DH4	86.2
88	Westjet Encore	Victoria–Kelowna	DH4	84.8
89	Westjet Encore	Vancouver–Kelowna	DH4	84.5
90	Westjet Encore	Vancouver–Kamloops	DH4	84.3
91	Westjet Encore	Vancouver–Victoria	DH4	82.7
92	Vancouver Island Air	Campbell River–Seymour Inlet	Otter, Beaver, Beech 18	81.1
93	Tofino Air	Nanaimo–Sechelt	Otter, Beaver, Cessna	79.5
94	Tofino Air	Vancouver–Gabriola Is	Otter, Beaver, Cessna	79.4
95	Orca Airways	Vancouver–Tofino	Piper Navajo Chieftain	75.8
96	Westjet	Vancouver–Prince George	73W	75.8
97	Orca Airways	Vancouver–Qualicum Beach	Piper Navajo Chieftain	75.2
98	Orca Airways	Abbotsford–Victoria	Piper Navajo Chieftain	75.2
99	Westjet	Vancouver–Kelowna	73W	74.5
Average				184.5

Table A2.12: Emissions of bus routes within BC

Rank	**Route**	**Distance (km)**	**Daily one-way trips**	**Annual CO_2 emissions (tonnes CO_2)**
1	Kamloops–Golden	360	4	1,534
2	Cache Creek–Prince George	443	3	1,416
3	Vancouver–Hope	155	8	1,321
4	Vancouver–Whistler	125	6	799
5	Prince George–Prince Rupert	718	1	765
6	Merritt–Kamloops	87	6	556
7	Hope–Merritt	124	4	529
8	Victoria–Nanaimo	111	4	474
9	Prince George–Dawson Creek	404	1	431
10	Fort St. John–Fort Nelson	380	1	405
11	Parksville–Port Hardy	352	1	375
12	Valemount–Kamloops	322	1	343
13	Golden–Alberta Border (for Banff)	74	4	315
14	Prince George–Valemount	292	1	311
15	Kelowna–Merritt	128	2	273
16	Hope–Osoyoos	251	1	268

17	Cranbrook–Golden	246	1	262
18	Castlegar–Cranbrook	229	1	244
19	Osoyoos–Castlegar	222	1	237
20	Kelowna–Vernon	54	4	230
21	Valemount–Alberta Border (for Jasper)	97	2	207
22	Hope–Cache Creek	191	1	204
23	Fort Nelson–Toad River	188	1	200
24	Parksville–Tofino	172	1	184
25	Kamloops–Cache Creek	83	2	177
26	Nanaimo–Parksville	38	4	162
27	Cranbrook–Alberta Border (for Fort Macleod)	146	1	156
28	Whistler–Pemberton	33	4	141
29	Osoyoos–Kelowna	125	1	133
30	Dawson Creek–Fort St. John	75	1	80
31	Vanderhoof–Fort. St. James	61	1	65
Total				12,795

Table A2.13: Ranking of BC routes by truck kilometres driven in 2007 and 2013

Rank	2007 distance driven (km)	Route	2013 distance driven (km)	Route
1	236,931,720	Vancouver–Chilliwack	229,529,155	Vancouver–Chilliwack
2	141,178,613	Hope–Merritt	147,093,529	Hope–Merritt
3	112,141,622	Vernon–Kelowna	119,382,682	Vernon–Kelowna
4	105,587,620	Ladysmith–Victoria	109,344,510	Ladysmith–Victoria
5	103,021,922	Parksville–Nanaimo	107,563,456	Kelowna–Penticton
6	99,898,514	Cache Creek–Williams Lake	105,757,071	Revelstoke–Golden
7	96,637,050	Kelowna–Penticton	104,756,533	Tete Jaune Cache–Kamloops
8	94,907,957	Tete Jaune Cache–Kamloops	102,181,677	Parksville–Nanaimo
9	94,421,996	Hope–Cache Creek	98,130,571	Kamloops–Merritt
10	91,100,314	Revelstoke–Golden	95,164,348	Cache Creek–Williams Lake
11	83,487,706	Kamloops–Merritt	84,329,454	Chilliwack–Hope
12	81,958,998	Chilliwack–Hope	80,246,801	Dawson Creek–Prince George
13	74,030,760	Hope–Penticton	79,337,480	Salmon Arm–Revelstoke
14	63,759,616	Salmon Arm–Revelstoke	75,989,350	Hope–Cache Creek

15	61,324,760	Monte Creek–Salmon Arm	69,360,512	Kelowna–Merritt
16	59,351,219	Kelowna–Merritt	65,749,056	Parksville–Campbell River
17	58,257,504	Parksville–Campbell River	63,046,815	Monte Creek–Salmon Arm
18	56,188,283	Dawson Creek–Prince George	57,450,708	Hope–Penticton
19	50,580,514	Fort Nelson–Liard River	55,501,079	Fort Nelson–Liard River
20	49,647,942	Quesnel–Williams Lake	50,790,298	Fort St. John–Wonowon
21	49,521,813	Prince George–Quesnel	49,428,300	Prince George–Quesnel
22	46,250,391	Golden–Alberta Border	49,134,446	Golden–Alberta Border
23	41,845,491	Golden–Radium Hot Springs	48,079,939	Quesnel–Williams Lake
24	39,006,287	Prince George–Vanderhoof	41,845,491	Golden–Radium Hot Springs
25	37,048,168	Fort St. John–Wonowon	39,006,287	Prince George–Vanderhoof
26	36,733,133	Cranbrook–Fairmont Hot Springs	37,688,805	Dawson Creek–Ft. St. John
27	33,899,229	Cranbrook–Creston	36,784,379	Cranbrook–Fairmont Hot Springs
28	33,324,617	Monte Creek–Vernon	34,238,635	Monte Creek–Vernon
29	33,146,614	Tete Jaune Cache–Prince George	32,622,240	Cranbrook–Creston
30	32,821,530	Dawson Creek–Ft. St. John	31,767,775	Cranbrook–Highway 93 Junction
31	30,393,054	Kamloops–Monte Creek	31,184,899	Kamloops–Monte Creek
32	30,078,555	Vernon–Salmon Arm	30,992,238	Tete Jaune Cache–Prince George
33	28,593,560	Rock Creek–Castlegar	30,864,327	Vernon–Salmon Arm
34	28,560,155	Cranbrook–Highway 93 Junction	29,165,281	Alberta/BC Boundary–Highway 93 Junction
35	26,382,200	Ucluelet Junction–Parksville	27,224,602	Kamloops–Cache Creek
36	25,438,317	Alberta/BC Boundary–Highway 93 Junction	25,997,096	Rock Creek–Castlegar
37	24,657,101	Kamloops–Cache Creek	25,704,851	Tete Jaune Cache–Alta border
38	23,744,528	Tete Jaune Cache–Alta border	24,073,758	Ucluelet Junction–Parksville

