A SKY-HIGH CHALLENGE: THE CARBON FOOTPRINT OF AVIATION IN BRITISH COLUMBIA, CANADA, AND MEASURES TO MITIGATE IT

by

Moritz Alexander Schare

B.A., University of Northern British Columbia, 2008

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS
IN
INTERNATIONAL STUDIES

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

September 2011

ABSTRACT

Greenhouse gas (GHG) emissions from civil aviation contribute to anthropogenic climate change and are expected to increase significantly in the future. GHG emission inventories exist for civil aviation at the global scale but not subnational scale. In this thesis, I present what seems to be the first detailed analysis of the carbon footprint (CF) of civil aviation at a subnational level together with an assessment of what key stakeholders are doing to mitigate their CF. I calculated the CF of civil aviation in British Columbia (BC), Canada, determined what efforts airlines and airports in BC are doing to mitigate it, and make recommendations on how to further decrease future GHG emissions. The annual CF of civil aviation in BC is approximately 525,000 tonnes of CO_2e. Passenger flights account for 198,000 tonnes (38%), airport operations for 148,000 tonnes (28%), and passenger travel to and from airports for 179,000 tonnes (34%). Large airlines and airports, as well as small airlines in southern BC, are generally proactive in reducing their CF, while small airlines in northern BC and small airports are generally not. To further reduce the CF of civil aviation in BC, I recommend a major effort to reduce emissions from passenger travel to/from airports, improved stakeholder cooperation including better technology dissemination, enhanced passenger and employee education and awareness programs, higher quality and more transparent offset programs, and incentives by the provincial government for airlines and airports to reduce their CF while remaining economically competitive.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ACRONYMS

APU	auxiliary power unit
BC	British Columbia
CAEP	Committee on Aviation Environmental Protection
CF	carbon footprint
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CT	carbon tax
DEFRA	United Kingdom Department for Environment, Food, and Rural Affairs
GHG	greenhouse gas
GPS	Global Positioning System
H_2O	water (or water vapour)
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
Mt	megatonnes = 10^6 tonnes
NGO	nongovernmental organization
NO_x	nitrogen oxide
tonnes	1000 kilograms (kg)
UNBC	University of Northern British Columbia
WRI	World Resources Institute

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisor, Dr. Ken Wilkening. Without his tireless support and editing, this thesis would not have been possible. I would also like to acknowledge my committee members, Dr. Arthur Freeden and Dr. Balbinder Deo, as well as the external examiner, Dr. Steve Helle. Thank you all.

I would also like to acknowledge the generous funding provided by the Pacific Institute for Climate Solutions (PICS), the Social Sciences and Humanities Research Council of Canada (SSHRC), and the University of Northern British Columbia (UNBC), all of which helped me greatly in pursuing my studies and completing this thesis.

Last but not least, I would like to thank all the interviewees who agreed to take part in my research. I would like to especially thank Jennifer Alderson of the Vancouver International Airport for her extensive assistance with data related to “YVR”.

CHAPTER 1: INTRODUCTION

1.1 Overview

Aviation is an integral part of modern life, especially for business and leisure travel in developed countries. This was vividly demonstrated during the eruption of the Icelandic volcano Eyjafjallajokull in April 2010, when grounded planes resulted in hundreds of cancelled business meetings and thousands of stranded travellers. While aviation is an essential element of modern life, it is also an important contributor to one of the most critical modern environmental problems, anthropogenic climate change. The impact of human activities on climate is often measured using the concept of a carbon footprint (CF).[1] In general, the greater the CF, the greater the impact on climate.

In 1900, at the dawn of the age of aviation, global emissions of CO_2 from fossil fuels were approximately 2.27 billion tonnes (World Resources Institute, "Global Emissions of CO2 from Fossil Fuels", n.d.). Emissions due to aviation were miniscule in the early days of aviation following the first flight of the Wright Brothers in 1903. Between 1900 and 2004 CO_2 emissions from fossil fuels grew from 2.27 billion tonnes to 24.5 billion tonnes (World Resources Institute, "Global Emissions of CO2 from Fossil Fuels", n.d.), and emissions from aviation also grew accordingly as air travel spread around the world. Transportation in general now accounts for about 20% of worldwide greenhouse gas (GHG) emissions (Nijkamp 2003, 2), and in 2010, civil aviation globally comprised about 2% of this total, with 62% of aviation-related emissions resulting from international flights and 38% from domestic flights (ICAO 2010b, 31). Furthermore, aviation is projected to be one of the

[1] The term "carbon footprint", as used in this thesis, is the amount of carbon dioxide, or the equivalent amount of carbon dioxide for non-carbon dioxide greenhouse gases, released into the atmosphere by a given activity over a given period of time.

fastest-growing sources of carbon emissions in the transportation sector, with some estimates claiming it could account for up to 15% of global emissions by 2050 (IPCC Working Groups I and III 1999), potentially a dramatic 7.5 fold increase in only 40 years.

Numerous activities in the aviation industry contribute to GHG emissions. All have to be considered in a complete assessment of aviation's contribution to climate change. Apart from the emissions generated by airplanes, significant emissions also are contributed by the vast supporting infrastructure that is required for aviation, such as airport operations (e.g., airport vehicles, generators, and high-powered runway lighting), auxiliary airport services (e.g., catering companies and laundry services), and passenger travel to and from airports. Mitigation of GHG emissions by the aviation industry thus requires a multi-layered approach.

There are numerous efforts by the industry to reduce its CF. For example, many airlines offer passengers the opportunity to offset their CF,[2] or offer advice on how passengers can prevent emissions in the first place (e.g., to lighten their luggage). Also, in cooperation with airport authorities, some airlines have begun to reduce superfluous emissions generated by inefficient ground practices; for example, virtual departure queues have been instituted to reduce the time planes spend idling on taxiways. Moreover, some airports are experimenting with new operational procedures such as advanced navigation techniques using GPS.

Despite the impact of the aviation industry on anthropogenic climate change and despite the efforts the industry is making to reduce its emissions, there is surprisingly little

---

[2] Offset programs allow consumers to purchase credits that "offset" the emissions generated by a specific activity, such as a flight. The CF of the activity is calculated and CO_2 credits are purchased from projects that result in a net savings of CO_2 emissions, thus nullifying the carbon impact of the activity.

published social scientific research on the CF of the aviation industry and on what the industry has done, is doing, and could do to mitigate its GHG emissions. The purpose of my research is to add to this modest body of knowledge. I do not tackle the global aviation industry as a whole; rather I focus on one corner of the world, British Columbia (BC), and examine the relationship between air traffic and its GHG emissions in this province of Canada.

In Canada, total CO_2 emissions have increased from 435.1 Mt CO_2e[3] in 1980 to 549.7 Mt CO_2e in 2006, an increase of 26.3% over roughly 25 years (World Resources Institute, "GHG Emissions by Sector", n.d.). The percentage for emissions from the transportation sector relative to total emissions in Canada has remained stable at around 28%, but the total quantity of emissions from transportation has increased 24.8% from 127.9 Mt CO_2e in 1980 to 159.6 Mt CO_2e in 2006 (World Resources Institute, "GHG Emissions by Sector", n.d.), or roughly 1% per year. For aviation, the increase is even more significant. GHG emissions from domestic Canadian aviation[4] increased by 43% from 5.22 Mt CO_2e in 1990 to 7.48 Mt CO_2e in 2008, or just over 2% per year (Environment Canada 2010).

Within Canada, BC has the highest percentage of emissions resulting from transportation at approximately 39% of total emissions (Natural Resources Canada 2003). The province, however, does not have the highest total GHG emissions of Canadian provinces; this dubious honour belongs to Alberta with an estimated 280 Mt CO_2e (Alberta Environment 2008, 8), followed by Ontario with an estimated 220 Mt CO_2e (Natural

---

[3] Mt CO_2e = megatonnes of CO_2 equivalent. The unit CO_2e is used to provide a common or equivalent unit of measure for the different warming effect of different GHGs. It represents the amount of CO_2 that would have the same relative warming effect as the basket of GHGs actually emitted (CO2 Australia Limited 2009).
[4] Domestic Canadian aviation refers to all flights within Canada, and excludes international flights including those to the United States.

Resources Canada 2006, 58).Total GHG emissions in BC grew 23.4% between 1990 and 2008, from 55.7 Mt CO_2e to 68.7 Mt CO_2e. During the same period, emissions from the transportation sector grew 38.9% and emissions from domestic BC aviation grew 41.0% from 1.07 Mt CO_2e in 1990 to 1.50 Mt CO_2e in 2008, based on data provided in the British Columbia Greenhouse Gas Inventory (British Columbia Ministry of Environment 2010). Thus, domestic BC aviation emissions grew at almost twice the rate as overall GHG emissions in BC.[5] This argues for the need to conduct research on GHG emissions in the aviation sector in BC.

In addition, BC has a set highly ambitious GHG reduction goals, which further strengthens the argument for detailed analysis of the CF of aviation in BC. To achieve its goals, the province, for instance, implemented a carbon tax in 2008 that encourages individuals and companies to reduce their consumption of fossil fuels (Ministry of Finance, "What is a carbon tax?", n.d.), and mandated public-sector organizations to be carbon-neutral through emission reductions or offsets by 2010 (Government of British Columbia, "Carbon-Neutral Government", n.d.). Despite the BC government's proactive approach to climate change, and despite the importance of the CF of aviation in BC, very little is known either quantitatively about BC's aviation CF or qualitatively about what the airline industry in BC is doing to reduce it. My research is designed to fill this gap in our knowledge.

The focus on BC is justified for two further reasons. First, BC has become a hotbed for research on GHG mitigation strategies. See, for example, the activities of the Pacific Institute for Climate Solutions (PICS) (http://www.pics.uvic.ca). Second, the limited

[5] The data provided by the BC Ministry of Environment includes all Canadian domestic flights which originate in BC, and provides an aggregate value for all branches of aviation, including commercial, military, charter, and agricultural. The calculations presented in this thesis are for commercial aviation only and include only flights that lie entirely within BC.

geographical scope of the research allows for intense and detailed collection of data. Such an effort at the national or global level would be daunting. The limited geographical scope allowed me to develop a template for the micro-analysis of the CF of aviation that may be applicable in other sub-national jurisdictions.

1.2 Research questions

The following questions guided my research:

(1) What is the CF of civil aviation in BC? It is relatively easy to calculate the total CF of civil aviation in BC; however, I sought to conduct a micro-level analysis. I calculated the CF of three elements of the "civil aviation system" in BC around the year 2010—passenger flights, airport operations, and passenger travel to and from airports.

(2) *What actions have BC-connected airlines and airports taken to mitigate their CF in BC and why have they taken these actions?* There is a complete lack of codified information on what airline companies or airports in BC have done or are doing to reduce their GHG emissions. I sought to find out what kinds of changes airline companies and airports have made and why they made them. In other words, I investigated aviation corporate behaviour change relative to GHG reductions.

(3) *What recommendations can be made to further reduce the CF of aviation in BC?* The answers to questions #1 and #2 positioned me to make general recommendations for how the aviation industry in BC can further reduce its GHG emissions.

1.3 Methods

The above questions are answered in the thesis in the order given above. The first step of my research, which answered the first question, was to quantitatively calculate the CF of civil aviation in BC (i.e., the CF of passenger air travel and passenger airports). For air travel, I gathered data for the year 2010 on routes, type of aircraft used on a flight and number of seats per flight, distance per flight, number of yearly flights per route, and yearly kilometres flown per route. Calculations were performed using three different publicly available CF calculator tools— the WRI CF calculation worksheet, the factors utilized in the GHG Protocol for the Business Travel Service Sector, and the calculator of the offset company, Offsetters. I used three calculators to enhance the credibility of my final results. For airports, I collected CF data from airports that have conducted GHG inventories, and estimated values for those that have not conducted an inventory. The outcome of this step was a detailed portrait of the CF of civil aviation in BC for the year 2010.

The second step of my research, which answered the second question, was to determine what airline companies and airports have done and are doing to reduce their GHG emissions. I gathered information on current emission reduction activities through a combination of document analysis and interviews with airline and airport representatives, scholars, offset agents, and representatives of government environmental agencies. Besides identifying what actions were taken to reduce GHG emissions, I attempted to determine why these actions were taken. The main objective in this second step was to evaluate corporate change. Corporate change occurs for many reasons. I sought to determine what factors motivated airlines and airports to proactively adjust their behaviour to reduce GHG emissions.

The third step of my research, which answered the third question, was to use the CF calculations and corporate change findings as a basis for making recommendations for how the BC civil aviation industry can further reduced its CF. These recommendations are presented in the concluding chapter.

1.4 Major research results

In this section, major research findings are outlined following the order of the three research questions discussed above.

1.4.1 Research Question 1

A total of 19 airline companies[6] offer scheduled passenger flights on 96 routes between 53 airports in BC. Of the 19 airlines, 16 were covered in my research as well as all of their associated routes and airports. For air travel, the CF calculations performed to answer Research Question 1 yielded a total emissions value of roughly 198,000 tonnes of CO_2e generated annually by over 180,000 BC-internal flights.