39	22,102,210	Kelowna–Rock Creek	21,382,926	Vancouver–Squamish
40	21,998,295	Radium Hot Springs–Fairmont Hot Springs	21,036,103	Kelowna–Rock Creek
41	21,382,926	Vancouver–Squamish	20,135,225	Squamish–Whisler
42	19,959,569	Whistler–Cache Creek/Pemberton	19,838,845	Radium Hot Springs–Fairmont Hot Springs
43	19,648,724	Creston–Castlegar	19,393,983	Nanaimo–Ladysmith
44	19,424,132	Nelson–Kaslo	19,129,212	Wonowon–Buckinghorse River
45	19,226,886	Nanaimo–Ladysmith	19,107,925	Penticton–Osoyoos
46	19,048,138	Penticton–Osoyoos	19,016,044	Whistler–Cache Creek/Pemberton
47	18,894,970	Houston–Smithers	18,560,542	Nelson–Kaslo
48	18,162,619	Squamish–Whisler	18,204,930	Creston–Castlegar
49	17,894,344	Burns Lake–Houston	17,894,344	Burns Lake–Houston
50	17,281,071	Wonowon–Buckinghorse River	17,085,650	Dawson Creek–Alberta Border
51	16,290,315	1 km north of Prophet River–Fort Nelson	15,791,550	Vanderhoof–Fraser Lake
52	15,280,506	Port Hardy–Campbell River	15,645,594	Houston–Smithers
53	14,994,638	Dawson Creek–Alberta Border	15,598,056	Port Hardy–Campbell River
54	14,821,482	Williams Lake–Alexis Creek	14,910,024	Kitwanga–Terrace
55	14,576,640	Castlegar–Christina Lake	14,583,473	Williams Lake–Alexis Creek
56	13,688,945	Vanderhoof–Fraser Lake	14,518,386	1 km north of Prophet River–Fort Nelson
57	13,124,955	Kitwanga–Terrace	13,877,227	Fraser Lake–Burns Lake
58	13,018,061	Buckinghorse River–1 km north of Prophet River	13,501,898	Castlegar–Christina Lake
59	12,761,203	Fraser Lake–Burns Lake	13,476,559	Vernon–Nakusp
60	12,169,407	Vernon–Nakusp	13,332,370	Prince Rupert–Terrace
61	12,120,628	Terrace–Kitimat	12,899,407	Buckinghorse River–1 km north of Prophet River
62	11,235,021	Smithers–New Hazelton	12,826,684	Terrace–Kitimat
63	11,100,672	Prince Rupert–Terrace	11,235,021	Smithers–New Hazelton
64	10,353,882	Parksville–Campbell	10,301,760	Parksville–Campbell

		River		River
65	10,059,261	Hope–Agassiz	9,248,994	Hope–Agassiz
66	8,316,437	Nakusp–Castlegar	8,032,745	Castlegar–Trail
67	7,516,080	Ucluelet Junction–Tofino	7,798,459	Nakusp–Castlegar
68	7,505,612	Castlegar–Trail	7,352,093	Ucluelet Junction–Tofino
69	6,940,417	Kitwanga–Meziadin Junction	6,954,936	Kitwanga–Meziadin Junction
70	6,403,188	Liard River–Lower Post	6,331,443	Liard River–Lower Post
71	5,859,783	Sechelt–ferry	6,093,909	Meziadin Junction–Dease Lake
72	5,784,929	Alexis Creek–Anahim Lake	6,023,113	Kitwanga–New Hazelton
73	5,654,142	Meziadin Junction–Dease Lake	5,611,437	Sechelt–ferry
74	5,468,138	Kitwanga–New Hazelton	4,600,708	Gibsons–Sechelt
75	4,683,096	Gibsons–Sechelt	4,315,293	Dease Lake–Yukon Border
76	4,007,058	Dease Lake–Yukon Border	3,098,295	Alexis Creek–Anahim Lake
77	1,718,070	Ucluelet Junction–Ucluelet	1,639,113	Ucluelet Junction–Ucluelet
78	1,632,470	Meziadin Junction–Stewart	1,389,336	Meziadin Junction–Stewart
79	1,273,266	Saltery Bay ferry terminal–Powell River	1,135,296	Saltery Bay ferry terminal–Powell River
Total	2,919,241,552		3,029,417,338	

Table A2.14: Percentage changes in trucking distance driven on BC routes 2007-2013

Rank	Route	2007 distance driven (km)	2013 distance driven (km)	% Change
1	Dawson Creek–Prince George	56,188,283	80,246,801	42.8
2	Fort St. John–Wonowon	37,048,168	50,790,298	37.1
3	Salmon Arm–Revelstoke	63,759,616	79,337,480	24.4
4	Prince Rupert–Terrace	11,100,672	13,332,370	20.1
5	Kamloops–Merritt	83,487,706	98,130,571	17.5

6	Kelowna–Merritt	59,351,219	69,360,512	16.9
7	Revelstoke–Golden	91,100,314	105,757,071	16.1
8	Vanderhoof–Fraser Lake	13,688,945	15,791,550	15.4
9	Dawson Creek–Ft. St. John	32,821,530	37,688,805	14.8
10	Alberta/BC Boundary–Highway 93 Junction	25,438,317	29,165,281	14.7
11	Dawson Creek–Alberta Border	14,994,638	17,085,650	13.9
12	Kitwanga–Terrace	13,124,955	14,910,024	13.6
13	Parksville–Campbell River	58,257,504	65,749,056	12.9
14	Kelowna–Penticton	96,637,050	107,563,456	11.3
15	Cranbrook–Highway 93 Junction	28,560,155	31,767,775	11.2
16	Squamish–Whisler	18,162,619	20,135,225	10.9
17	Vernon–Nakusp	12,169,407	13,476,559	10.7
18	Wonowon–Buckinghorse River	17,281,071	19,129,212	10.7
19	Kamloops–Cache Creek	24,657,101	27,224,602	10.4
20	Tete Jaune Cache–Kamloops	94,907,957	104,756,533	10.4
21	Kitwanga–New Hazelton	5,468,138	6,023,113	10.1
22	Fort Nelson–Liard River	50,580,514	55,501,079	9.7
23	Fraser Lake–Burns Lake	12,761,203	13,877,227	8.7
24	Tete Jaune Cache–Alta border	23,744,528	25,704,851	8.3
25	Meziadin Junction–Dease Lake	5,654,142	6,093,909	7.8
26	Dease Lake–Yukon Border	4,007,058	4,315,293	7.7
27	Castlegar–Trail	7,505,612	8,032,745	7.0
28	Vernon–Kelowna	112,141,622	119,382,682	6.5
29	Golden–Alberta Border	46,250,391	49,134,446	6.2
30	Terrace–Kitimat	12,120,628	12,826,684	5.8
31	Hope–Merritt	141,178,613	147,093,529	4.2
32	Ladysmith–Victoria	105,587,620	109,344,510	3.6
33	Chilliwack–Hope	81,958,998	84,329,454	2.9
34	Monte Creek–Salmon Arm	61,324,760	63,046,815	2.8
35	Monte Creek–Vernon	33,324,617	34,238,635	2.7
36	Vernon–Salmon Arm	30,078,555	30,864,327	2.6

37	Kamloops–Monte Creek	30,393,054	31,184,899	2.6
38	Port Hardy–Campbell River	15,280,506	15,598,056	2.1
39	Nanaimo–Ladysmith	19,226,886	19,393,983	0.9
40	Penticton–Osoyoos	19,048,138	19,107,925	0.3
41	Kitwanga–Meziadin Junction	6,940,417	6,954,936	0.2
42	Cranbrook–Fairmont Hot Springs	36,733,133	36,784,379	0.1
43	Vancouver–Squamish	21,382,926	21,382,926	0.0
44	Prince George–Vanderhoof	39,006,287	39,006,287	0.0
45	Burns Lake–Houston	17,894,344	17,894,344	0.0
46	Smithers–New Hazelton	11,235,021	11,235,021	0.0
47	Golden–Radium Hot Springs	41,845,491	41,845,491	0.0
48	Prince George–Quesnel	49,521,813	49,428,300	-0.2
49	Parksville–Campbell River	10,353,882	10,301,760	-0.5
50	Parksville–Nanaimo	103,021,922	102,181,677	-0.8
51	Buckinghorse River–1 km north of Prophet River	13,018,061	12,899,407	-0.9
52	Liard River–Lower Post	6,403,188	6,331,443	-1.1
53	Williams Lake–Alexis Creek	14,821,482	14,583,473	-1.6
54	Gibsons–Sechelt	4,683,096	4,600,708	-1.8
55	Ucluelet Junction–Tofino	7,516,080	7,352,093	-2.2
56	Vancouver–Chilliwack	236,931,720	229,529,155	-3.1
57	Quesnel–Williams Lake	49,647,942	48,079,939	-3.2
58	Cranbrook–Creston	33,899,229	32,622,240	-3.8
59	Sechelt–ferry	5,859,783	5,611,437	-4.2
60	Nelson–Kaslo	19,424,132	18,560,542	-4.4
61	Ucluelet Junction–Ucluelet	1,718,070	1,639,113	-4.6
62	Whistler–Cache Creek/Pemberton	19,959,569	19,016,044	-4.7
63	Cache Creek–Williams Lake	99,898,514	95,164,348	-4.7
64	Kelowna–Rock Creek	22,102,210	21,036,103	-4.8
65	Nakusp–Castlegar	8,316,437	7,798,459	-6.2
66	Tete Jaune Cache–	33,146,614	30,992,238	-6.5

	Prince George			
67	Creston–Castlegar	19,648,724	18,204,930	-7.3
68	Castlegar–Christina Lake	14,576,640	13,501,898	-7.4
69	Hope–Agassiz	10,059,261	9,248,994	-8.1
70	Ucluelet Junction–Parksville	26,382,200	24,073,758	-8.8
71	Rock Creek–Castlegar	28,593,560	25,997,096	-9.1
72	Radium Hot Springs–Fairmont Hot Springs	21,998,295	19,838,845	-9.8
73	Saltery Bay ferry terminal–Powell River	1,273,266	1,135,296	-10.8
74	1 km north of Prophet River–Fort Nelson	16,290,315	14,518,386	-10.9
75	Meziadin Junction–Stewart	1,632,470	1,389,336	-14.9
76	Houston–Smithers	18,894,970	15,645,594	-17.2
77	Hope–Cache Creek	94,421,996	75,989,350	-19.5
78	Hope–Penticton	74,030,760	57,450,708	-22.4
79	Alexis Creek–Anahim Lake	5,784,929	3,098,295	-46.4
Average				2.4