Air Canada Jazz is the largest contributor to BC's aviation CF with 102,000 tonnes of CO_2e per year, or 51.3% of total BC aviation emissions. Westjet is the second largest contributor with 44,000 tonnes of CO_2e per year, or 22.1% of total BC airline emissions. Pacific Coastal Airlines is the third largest contributor with 18,000 tonnes of CO_2e per year, or 9.3% of total BC airline emissions. The remaining 13 airlines contribute 34,000 tonnes of CO_2e per year, or 17.2% of total BC airline emissions.

The airline-specific, BC-internal route with the highest CF is Westjet's Vancouver–Prince George route, which accounts for 10.8% of total passenger air travel emissions. The second highest route is Air Canada Jazz's Vancouver–Fort St. John route, which accounts for 8.6% of total passenger air travel emissions, while the third highest is Westjet's Vancouver–Kelowna route, which accounts for 8.2% of total air passenger air travel emissions. In terms of overall emissions generated per kilometre flown, the top three routes were Victoria–

[6] These airlines are, in alphabetical order, Airspeed Aviation, Air Canada Jazz, Air Nootka, Central Mountain Air, Corilair, Harbour Air, Hawkair, Helijet, KD Air, Northern Hawk, North Pacific Seaplanes, Orca Air, Pacific Coastal Airlines, Salt Spring Air, Seair, Swanberg Air, Tofino Air, Vancouver Island Air, and Westjet.

Kelowna, Vancouver–Kelowna, and Vancouver–Prince George. The Westjet flights on the two latter routes had the highest overall CF per unit distance flown, followed by Air Canada Jazz flights (Air Canada Jazz does not offer direct service between Victoria and Kelowna). In terms of CF per passenger on airline-specific routes, the top three routes were Pacific Coastal Airline's Port Hardy–Bella Bella, Air Canada Jazz's Vancouver–Fort St. John, and Hawkair's Vancouver–Prince Rupert routes.

City-pairs were also considered. For these calculations, both duplicate routes (identical routes served by more than one airline) and multiple airports within a city (such as Greater Vancouver) were considered. The city-pair with the highest total CF is Vancouver–Prince George (17.8% of total BC air travel emissions), followed by Vancouver–Kelowna (14.2%), Vancouver–Terrace (7.6%), and Vancouver–Victoria (6.9%). Despite the large volume of flights over the short distance of the Vancouver–Victoria route, it generates only 6.9% of total BC air travel emissions even though it accounts for over 13% of the total distance travelled. The city-pair with the highest overall CF per unit distance flown is Vancouver–Kelowna (1.391 tonnes of CO_2e per 100 km flown), followed by Vancouver–Prince George (1.158 tonnes of CO_2e per 100 km flown), and Vancouver–Kamloops (0.851 tonnes of CO_2e per 100 km flown). The city-pair with the highest CF per passenger is Port Hardy–Bella Bella, which generates 0.141 tonnes of CO_2e per passenger per flight. Rounding out the top five ranking for CF per passenger per flight were long routes.

The total CF of BC passenger airports is 327,000 tonnes of CO_2e per year. Out of this, 148,000 tonnes are generated by airport operations and 179,000 tonnes are generated by passenger airport access (i.e., passenger travel to and from airports). The BC airports with the highest CFs are, in order, Vancouver International Airport (229,000 tonnes of CO_2e per year, or 70.1% of total BC airport emissions), Victoria International Airport (23,000 tonnes of CO_2e per year, or 7.0% or total BC airport emissions), and Kelowna Airport (21,000 tonnes of CO_2e per year, or 6.4% of total BC airport emissions).

1.4.2 Research Question 2

The large airlines serving BC (Air Canada Jazz and Westjet) are engaged in CF reduction efforts, but are not the most proactive airline companies. This distinction falls to small airlines based in Vancouver. Thus, airline size does not seem to directly correlate with environmental activity, even though large airlines obtain greater financial benefits from reducing their energy consumption due to economies of scale. Most other small airlines, especially those based in northern BC, are not engaged in CF reduction efforts. The most common strategy among airlines to reduce their CF is to reduce energy consumption, and the most common motivation for engaging in this activity is financial benefit.

The larger airports in BC (such as Vancouver and Prince George) are engaged in CF reduction efforts, while most small airports are not. Larger airports are able to achieve significant financial benefits from reducing their energy consumption and thus their CF. As with airlines, financial benefits is the most significant factor explaining why airports reduce their CF.

1.4.3 Research Question 3

Based on the answers to the first two research questions, I developed the following recommendations for further reducing the CF of civil aviation in BC:

- Taking more active measures to address the significant emissions generated by passenger travel to and from airports,
- Increasing cooperation between civil aviation stakeholders

- pursuing incremental operational improvements by airlines and airports,
- enhancing passenger and employee programs,
- improving the quality and transparency of offset programs used by the aviation industry,
- and providing government incentives at the provincial level for airlines and airports to reduce their CF while allowing them to remain economically competitive.

Two airlines in BC are now carbon-neutral for both their flights and operations. Their efforts can be used as a template for how other airlines can achieve carbon neutral objectives yet remain competitive in the aviation industry. Vancouver International Airport is exemplary in its CF reduction efforts and an illustration of the financial benefits that can be accrued through these efforts. Its example should be used as a template for how other airports can reduce their CF.

1.5 Value of research

There are two main types of benefits of this research, one practical and one theoretical. At the practical level, my research provides the first detailed snapshot of civil aviation-generated GHG emissions in BC in terms of not only emission quantities but also what the BC aviation industry is doing to reduce GHG emissions. It is also, to the best of my knowledge, the first such work in Canada. This snapshot allows us to understand the present situation and provides guidance for targeting future efforts to further reduce GHGs in the BC aviation industry. Scholars, policymakers, and practitioners in the aviation field should find the results useful.

At the theoretical level, while the analysis contained in this thesis is BC-specific, the methodological approach used can serve as a template for research in other jurisdictions. I have attempted to construct a set of analytic steps that are independent of geographical scale. This method can be applied to differing scales.

1.6 Introduction to chapters

Following this introductory chapter, the second chapter presents a review of the literature on the CF of aviation, and briefly discusses corporate change relative to reducing the CF of the aviation industry. The third chapter explains the methodology adopted for this thesis, while the fourth chapter is a detailed micro-analysis of the CF of civil aviation in BC. In the fifth chapter, I analyze what is currently being done to reduce the CF of BC aviation, and why stakeholders have taken these measures. Recommendations are presented in the concluding sixth chapter.

CHAPTER 2: CLIMATE CHANGE AND AVIATION: A LITERATURE REVIEW

2.1 Introduction

This chapter contains a review of the literature on the CF of aviation, which serves not only to identify the gaps in the literature that are addressed by my research but also to establish the context for understanding the specific focus chosen for my research. I reviewed literature that pertains to the negative environmental impacts of aviation, specifically climate change-related impacts. I also discuss a second, and very sparse, literature pertaining to corporate environmental change in the aviation industry. I examine this literature because it concerns solutions to the problem of reducing GHG emission. It was used to help understand and explain why aviation-related corporations (namely, airline companies and airports in this thesis) made decisions to reduce their GHG emissions.