Table A2.15: Trucking emissions per kilometre of road for 2007 and 2013

Rank	Route	2007 emissions per km of road (tonnes CO_2/km)	2013 emissions per km of road (tonnes CO_2/km)
1	Parksville–Nanaimo	4,861	4,821
2	Vancouver–Chilliwack	4,248	4,115
3	Vernon–Kelowna	3,723	3,964
4	Kelowna–Penticton	2,707	3,013
5	Chilliwack–Hope	2,672	2,749
6	Nanaimo–Ladysmith	2,298	2,318
7	Ladysmith–Victoria	2,127	2,203
8	Hope–Merritt	2,058	2,144
9	Kamloops–Merritt	1,946	2,022
10	Kamloops–Monte Creek	1,721	1,997
11	Salmon Arm–Revelstoke	1,278	1,381
12	Monte Creek–Salmon Arm	1,136	1,314
13	Revelstoke–Golden	1,110	1,273
14	Golden–Alberta Border	1,096	1,207
15	Fort St. John–Wonowon	1,066	1,023
16	Parksville–Campbell River	899	982
17	Kelowna–Merritt	886	972

18	Radium Hot Springs–Fairmont Hot Springs	878	961
19	Vernon–Salmon Arm	870	922
20	Dawson Creek–Ft. St. John	831	901
21	Cranbrook–Highway 93 Junction	788	876
22	Cache Creek–Williams Lake	785	836
23	Dawson Creek–Alberta Border	748	766
24	Golden–Radium Hot Springs	746	728
25	Prince George–Quesnel	728	726
26	Quesnel–Williams Lake	728	724
27	Hope–Cache Creek	706	713
28	Prince George–Vanderhoof	672	706
29	Monte Creek–Vernon	636	653
30	Alberta/BC Boundary–Highway 93 Junction	610	646
31	Tete Jaune Cache–Alta border	579	614
32	Squamish–Whisler	568	612
33	Cranbrook–Fairmont Hot Springs	564	611
34	Kamloops–Cache Creek	563	588
35	Vancouver–Squamish	552	564
36	Cranbrook–Creston	547	557
37	Tete Jaune Cache–Kamloops	542	552
38	Penticton–Osoyoos	533	544
39	Hope–Agassiz	529	503
40	Castlegar–Trail	500	497
41	Vanderhoof–Fraser Lake	498	488
42	Nelson–Kaslo	492	475
43	Houston–Smithers	464	438
44	Ucluelet Junction–Tofino	423	412
45	Burns Lake–Houston	421	401
46	Hope–Penticton	401	381
47	Gibsons–Sechelt	385	375
48	Terrace–Kitimat	382	371
49	Ucluelet Junction–Ucluelet	351	367
50	Fraser Lake–Burns Lake	340	355
51	Dawson Creek–Prince George	335	355
52	Fort Nelson–Liard River	327	326
53	Ucluelet Junction–Parksville	325	311
54	Castlegar–Christina Lake	300	310
55	Smithers–New Hazelton	297	296
56	Wonowon–Buckinghorse River	296	296
57	1 km north of Prophet River–Fort Nelson	289	289
58	Kelowna–Rock Creek	286	275
59	Whistler–Cache Creek/Pemberton	284	273
60	Rock Creek–Castlegar	271	273

61	Kitwanga–Terrace	267	270
62	Buckinghorse River–1 km north of Prophet River	249	269
63	Creston–Castlegar	238	263
64	Kitwanga–New Hazelton	233	251
65	Williams Lake–Alexis Creek	228	229
66	Tete Jaune Cache–Prince George	218	204
67	Sechelt–ferry	195	186
68	Prince Rupert–Terrace	155	166
69	Parksville–Campbell River	138	154
70	Vernon–Nakusp	118	125
71	Port Hardy–Campbell River	112	121
72	Nakusp–Castlegar	102	96
73	Kitwanga–Meziadin Junction	81	82
74	Saltery Bay ferry terminal–Powell River	76	68
75	Liard River–Lower Post	61	60
76	Meziadin Junction–Stewart	49	41
77	Dease Lake–Yukon Border	48	33
78	Meziadin Junction–Dease Lake	31	33
79	Alexis Creek–Anahim Lake	31	26

Table A2.16: Trucking interurban CO_2 emissions by route in BC

Rank	2007 emissions (tonnes CO_2)	Route	2013 emissions (tonnes CO_2)	Route
1	424,796	Vancouver–Chilliwack	411,523	Vancouver–Chilliwack
2	253,120	Hope–Merritt	263,724	Hope–Merritt
3	201,059	Vernon–Kelowna	214,042	Vernon–Kelowna
4	189,308	Ladysmith–Victoria	196,044	Ladysmith–Victoria
5	184,708	Parksville–Nanaimo	192,851	Kelowna–Penticton
6	179,108	Cache Creek–Williams Lake	189,612	Revelstoke–Golden
7	173,261	Kelowna–Penticton	187,818	Tete Jaune Cache–Kamloops
8	170,161	Tete Jaune Cache–Kamloops	183,202	Parksville–Nanaimo
9	169,289	Hope–Cache Creek	175,939	Kamloops–Merritt
10	163,334	Revelstoke–Golden	170,620	Cache Creek–Williams Lake
11	149,685	Kamloops–Merritt	151,195	Chilliwack–Hope
12	146,945	Chilliwack–Hope	143,875	Dawson Creek–Prince George

13	132,730	Hope–Penticton	142,244	Salmon Arm–Revelstoke
14	114,315	Salmon Arm–Revelstoke	136,242	Hope–Cache Creek
15	109,949	Monte Creek–Salmon Arm	124,357	Kelowna–Merritt
16	106,411	Kelowna–Merritt	117,882	Parksville–Campbell River
17	104,450	Parksville–Campbell River	113,037	Monte Creek–Salmon Arm
18	100,740	Dawson Creek–Prince George	103,004	Hope–Penticton
19	90,686	Fort Nelson–Liard River	99,508	Fort Nelson–Liard River
20	89,014	Quesnel–Williams Lake	91,062	Fort St. John–Wonowon
21	88,788	Prince George–Quesnel	88,620	Prince George–Quesnel
22	82,922	Golden–Alberta Border	88,093	Golden–Alberta Border
23	75,025	Golden–Radium Hot Springs	86,203	Quesnel–Williams Lake
24	69,934	Prince George–Vanderhoof	75,025	Golden–Radium Hot Springs
25	66,424	Fort St. John–Wonowon	69,934	Prince George–Vanderhoof
26	65,859	Cranbrook–Fairmont Hot Springs	67,572	Dawson Creek–Ft. St. John
27	60,778	Cranbrook–Creston	65,951	Cranbrook–Fairmont Hot Springs
28	59,748	Monte Creek–Vernon	61,387	Monte Creek–Vernon
29	59,429	Tete Jaune Cache–Prince George	58,489	Cranbrook–Creston
30	58,846	Dawson Creek–Ft. St. John	56,957	Cranbrook–Highway 93 Junction
31	54,492	Kamloops–Monte Creek	55,911	Kamloops–Monte Creek
32	53,928	Vernon–Salmon Arm	55,566	Tete Jaune Cache–Prince George
33	51,265	Rock Creek–Castlegar	55,337	Vernon–Salmon Arm
34	51,206	Cranbrook–Highway 93 Junction	52,291	Alberta/BC Boundary–Highway 93 Junction
35	47,301	Ucluelet Junction–Parksville	48,811	Kamloops–Cache Creek
36	45,608	Alberta/BC Boundary–Highway 93 Junction	46,610	Rock Creek–Castlegar

37	44,208	Kamloops–Cache Creek	46,086	Tete Jaune Cache–Alta border
38	42,572	Tete Jaune Cache–Alta border	43,162	Ucluelet Junction–Parksville
39	39,627	Kelowna–Rock Creek	38,338	Vancouver–Squamish
40	39,441	Radium Hot Springs–Fairmont Hot Springs	37,716	Kelowna–Rock Creek
41	38,338	Vancouver–Squamish	36,101	Squamish–Whisler
42	35,786	Whistler–Cache Creek/Pemberton	35,569	Radium Hot Springs–Fairmont Hot Springs
43	35,228	Creston–Castlegar	34,772	Nanaimo–Ladysmith
44	34,826	Nelson–Kaslo	34,297	Wonowon–Buckinghorse River
45	34,472	Nanaimo–Ladysmith	34,259	Penticton–Osoyoos
46	34,151	Penticton–Osoyoos	34,094	Whistler–Cache Creek/Pemberton
47	33,877	Houston–Smithers	33,277	Nelson–Kaslo
48	32,564	Squamish–Whisler	32,640	Creston–Castlegar
49	32,083	Burns Lake–Houston	32,083	Burns Lake–Houston
50	30,983	Wonowon–Buckinghorse River	30,633	Dawson Creek–Alberta Border
51	29,207	1 km north of Prophet River–Fort Nelson	28,313	Vanderhoof–Fraser Lake
52	27,396	Port Hardy–Campbell River	28,051	Houston–Smithers
53	26,884	Dawson Creek–Alberta Border	27,966	Port Hardy–Campbell River
54	26,573	Williams Lake–Alexis Creek	26,732	Kitwanga–Terrace
55	26,135	Castlegar–Christina Lake	26,147	Williams Lake–Alexis Creek
56	24,543	Vanderhoof–Fraser Lake	26,030	1 km north of Prophet River–Fort Nelson
57	23,532	Kitwanga–Terrace	24,881	Fraser Lake–Burns Lake
58	23,340	Buckinghorse River–1 km north of Prophet River	24,208	Castlegar–Christina Lake
59	22,880	Fraser Lake–Burns Lake	24,162	Vernon–Nakusp
60	21,819	Vernon–Nakusp	23,904	Prince Rupert–Terrace
61	21,731	Terrace–Kitimat	23,127	Buckinghorse River–1 km north of Prophet River
62	20,143	Smithers–New Hazelton	22,997	Terrace–Kitimat

63	19,902	Prince Rupert–Terrace	20,143	Smithers–New Hazelton
64	18,564	Parksville–Campbell River	18,470	Parksville–Campbell River
65	18,035	Hope–Agassiz	16,583	Hope–Agassiz
66	14,911	Nakusp–Castlegar	14,402	Castlegar–Trail
67	13,476	Ucluelet Junction–Tofino	13,982	Nakusp–Castlegar
68	13,457	Castlegar–Trail	13,182	Ucluelet Junction–Tofino
69	12,443	Kitwanga–Meziadin Junction	12,470	Kitwanga–Meziadin Junction
70	11,480	Liard River–Lower Post	11,352	Liard River–Lower Post
71	10,506	Sechelt–ferry	10,926	Meziadin Junction–Dease Lake
72	10,372	Alexis Creek–Anahim Lake	10,799	Kitwanga–New Hazelton
73	10,137	Meziadin Junction–Dease Lake	10,061	Sechelt–ferry
74	9,804	Kitwanga–New Hazelton	8,249	Gibsons–Sechelt
75	8,396	Gibsons–Sechelt	7,737	Dease Lake–Yukon Border
76	7,184	Dease Lake–Yukon Border	5,555	Alexis Creek–Anahim Lake
77	3,080	Ucluelet Junction–Ucluelet	2,939	Ucluelet Junction–Ucluelet
78	2,927	Meziadin Junction–Stewart	2,491	Meziadin Junction–Stewart
79	2,283	Saltery Bay ferry terminal–Powell River	2,035	Saltery Bay ferry terminal–Powell River
Total	5,233,917		5,431,451	

APPENDIX 3: SMITE future scenarios

Table A3.1: SMITE future scenarios

Legend:

Scen	= Scenario number
%2020	= Discrepancy to 2020 target (%)
% 2050	= Discrepancy to 2050 target (%)
Cost to offset ($bn)	= Estimated offset cost (positive values) or excess credit value (negative values) (billions of dollars)
PA	= Changes to passenger aviation
PB	= Changes to passenger bus
PC	= Changes to passenger cars
PF	= Changes to passenger ferries
PT	= Changes to passenger trains
AF	= Changes to aviation freight
MF	= Changes to marine freight
TF	= Changes to train freight
FT	= Changes to freight trucks
BAU	= Business-as-usual (no changes made to current emission trends of mode)