The literature on climate change-related impacts of aviation is large. It is a subset of a huge literature on climate change-related impacts of the transportation sector. I did not attempt to review the climate change and transportation literature, nor did I attempt to review the full gamut of scholarly work on climate change and aviation. I did not address, for instance, research on aviation technology related to GHG emissions. My specific focus was on literature related to calculating the CF of aviation. I divided this literature into four areas, each addressed in a separate subsection in this chapter.

The first area is work related to the scope or breadth of analysis to be used when calculating a CF. In other words, what aviation-related activities to include in such a calculation. I establish that my focus is on airports and flights. The takeoff-to-landing cycle (i.e., flights) is the dominant activity emphasized in the literature because it is a significant contributor to GHG emissions.

The second area of work I review is the wide range of negative climate change impacts of airports and airplanes, especially the takeoff-to-landing cycle of flights. The four main pollutants emitted are aerosols, water vapour, nitrogen oxides, and carbon dioxide (CO_2). Of these, CO_2 emissions are the dominant climate change-related impact of the aviation transportation system.

The third area of work I review is on flight CO_2 emission inventories (i.e., calculation of the total CF of all flights in a given geographical area). I establish that the focus in this literature has been almost exclusively on global inventories, that there seems to be no micro-inventories at a subnational level such as a province. This is the gap in the literature that I seek to fill.

The fourth area of work I review is on efforts to reduce the CF of flights. I establish that while significant engineering effort is being invested in new aircraft technologies, revolutionary technological improvements do not seem to be the solution to reducing aviation's CF in the foreseeable future. Therefore, small technological innovations (e.g., use of biofuels) and non-technological solutions (e.g., changes to operating practices) have to be pursued in the short and immediate term. My research focuses, in part, on determining what technological and non-technological options are being and can be pursued by the aviation industry to reduce its CF in BC.

2.2 Review of literature on the CF of aviation

There is a large body of scholarship on the relationship between aviation and climate change, most of which has been published in the past 15 years. Its rapid growth attests to the increased attention paid to the negative climate change-related consequences of air travel, and of transportation more generally. A large fraction of this literature, however, is scientific and technological. It focuses on the physics and chemistry of aviation emissions in the atmosphere and the engineering of new airplanes.

The earliest research I have discovered on the negative environmental consequences of aviation appeared in 1917 (Diederichs and Upton 1917). The U.S. National Advisory Committee for Aeronautics, established in 1915 and the predecessor for today's National Aeronautics and Space Administration (NASA), published a report on the muffling of airplane engines to, among other things, protect those living close to airfields from noise (Committee on Aeronautics Research and Technology for Environmental Compatibility of the National Research Council 2002). Somerville (1997) argued almost 15 years ago that while the impact of noise on communities around airports had historically been the most prominent aviation-related environmental issue, this was being superseded in importance by the local to global effects of aircraft emissions on air quality and climate. Many scholars, such as Green (2003), now argue that climate change is the most important environmental issue associated with aviation, and that the climate-related impacts of aviation will increasingly limit the expansion of air travel and the social benefits it brings.

Soon after Somerville's assessment, the Intergovernmental Panel on Climate Change (IPCC) published the most comprehensive study to date of the impact of aviation on climate change, the *Special Report on Aviation and the Global Atmosphere* (IPCC Working Groups I and III 1999). It summarizes the state of knowledge up to the late 1990s. The authors concluded that total aviation emissions had increased because increased demand for air transport had outpaced the reductions in emissions from continuing improvements in technology and operational procedures, and gave a detailed explanation of how airplane emissions alter the concentration of atmospheric GHGs, trigger the formation of contrails, and may increase cirrus cloudiness—all of which contribute to climate change.

Also in the late 1990s, the United Nations body tasked with governing aviation, the International Civil Aviation Organization (ICAO), turned its attention to the climate change-related impacts of the aviation industry. Indeed, it was ICAO that requested the IPCC to produce the *Special Report on Aviation and the Global Atmosphere* (IPCC (Intergovernmental Panel on Climate Change) Working Groups I and III 1999, v). ICAO is the leading international non-governmental body dealing with all facets of aviation. It was formed in 1944 to secure international cooperation and the highest possible degree of uniformity in regulations, standards, procedures, and organization regarding civil aviation matters (ICAO, "Foundation of the International Civil Aviation Organization", n.d.), which today include safety, security, efficiency, and environmental considerations (ICAO, "Strategic Objectives of ICAO", n.d.).

ICAO has produced a wide range of standards, policies and guidelines on the environmental aspects of aviation, including climate change, mostly through its Committee on Aviation Environmental Protection (CAEP), which was established in 1983 (ICAO, "Environment Branch", n.d.). CAEP houses a series of working groups, including a Working Group on Emissions Technical Issues, a Working Group on Operations, and an Aviation Carbon Calculator Support Group (ICAO, “CAEP Structure”, n.d.). ICAO and CAEP are synthesizers and summarizers of a vast array of expert research being conducted at universities, government labs, private research institutes, and NGOs. Their publications represent the tip of a pyramid of scholarly literature related to climate change and aviation.

In addition to expert literature, there exists an increasingly large body of popular literature discussing the relationship between climate change and aviation emissions. For example, the BC-based David Suzuki Foundation has analyzed the CO_2 intensity of aviation compared to other modes of transportation, GHGs and contrails produced by airplanes, aviation emission mitigation measures, and the potential impact of new technologies (David Suzuki Foundation, "Air Travel and Climate Change", n.d.).

2.2.1 The civil aviation system

Calculating the CF of civil aviation may initially seem like a straightforward process. It is not. There are multiple facets to consider, and this is what makes CF calculations complex. A complete and comprehensive calculation must include not only emissions generated during a particular flight but also related emissions, including the construction of aircraft and other aviation equipment, passengers' transit to and from the airport, and airport operations including processing of passengers. This comprehensive system, referred to here as the "civil aviation system", can be divided into four domains: (1) the lifecycle of aviation equipment, (2) airport operations, (3) customer travel to and from an airport, and (4) a flight from take-off to landing. Each domain is discussed.

Lifecycle of aviation equipment

The CF of aviation starts with the manufacture of aviation equipment, in particular the construction of aircraft. CO_2 and other GHGs are emitted in the manufacturing process and subsequently in multiple other processes over the lifetime of an aircraft until the plane is finally disposed of. Lifecycle assessment (also referred to as lifecycle analysis) in the context of aviation includes a determination of emissions generated during the entire lifetime of an airplane or other piece of aviation-related equipment, including production, testing, maintenance, and eventual scrapping of the product. Inclusion of lifecycle assessment results in a higher CF value than simply calculating the emissions generated during a particular flight.