Scen	% 2020	% 2050	Cost to offset ($bn)	PA	PB	PC	PF	PT	AF	MF	TF	FT
1	35.8	236.5	14.36	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa
2	25.9	130.1	8.99	-2% pa	-2% pa	-2% pa	-2% pa	-2% pa	-2% pa	-2% pa	-2% pa	-2% pa
3	17.1	57.3	4.78	-3% pa	-3% pa	-3% pa	-3% pa	-3% pa	-3% pa	-3% pa	-3% pa	-3% pa
4	8.7	7.0	1.44	-4% pa	-4% pa	-4% pa	-4% pa	-4% pa	-4% pa	-4% pa	-4% pa	-4% pa
5	0.9	-27.4	-1.23	-5% pa	-5% pa	-5% pa	-5% pa	-5% pa	-5% pa	-5% pa	-5% pa	-5% pa

6	-2.3	-2.3	-0.07	+0.54% pa to 2020 to reach target, then -3.82995 pa	-8.58% to 2020, then - 3.95	-6.33% pa to 2020, then -3.95	-4.35% pa to 2020, then -3.95	-5.56% pa to 2020, then -3.95	-6.46% pa to 2020, then -3.95	-3.10% pa to 2020, then -3.95	-5.45% pa from 2013 to 2020, then -3.95	-6% pa
7	35.4	177.1	11.40	-1% pa reduction until 2030, then 5% pa reduction, e.g. because of revolution ary technology	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction to 2030, e.g. because of efficiency, then all cars electric with 0 emissions	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction through to 2050, e.g. because of efficiency gains	-1% pa reduction through to 2050, e.g. because of efficiency gains
8	28.9	103.6	7.70	-1% pa reduction to 2025 e.g. efficiency, then 5% pa reduction revolution ary tech	-1% pa reduction to 2030 e.g. efficiency, then all buses electric/hy drogen, 0 emissions	-1% pa reduction to 2030 e.g. efficiency, then all cars electric/hy drogen, 0 emissions	-2% pa reduction, e.g. because of efficiency, route consolidati on etc.	-1% pa reduction, e.g. because of efficiency	-1% pa reduction, e.g. because of efficiency	-2% pa reduction, e.g. because of efficiency, consolidati on	-1% pa reduction, e.g. because of efficiency	-2% pa reduction, e.g. because of efficiency and modal shift to rail
9	35.4	81.7	9.16	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050	1% pa reduction to 2020, 2% pa to 2030, 3% pa to 2040, 4% pa to 2050

10	25.9	130.0	8.98	2% pa reduction	2% pa reduction	-4.396% pa up to 2026 and continued (efficiency projection from GHGenius software Vehicular emissions section)	0	2% pa reduction	2% pa reduction	2% pa reduction	2% pa reduction	2% pa reduction
11	24.6	65.6	5.58	-2% pa e.g. efficiency until 2030, then revolution ary tech to halve emissions, then steady because increase from ferry and usage	-1% pa e.g. efficiency	-2% pa efficiency until 2030, then revolution ary tech to halve emissions, then steady	-2% pa efficiency until 2030, then 4% because of efficiency and people switching to lower emissions plane	-1% pa e.g. efficiency	-2% pa e.g. efficiency until 2040, then revolution ary tech to halve emissions, then steady	-2% pa e.g. efficiency	-1% pa e.g. efficiency but increase from truck switch	-3% pa e.g. between efficiency and modal shift to train
12	14.8	31.5	1.82	-2% pa to 2025, e.g. because of efficiency, then revolution ary tech halves emissions, then 2% pa	-2% pa e.g. efficiency	-2% pa e.g. efficiency to 2025, then 0 emission cars	-3% pa, e.g. because of efficiency and consolidati on	Steady e.g. efficiency gains but higher usage	-2% pa to 2035, e.g. because of efficiency, then revolution ary tech halves emissions, then 2% pa	-3% pa, e.g. because of efficiency and consolidati on	Steady e.g. efficiency but higher usage from truck modal shift	-5% pa e.g. from modal shift to train

				efficiency					efficiency			
13	45.5	387.3	21.08	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.	No changes e.g. emissions steady between increased usage but higher efficiency.
14	56.1	605.0	29.74	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents	+1% pa e.g. because of higher usage despite efficiency improvem ents
15	67.5	916.5	40.85	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents	+2% pa e.g. because of higher usage despite efficiency improvem ents

16	79.6	1360.2	55.17	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements	+3% pa e.g. because of higher usage despite efficiency improvements
17	92.4	1990.5	73.70	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements	+4% pa e.g. because of higher usage despite efficiency improvements
18	106.0	2882.4	97.73	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements	+5% pa e.g. because of higher usage despite efficiency improvements

19	24.6	67.7	5.64	10% e.g. immediate reduction from efficiency and consolidation. Then 1% pa to 2030, then revolutionary tech halves emissions, then 1% pa e.g. efficiency.	-1% pa to 2030, then 0 emission buses	-1% pa to 2030, then 0 emission cars	-2% pa, e.g. because of efficiency and consolidation	Steady e.g. because of higher usage	-1% pa e.g. efficiency through to 2030, then 50% cut from revolutionary tech and modal shift, then 1% pa efficiency	-2% pa, e.g. because of efficiency and consolidation	-1% pa e.g. efficiency despite increased usage	-3% pa e.g. efficiency, e.g. because of efficiency and modal shift
20	24.6	24.6	5.53	-1% pa e.g. efficiency through to 2030, then 0 emission planes	-1% pa e.g. efficiency through to 2030, then 0 emission buses	-1% pa e.g. efficiency through to 2030, then 0 emission cars	-2% pa e.g. efficiency and consolidation	-1% pa e.g. efficiency	-1% pa e.g. efficiency through to 2030, then 0 emission planes	-2% pa e.g. efficiency and consolidation	-1% pa e.g. efficiency despite higher usage	-3% pa e.g. efficiency and modal shift
21	45.5	298.5	18.91	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency	No changes to 2030, then -1% pa e.g. efficiency
22	45.5	225.3	16.99	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency	No changes to 2030, then -2% pa. e.g. efficiency

23	45.5	165.0	15.30	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency	No changes to 2030, then -3% pa. e.g. efficiency
24	45.5	115.4	13.80	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% pa. e.g. efficiency	No changes to 2030, then -4% efficiency
25	45.5	74.7	12.48	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency	No changes to 2030, then -5% pa. e.g. efficiency
26	0.9	-0.8	-0.55	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.	-5% pa. e.g. to 2030 efficiency, then -4% pa to 2040, then -3% pa to 2050. Slowdown because of population growth and higher usage.

27	8.7	45.9	2.37	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa. to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.	-4% pa. e.g. to 2030 efficiency, then -3% pa to 2040, then -2% pa to 2050. Slowdown because of population growth and higher usage.
28	17.1	113.7	6.06	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa. to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.	-3% pa. e.g. to 2030 efficiency, then -2% pa to 2040, then -1% pa to 2050. Slowdown because of population growth and higher usage.
29	35.4	-100.0	-2.41	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all	-1% pa. e.g. efficiency through to 2030, then because of revolution ary tech all

				modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions	modes 0 emissions
30	45.5	260.4	16.42	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency	No changes to 2020, then -1% pa. e.g. efficiency
31	45.5	165.8	12.57	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency	No changes to 2020, then -2% pa. e.g. efficiency
32	45.5	95.4	9.37	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency	No changes to 2020, then -3% pa. e.g. efficiency
33	45.5	43.2	6.70	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency	No changes to 2020, then -4% pa. e.g. efficiency
34	45.5	4.6	4.47	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency	No changes to 2020, then -5% pa. e.g. efficiency

35	45.5	340.7	20.49	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency	No changes to 2040, then -1% pa. e.g. efficiency
36	45.5	298.1	19.94	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency	No changes to 2040, then -2% pa. e.g. efficiency
37	45.5	259.3	19.42	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency	No changes to 2040, then -3% pa. e.g. efficiency
38	45.5	223.9	18.93	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency	No changes to 2040, then -4% pa. e.g. efficiency
39	45.5	191.7	18.46	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency	No changes to 2040, then -5% pa. e.g. efficiency
40	55.9	372.0	24.18	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.	1% pa. e.g. growth because of higher usage to 2030, then -1% pa. e.g.

				efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency
41	42.3	280.0	17.55	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 1% pa
42	42.3	211.3	15.78	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 2% pa
43	42.3	154.7	14.23	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 3% pa
44	42.3	108.0	12.85	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 4% pa

45	42.3	69.4	11.63	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2030, then mandated - 5% pa
46	42.3	265.5	16.70	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 1% pa
47	42.3	184.8	14.07	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 2% pa
48	42.3	121.4	11.81	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 3% pa
49	42.3	71.7	9.87	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 4% pa

50	42.3	32.8	8.19	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa	Each mode follows 2007-2013 trend to 2025, then mandated - 5% pa
51	42.3	252.7	15.77	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 1% pa
52	42.3	161.1	12.09	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 2% pa
53	42.3	92.9	9.05	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 3% pa
54	42.3	41.1	6.39	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa	Each mode follows 2007-2013 trend to 2020, then mandated - 4% pa

55	42.3	4.3	4.38	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa	Each mode follows 2007-2013 trend to 2020, then mandated -5% pa
56	24.7	68.2	5.85	-2% pa. e.g. efficiency	-1% pa. e.g. efficiency	-2% pa. e.g. efficiency	-1% pa. e.g. efficiency	-1% pa. e.g. efficiency to 2030, then 0 emissions because of electric trains	-2% pa. e.g. efficiency	-2% pa. e.g. efficiency	Steady to 2030 because of modal shift from truck, then 0 emissions because of electric trains	-3% pa. e.g. efficiency and modal shift to train
57	30.9	47.3	7.34	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050	Mandated 10% over 2007 reduction by 2020, 20% over 2020 by 2030, 30% over 2030 by 2040, 40% over 2040 by 2050

58	4.7	-26.3	0.51	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.	Mandated 10% over 2007 reduction by 2015, 20% over 2015 by 2020, 30% over 2020 by 2030, 40% over 2030 by 2040, 50% over 2040 by 2050.
59	21.5	103.9	7.23	-2% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	30% lower by 2025 modal shift, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency and consolidation	Steady e.g. because of efficiency despite higher near-urban use	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-1% pa. e.g. because of despite higher usage	-3% pa. e.g. because of efficiency and modal shift to train
60	21.5	103.7	7.22	-2% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	30% lower by 2025 modal shift, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency and consolidation	Steady to 2030 e.g. because of efficiency despite higher near-urban use, then 0 emissions because of electric trains	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-1% pa. e.g. because of despite higher usage to 2030, then 0 emissions because of electric trains	-3% pa. e.g. because of efficiency and modal shift to train

61	35.4	69.4	6.04	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -1% pa. e.g. because of efficiency
62	25.9	17.4	2.77	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -2% pa. e.g. because of efficiency
63	17.1	-18.9	0.11	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,	-3% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech,

				then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency	then -3% pa. e.g. because of efficiency
64	8.7	-44.3	-2.07	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -4% pa. e.g. because of efficiency
65	0.9	-61.8	-3.88	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then halved because of revolution ary tech, then -5% pa. e.g. because of efficiency