The only applicable work I found addressing aviation lifecycle assessment is Weidema et al. (2008). The authors discuss the importance of such an assessment and recommend using existing ISO standards, but caution that many CF calculators do not specify whether they include lifecycle assessment. To my knowledge, publicly available CF calculators generally do not include it. The complexity of data and calculations required is too demanding. For this reason, too, I did not tackle this dimension in my thesis research.

Airport operations

Airport operations and infrastructure are another important dimension of the aviation system (Airports Council International - North America 2009). Energy use at airports, air freight handling, vehicles for ground support and maintenance, and the energy required to manufacture, transport and store jet fuel, for example, sharply increase aviation's CF (Society of Environmental Journalists 2007). However, the literature on the climate change-related impacts of airports is modest. Reimer and Putnam (2007) discuss the role of airport proprietors in reducing GHG emissions, while Klin et al. (2009) discuss sources of GHG emissions at airports and how climate change may impact airport planning and maintenance. Kim et al. (2009) have compiled a comprehensive guidebook for identifying and quantifying specific components of airport contributions to GHG emissions. Emissions for airport operations, including those of the airport authority and of tenants such as restaurants in an airport, are calculated in my research. I have also included analyses of current mitigation efforts by BC airports to illustrate what steps airports are taking and with what results.

Passenger transportation to and from an airport

Passengers travel from home or office to a departure airport (e.g., by private vehicle or public transit) and travel from the arrival airport to their final destination is another important element of the civil aviation system. Studies of the CF of passenger transportation to and from airports seem virtually non-existent. Smirti (2008), the only work I have been able to locate, studied low-carbon airport access modes and found that use of door-to-door electric vans could reduce access emissions by 36%. Emissions from passenger transportation to and from airports are calculated in my research.

Flights

The most visible dimension of the civil aviation system is air flights. Calculating an aircraft's emissions from take-off to landing is the most basic way of calculating an aviation CF, and accounts for a significant percentage of emissions in the aviation system. The literature in this area is discussed in section 2.2.2. My thesis research focused primarily on this dimension, in particular a micro-analysis of the CF of all civil aviation flights within BC.

Summary

For my research, I divided the civil aviation system into four domains—lifecycle of aviation equipment, airport operations, customer travel to and from an airport, and flight from take-off to landing. The literature in each area is relatively sparse. Works on aviation lifecycle assessment are limited and calculations related to such analyses are exceedingly complex. Lifecycle assessment is not included in my research. The literature on airport operations and on transportation of passengers to and from airports is also limited. Data and calculations for both are included in my research. The literature on the CF of flights is discussed below. Calculating the CF of flights (specifically, the take-off, in-flight cruising, and landing cycle) within BC is the centerpiece of my thesis research. In summary, my thesis research consists of CF analysis of (1) flights, (2) airport operations, and (3) passenger transportation to and from airports.

2.2.2 CF and climate change-related impacts of aviation

There are numerous negative effects of aviation on the environment. I focus only on those related to climate change. Furthermore, as discussed above, I focus only on those emissions generated by flights, airport operations, and passenger transportation to and from airports. The primary climate-damaging pollutants considered in this thesis are:

- black carbon aerosols (alternatively referred to as particulate matter or soot)
- nitrogen oxides (NO_x)
- water vapour (H_2O), released during flights and resulting in contrails
- carbon dioxide (CO_2).

The latter three pollutants are GHGs. CO_2 and NO_x are collectively measured in terms of CO_2e.

In general, relative to climate change, it is the impact of these pollutants on radiative forcing[7] during airplane flights that is often the center of attention. The process of radiative forcing is well-understood (Miake-Lye et al. 2000; Society of Environmental Journalists 2007). Overall, aviation emissions are estimated to cause a positive radiative forcing, implying a net warming effect (IPCC Working Groups I and III 1999, 3). According to the ICAO ("Environment Section: Aircraft Engine Emissions"), aircraft contribute about 3.0% of

---

[7] Radiative forcing refers to a change in the radiative properties of the atmosphere; specifically it is a measure of the perturbation or alteration to the energy balance of the atmosphere (IPCC Working Groups I and III 1999, 3). It is a measure of the potential of a constituent in the Earth's lower atmosphere (the troposphere) to alter the energy balance of the Earth, and is defined as the difference between incoming and outgoing radiation for a given climate system. It can have a positive or a negative value. A positive value implies that more radiation is trapped in the troposphere than escapes to outer space; a negative value implies that more radiation is lost to outer space than is retained in the troposphere. Radiative forcing due to aviation activity occurs due to the release of GHGs and soot (fine particles), creation of contrails, and other factors.

total anthropogenic radiative forcing by all human activities. Of total aviation flight emissions, less than 1% each are estimated to be aerosols and NO_x, slightly less than 30% is H_2O, and about 70% is CO_2 (Federal Aviation Administration 2005, 1).

Aerosols alter the radiative properties of the atmosphere in complex ways. Aerosols released by aircraft include black carbon (i.e., dark organic and inorganic carbon left over from incomplete combustion that can absorb light) and sulphate particles. These and other types of aerosols can be released by the various other components of the aviation system. Aerosols can cool the Earth's surface by reflecting sunlight to space and by forcing changes in cloud microphysics that consequently increase cloud reflection of sunlight. Aerosol cooling effects have been used to explain why observed global warming over the last century is only 0.6°C rather than the predicted 1°C based on models in which aerosols are not included (Remer 2007). Aerosols can also warm the Earth's surface. In particular, black carbon aerosols can absorb radiation due to their dark colour (Ramanathan and Carmichael 2008). Including the warming effects of black carbon aerosols can explain why global warming took place in the last century at all despite the strong aerosol cooling (Remer 2007). Finally, aerosols can serve as condensation nuclei for water vapour which in turn form clouds that alter the radiation balance (Burkhardt and Kaercher 2011, 54).

NO_x indirectly affects climate change. It forms when fuels are burned at high temperatures (Environmental Defense Fund 2002). NO_x is not a GHG; however, it reacts in the atmosphere to produce tropospheric ozone (O_3), which is a GHG (IPCC Working Groups I and III 1999, 3). In addition, NO_x emissions also contribute to the formation of fine particles, which affect radiative forcing.

Water vapour is a GHG, and when emitted by airplanes can cause contrails, which are unique to aviation (David Suzuki Foundation; Miake-Lye et al. 2000; Williams and Noland 2005; Chapman 2007; ICAO, Environment Section: Aircraft Engine Emissions", n.d.). In a recent article, Burkhardt and Kaercher (2011) conclude that contrail-induced cloudiness is a more important component of aviation impacts on climate than previously acknowledged.

CO_2 is generally considered to be the dominant aviation-related GHG. When fossil fuels are burned to produce energy, the carbon stored in them is emitted almost entirely as CO_2. Almost all of the energy consumed in the transportation sector is petroleum based, including gasoline, diesel, and jet fuel (U.S. Environmental Protection Agency 2011).

In summary, aviation produces multiple pollutants that results in negative impacts on the global climate. The focus in this thesis is on GHGs because these are what are included in the CF calculators used for my research. All GHG emissions are calculated in terms of CO_2e, which, in the case of the aviation calculations in this thesis are dominantly CO_2.

2.2.3 Calculating the CF of aviation

How are CFs calculated and who has calculated such footprints? This section contains a review of the literature related to calculating the CF of aviation.

Calculating a CF

A "carbon footprint" is the quantity of GHGs emitted by an activity measured in terms of CO_2 or CO_2e. University of British Columbia scholars, William Rees and Mathis Wackernagel, coined the term "ecological footprint",[8] out of which developed the concept of

[8] An ecological footprint is defined as "accounting for the flows of energy and matter to and from any defined economy and converting these into the corresponding land/water area required from nature to support these flows" (Rees, Wackernagel, and Testemale 1998, 3).

a CF (East 2008). I have been unable to determine who created the first CF calculator. They began appearing in the mid-2000s, and have since proliferated (Safire 2008).

A CF can be calculated in various ways. Despite a multitude of CF calculators, there is only a modest body of literature analyzing them. East (2008) presents the history of the concept of carbon footprinting and definitions of CF. Jones (2005) discusses how a CF calculator can be used to allow users to understand the impacts of spending decisions on a broad range of environmental, economic and social issues. Weidema et al. (2008) caution that use of CFs has been driven not by research but by NGOs, companies, and private initiatives, resulting in many definitions and suggestions for how a CF should be calculated. Pandey, Agrawal and Pandey (2010) argue that the concept of carbon footprinting now permeates society, but that there is little coherence in definitions and calculations. This argument is also found in Hertwich et al. (2008), who assess that CF calculators vary significantly with respect to system boundaries, methodologies, correctness of data, and results obtained. Similarly, Murray and Dey (2009) caution that businesses offering to make companies carbon neutral are proliferating on the Internet, but that since there are no standard ways of measuring carbon emissions (i.e., calculating a CF) there are no standard ways for becoming carbon neutral, which results in differing and uncoordinated approaches to becoming carbon neutral. Padgett et al. (2008) state that while CF calculators have become prevalent on the Internet, they often generate significantly varying results even with similar inputs. The authors examined ten US-based calculators and found that most lack information about their methods, impeding comparison and validation, and, while CF calculators can promote public awareness of carbon emissions, there is significant need for improving their consistency and transparency. This thought is reflected in Kitzes and Wackernagel (2009).

In summary, while scholarly analysis of CF calculators is modest, there seems to be a consensus in the literature that significant uncertainty exists on how to calculate a CF. Not only is there is no standard methodology but also there is a frustrating lack of transparency as to what is and is not included in the calculations. It was for these reasons that in this thesis I chose to use three different CF calculators instead of relying on just one.

Calculating the CF of aviation

As far as I have been able to determine, there are over 100 online CF calculator tools that can compute aviation emissions. Basic aviation emission calculators allow users to input their origin and destination airports, and to select whether a trip will be one-way or return, as well as the number of people travelling. The calculator then uses these inputs to determine the emissions associated with the flight. More advanced calculators also allow input of details such as the class of travel and the aircraft type to more realistically model a particular flight.

Even though there are plenty of aviation CF calculators available, the scholarly literature describing and analyzing them is thin. Much of it focuses on the many reasons for uncertainties in their estimates. According to Chapman (2007), one reason for the differing estimates given by different calculators is the difficulty of apportioning international aviation to a national or subnational level. If international flights departing from a country are not included in that country's emission inventory, the national emissions value will be underestimated. This holds true especially for small countries which have few or no domestic routes. A second reason for differences in calculator estimates relates to airplane type. Miyoshi and Mason (2009) point out that estimates can vary by a factor of 2.5 depending on plane type. A third reason is uncertainties in parameters and methodologies used in the calculators.

Emissions resulting from aviation differ from emissions from other modes of transportation. They have, for instance, a dual impact on climate, first when planes are on the ground and second when they are in the air (ICAO, "Environment Section: Aircraft Engine Emissions", n.d.). Most aircraft emissions are produced in the air at cruising altitudes because this phase is commonly the longest part of a flight. Notably, GHGs released at high altitudes have a more harmful climate impact than emissions at ground-level because the radiative forcing of high altitude emissions is several times that of ground level emissions. Aviation CF calculators vary on whether ground-level and high altitude emissions are included and, if included, the multiplier value used to account for the greater impact of high altitude emissions. Radiative forcing multiplier estimates vary from 1.7 (Fahey 2008), to 2.7 proposed by the UK-based Aviation Environmental Federation (Oliver 2007), to claims that the impact of high-altitude emissions is up to five times that of emissions occurring on the ground (WWF 2008). Others argue that currently not enough is known to accurately estimate radiative forcing multiplier values (Sausen et al. 2005). The differing multiplier values well illustrate the problems inherent in the various factors used to calculate the CF of aviation.

In summary, the scholarly literature on aviation-related CF calculators is modest and is primarily focused on the uncertainties inherent in their calculations. In my research, I don’t develop an aviation CF from scratch. Instead, I am relying on publicly available calculators. To attempt to circumvent some of the problems related to calculator uncertainties, I chose to use three different CF calculators.

Aviation emission inventories

A CF is essentially equivalent to a GHG emission inventory. The terms can be used interchangeably. Both express emissions generated from one activity or a set of activities, such as those of the civil aviation system. In this thesis, I primarily use the term "carbon footprint" but also occasionally use "GHG emissions inventory". A large body of scholarship exists on transportation sector inventories (Greene and Wegener 1997; Koopman 1997; Akerman and Hojer 2006; Yang et al. 2009). However, there exists only a modest body of literature on aviation-related inventories, and these tend to be global in scale. Scholars generally conclude that global emissions from civil aviation will increase significantly in the foreseeable future because of growth in passenger travel.

At the global level, Whitelegg, Williams, and Evans ("The Plane Truth: Aviation and the Environment", n.d.) estimated, based on IPCC aviation data, that aviation in the early 1990s contributed 3.5% of total new anthropogenic global warming, and predicted that it would be one of the single biggest contributors to global climate change by the year 2050. Miake-Lye et al. (2000) projected future aviation emissions and concluded that the growth expected in the aviation industry in the coming decades may significantly exceed emission reductions through technological improvements.