66	35.4	218.4	12.96	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to diesels, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency
67	28.5	10.0	2.75	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to diesels, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-1% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -1% pa. e.g. because of efficiency
68	25.9	4.5	0.14	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric	-2% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal

						diesels, then -2% pa. e.g. because of efficiency		trains			trains	shift to trains, then -2% pa. e.g. because of efficiency
69	17.1	-28.1	-2.09	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to diesels, then -3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-3% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -3% pa. e.g. because of efficiency
70	8.7	-50.7	-3.92	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to diesels, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-4% pa. e.g. because of efficiency	-:% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-4% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -4% pa. e.g. because of efficiency

71	0.9	-66.3	-5.42	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2020, then 30% reduction because of switch to diesels, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-5% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -5% pa. e.g. because of efficiency
72	35.4	81.4	4.64	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2020, then 50% reduction because of switch to diesels and modal shift, then -1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency	-1% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-1% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -1% pa. e.g. because of efficiency

73	25.9	-3.6	-0.62	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2020, then 50% reduction because of switch to diesels and modal shift, then -2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency	-2% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-2% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -2% pa. e.g. because of efficiency
74	17.1	-33.7	-2.71	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2020, then 50% reduction because of switch to diesels and modal shift, then -3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency	-3% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-3% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -3% pa. e.g. because of efficiency

75	8.7	-54.6	-4.43	-4% pa. e.g. because of efficiency	-:% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2020, then 50% reduction because of switch to diesels and modal shift, then -4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency	-4% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-4% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -4% pa. e.g. because of efficiency
76	0.9	-69.0	-5.84	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2020, then 50% reduction because of switch to diesels and modal shift, then -5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency	-5% pa. e.g. because of efficiency to 2030, then 0 emissions because of electric trains	-5% pa. e.g. because of efficiency to 2025, then 75% reduction because of modal shift to trains, then -5% pa. e.g. because of efficiency
77	67.5	356.7	27.71	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to	2% pa. e.g. because of growth because of higher usage to

				2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency	2030, then -2% pa. e.g. because of efficiency
78	79.6	339.7	31.54	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2030, then -3% pa. e.g. because of efficiency
79	92.4	321.7	35.78	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2030, then -4% pa. e.g. because of efficiency
80	106.0	303.0	40.47	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of	5% pa. e.g. because of growth because of higher usage to 2030, then -5% pa. e.g. because of

				efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency
81	56.1	286.9	18.66	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency	1% pa. e.g. because of growth because of higher usage to 2020, then -1% pa. e.g. because of efficiency
82	67.5	206.1	16.61	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2020, then -2% pa. e.g. because of efficiency
83	79.6	141.2	14.86	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of	3% pa. e.g. because of growth because of higher usage to 2020, then -3% pa. e.g. because of

				efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency
84	92.4	89.4	13.39	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency	4% pa. e.g. because of growth because of higher usage to 2020, then -4% pa. e.g. because of efficiency
85	106.0	48.1	12.17	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2020, then -5% pa. e.g. because of efficiency
86	56.1	327.6	21.62	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of	1% pa. e.g. because of growth because of higher usage to 2025, then -1% pa. e.g. because of

				efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency
87	67.5	303.6	23.32	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency	2% pa. e.g. because of growth because of higher usage to 2025, then -2% pa. e.g. because of efficiency
88	79.6	225.7	23.13	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency	3% pa. e.g. because of growth because of higher usage to 2025, then -3% pa. e.g. because of efficiency
89	92.4	182.6	24.12	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of	4% pa. e.g. because of growth because of higher usage to 2025, then -4% pa. e.g. because of

				efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency	efficiency
90	106.0	144.3	25.28	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 202(, then -5% pa. e.g. because of efficiency	5% pa. e.g. because of growth because of higher usage to 2025, then -5% pa. e.g. because of efficiency
91	42.3	352.2	19.27	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)	All modes follow BAU (growth/shrink rate 2007-2013)
92	32.4	211.1	12.87	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa	All modes follow BAU (growth/shrink rate 2007-2013) -1% pa

93	23.2	113.2	7.83	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa	All modes follow BAU (growth/shrink rate 2007-2013) -2% pa
94	14.4	45.6	3.85	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa	All modes follow BAU (growth/shrink rate 2007-2013) -3% pa
95	6.3	-1.0	0.69	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa	All modes follow BAU (growth/shrink rate 2007-2013) -4% pa
96	-1.4	-33.0	-1.85	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa	All modes follow BAU (growth/shrink rate 2007-2013) -5% pa
97	52.8	554.9	27.44	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-	All modes follow BAU (growth/shrink rate 2007-

				2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa	2013) +1% pa
98	64.0	845.0	37.94	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa	All modes follow BAU (growth/shrink rate 2007-2013) +2% pa
99	75.9	1258.8	51.46	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa	All modes follow BAU (growth/shrink rate 2007-2013) +3% pa
100	88.5	1847.0	68.95	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa	All modes follow BAU (growth/shrink rate 2007-2013) +4% pa

101	28.2	217.7	12.96	-1% pa	-1% pa	By 2020, all cars improved to efficiency of Prius (53% improvement from current average EF), then -1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa
102	28.2	204.0	12.24	-1% pa	-1% pa	'By 2020, all cars improved to efficiency of Prius (53% improvement from current average EF), then -1% until 2030, then 50% reduction more technology, then -1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa

103	40.6	208.2	12.79	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa. e.g. despite higher volume from modal shift because of efficiency and electrification	-1% pa until 2025, then 25% e.g. modal shift to train
104	40.6	166.4	9.99	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa e.g. despite higher volume from modal shift because of efficiency and electrification	-1% pa until 2025, then 50% e.g. modal shift to train
105	40.6	124.6	7.19	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa	-1% pa e.g. despite higher volume from modal shift because of efficiency and electrificat	-1% pa until 2025, then 75% e.g. modal shift to train

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106	17.1	15.1	3.71	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.	-3% pa to 2030, -4% 2030 to 2040, -5% 2040 to 2050.