The Dutch Civil Aviation Authority commissioned a report on aviation and marine CO_2 emissions (Delzen and Wit 2000). It provides CO_2 emission estimates for 23 countries for "transport" but does not provide estimates of national aviation emissions. Instead it contains a discussion of how international aviation emissions should be allocated. The UK Department of Energy and Climate Change (2009) publishes GHG emission inventories annually, but emissions for domestic aviation are not listed separately from general transportation emissions. At the national level, Canada published a map of provincial GHG emissions by sector, however aviation is only included under the umbrella category of transportation (Natural Resources Canada 2003). At the subnational level, an aviation emission inventory exists for Alaska (Sierra Research Inc. 2005); however, it only includes CO emissions and not CO_2 or CO_2e emissions.

Researchers have predicted global emission increases from aviation between 300% from 1995 to 2050 (Olsthoorn 2001) and 800% from 1990 to 2100 (Vedantham and Oppenheimer 1998), while others predict a relative decrease in the negative impacts of aviation (Janic 1999). The David Suzuki Foundation ("Air Travel and Climate Change", n.d.) argues that the aviation industry is expanding rapidly in part due to regulatory and taxing policies that do not reflect the true environmental cost of flying. The Foundation provides very high CO_2 emission estimates. ICAO ("Environment Section: Aircraft Engine Emissions", n.d.) counters that medium-term, partial mitigation of CO_2 emissions can come from improved fuel efficiency. Solon (2007) proposes that low-cost carriers are the most environmentally-friendly sector of the industry because of their high seat densities and that aviation plays a far smaller role in generating global CO_2 emissions than road traffic and power plants, but Chapman (2007) claims that short-haul travel has seen significant growth because of low-cost carriers and that short-haul flights use disproportionately more fuel than longer flights. Most studies base their estimates on passenger travel, but some also include technological developments and other factors. Green (2003), for instance, concludes that significant emission reductions from aviation require radical changes to aircraft designs. Akerman (2005) concludes that lowering aviation emissions hinges significantly on technology trajectories such as information technology developments (e.g., using telecommuting instead of business travel).

In summary, most scholarship addresses aviation emissions on a large scale. There are national GHG inventories for the transportation sectors but they tend not to go into much detail on aviation. Detailed analysis of the CF of aviation at the subnational level seems to be non-existent. I have been unable to locate any GHG emission inventories for the aviation industry on a subnational scale such as a province. Thus, there seems to be a significant gap in the literature on smaller-scale emission inventories.

2.3 Review of literature on reducing the CF of aviation

2.3.1 Reducing the CF of aviation

In general, the motivation for calculating the CF of aviation (or any other human activity) is to provide a basis or rationale for reducing the footprint. In my thesis research, I have attempted to not only calculate the CF of aviation in BC but also assess efforts to reduce it. I therefore reviewed the literature on reducing the CF of aviation. There are two main areas of change in the aviation industry to reduce carbon emissions, technological and non-technological.

A large body of literature discusses aviation-related technological change. Topics include new plane designs (Nederveen, Konings, and Stoop 2003; Bradbury 2007), NO_x emission standards for engines (ICAO, "Environment Section: Aircraft Engine Emissions", n.d.), and alternative fuels (Daggett et al. 2006; Daggett et al. 2008). The general consensus in the literature seems to be that revolutionary improvements to airplane designs, such as running on hydrogen fuel, are so distant in the future that alternative emission reduction strategies have to be pursued in the near-term. Incremental technological changes, such as improved engine design or use of alternative fuels, are likely to be the main source of technological-related CO_2 emission reductions.

Only a small body of literature discusses non-technological change related to aviation. Topics discussed include operational improvements (such as improved air traffic guidance), financial instruments (such as taxes), and policy instruments (such as legislation). While there is a sizeable body of literature on non-technological changes in the transportation sector in response to climate change (Alic, Mowery, and Rubin 1995; McNeil, Wallace, and Humphrey 2000; Crass 2008; Lutsey 2008), only Dewes et al. (2000) discuss aviation in particular, specifically the AERONET project, a network among European countries to support and strengthen the European aviation industry's efforts to reduce its environmental impact.

In summary, the general consensus in the literature on GHG reduction efforts in the aviation industry is that the lack of revolutionary technological breakthroughs on the horizon emphasizes the need to pursue incremental technological innovations and non-technological changes. The focus in the thesis is on such incremental improvements.

2.3.2 Corporate environmental change in the aviation industry

Incremental changes are made by the important actors in the aviation industry—airline companies, airport authorities, transportation businesses, catering companies, etc. Thus, an important body of literature relevant to my thesis relates to reducing the CF of aviation through corporate behaviour change in the aviation industry. In an extensive survey of the social science literature, I was unable to find any studies of why airline companies, or related actors such as airports, change or do not change their behaviour to reduce GHG emissions. After turning up empty handed, I therefore went one level higher and examined the literature on corporate environmental change for ways it could inform my specific study of the airline industry. At this higher level, a huge literature exists both on the categorization of corporate environmental behaviour and on drivers of change. I do not attempt to review this literature. It is beyond the scope of this thesis. However, what I gleaned from this literature was used to explain and clarify my results in Chapter 5. Portions of the literature on corporate environmental change are discussed in that chapter.

2.4 Summary of the literature on climate change and aviation

There is a broad literature on aviation and climate change, which for the purposes of this review was divided into four topic areas. The first area was the "civil aviation system", divided into four domains—lifecycle of aviation equipment, airport operations, customer travel to and from airports, and flights. The later three are sometimes referred to as the door-to-door aviation system. The scope of research in this thesis was limited to this door-to-door aviation system and excluded lifecycle assessment. The second topic area was aviation-related pollutants and impacts. The focus in this thesis is on calculating GHGs produced by the door-to-door aviation system. The third area was aviation GHG emission inventories. While there is a large body of scholarship studying the CF of transportation in general, few scholars have studied the CF of aviation specifically. Moreover, these studies generally approach aviation on a global scale. There do not seem to be any microanalyses on a subnational scale, which is the focus in this thesis. The final topic area covered in my literature review was GHG mitigation efforts in the aviation industry. The literature indicates that in the near and immediate term, non-technological and small-scale technological solutions will be the focus of attention. The literature review in this chapter provides the context for the results and analyses contained in the remainder of this thesis.

CHAPTER 3: METHODOLOGY

3.1 Introduction

In my survey of the literature on climate change and aviation, I did not find any research similar to what is contained in this thesis. Thus, I found no methodology to follow. I consequently devised my own methodological approach. The purpose of this chapter is to explain this approach, which was used to answer my three research questions. The chapter is divided into three sections, each explaining the approach used to answer each research question.

3.2 Methodology for Question 1

Question 1: What is the CF of civil aviation in BC?

To calculate the CF of civil aviation, three elements of the civil aviation system were considered: flights, airport operations, and passenger travel to and from airports. To determine the CF of routes, three publicly available CF calculators were used. Instead of relying on a single calculator, I used three different calculators so as to enhance the credibility of my estimates. To determine the CF of airport operations and passenger travel, I used information from the Prince George Airport GHG Report as the basis for scaling to all airports other than Vancouver International Airport. Vancouver International Airport was derived from interview data. In the remainder of this section, I first provide a description of the flight calculators used, then explain the steps followed to obtain the necessary data for use with the calculators, and lastly, describe the approach taken to calculate the CF of BC airports.

3.2.1 CF flight calculators used

I chose three calculators for my research. The first was the World Resources Institute (WRI) CF calculation worksheet, referred to here as the WRI calculator. It was chosen because of WRI's cooperation with the Greenhouse Gas Protocol Initiative, the most widely used international accounting tool for government and business leaders to understand, quantify, and manage GHG emissions (Greenhouse Gas Protocol Initiative, "About the GHG Protocol", n.d.) and because of WRI's reputation as an unbiased source of environmental statistics. The second calculation method was to combine factors from the GHG Protocol for the Business Travel Service Sector into a spreadsheet, referred to here as the GHG Protocol Travel calculator. I chose to use factors from this protocol because of their widespread acceptance in the business community. The third calculator was the calculation tool developed by the company, Offsetters. It was chosen because Offsetters is a large, commercial organization and was the official offsetting organization for the 2010 Vancouver Winter Olympics.

The WRI and GHG Protocol Travel calculators are similar in that they require user input of travel distance to calculate CO_2e emissions. A consumer must thus know the distance travelled by a particular flight. By contrast, the Offsetters calculator only requires input of origin and destination airports. The calculator then determines the distance and emissions for the user, making it somewhat more user-friendly. All calculators display their results in CO_2e. Each calculator is discussed.

WRI calculator [9]

The WRI aviation calculator is one part of a larger WRI general transportation worksheet. The aviation portion utilizes built-in emission factors (i.e., preset values of emissions per unit distance travelled per passenger). To calculate the CF, a user first selects the region where emissions take place (the only options are UK, US, and Other), scope (scope 1 refers to all direct GHG emissions, as opposed to scope 3, which refers to indirect emissions such as the extraction and production of purchased materials and fuels and waste disposal), type of activity ("passenger distance" is the appropriate selection for public transportation), and vehicle type (where for airplanes, flights up to 350 km are considered "air-domestic", between 350-700 km are "air-short haul", and over 700 km are "air-long haul"). In BC, "economy class" is the correct choice for seating in the vehicle type field since no scheduled carrier operates premium cabins on BC-internal flights. Finally, a user chooses the unit of distance (passenger kilometre is the appropriate selection), the distance travelled, and the number of passengers. With these settings and inputs, emissions per flight can be calculated.

For making BC-based calculations, I used the following procedure. I selected the region as "other" and scope as "scope 1" (i.e., direct emissions, which means any lifecycle assessment was excluded). I then used individual stage length (flight distance) per route to determine the choice for the "vehicle type" category, and chose economy class as seating for all instances. Instead of calculating the emissions for a single passenger, I input the maximum passenger number for the respective aircraft, thus assuming a full passenger load. With this information entered and total yearly distance travelled, the WRI calculator

---

[9] The worksheet "GHG emissions from transport or mobile sources" is available for download at http://www.ghgprotocol.org/calculation-tools/service-sector.

computes tonnes of CO_2e per route per year. There are fields in the WRI calculator for CH_4 (methane) and N_2O (nitrous oxide); however, the calculator did not compute any values for these pollutants because they are not generated by fuel combustion in aircraft. The only pollutants considered in the calculator are CO_2 and NO_x. In the end, the formula I used was as follows:

$$WRI\ CF_R = EF_A\ x\ D\ x\ \ P$$

Where,

WRI CF_R = annual GHG emissions for a given route for a given airline (tonnes CO_2e/year/route)

EF_A = Emission Factor for a given airplane type (tonnes CO_2e/km/person); 3 airplane types (A): air-domestic (< 350 km), air-short haul (between 350-700 km), and air-long haul (>700 km)

D = total annual distance flown on the route
= D_F (distance of flight (km/flight)) x F (number of flights/year)

P = total annual number of passengers on the route
= P_F (passengers/flight) x F (number of flights/year); all flights are assumed full, so the number of seats on a plane equals the number of passengers

GHG Protocol Travel calculator [10]

The GHG Protocol Travel calculator provides emission factors based on distance travelled. Consequently, a user only needs to know the distance between origin and destination airports to compute emissions using this calculator. For this method, I listed routes by carrier, route, distance per route, and yearly kilometres per route. I then assigned emissions factors from the GHG Protocol to each route depending on stage length. Unlike the WRI calculator, for which three emission factors based on flight distances were applicable

[10] The methodology of this calculator is explained in Judd et al. (2009, 10). The calculator uses emission factors from the United Kingdom Department for Environment, Food, and Rural Affairs (DEFRA).

(<350 km, 350-700 km, >700 km), only two emission factors from the GHG Protocol Travel calculator were applicable (≤500 km and >500 km). The emission factors associated with these distances are 0.15 kg CO_2e/km/passenger for routes up to 500 km in distance, and 0.12 kg CO_2e/km/passenger for routes between 501 km and 1600 km in distance. A factor of 0.11 kg CO_2e/km/passenger is available through this Protocol for routes of more than 1600 km in distance but is not applicable as this minimum required route distance exceeds possible stage lengths within BC. I then multiplied the total distance per route per year by the respective emission factor to obtain kg of CO_2e per seat per route per year, which I divided by a factor of 1000 (1 tonne = 1000 kg) to obtain tonnes of CO_2e per seat per route per year. I consequently multiplied these values by the available number of seats per plane (thus assuming a full passenger load) to obtain the total tonnes of CO_2e per route per year. In summary, the formula I used was as follows:

$$GHG\ Protocol\ Travel\ CF_R = EF_A x\ D\ x\ P$$

Where,

GHG Protocol Travel CF_R = annual GHG emissions for a given route for a given airline (tonnes CO_2e/year/route)

EF_A = Emission Factor for a given airplane type (tonnes CO_2e/km/person); 2 airplane types (A): ≤ 500 km and >500 km

D = total annual distance flown on the route
= D_F (distance of flight (km/flight)) x F (number of flights/year)

P = total annual number of passengers on the route
= P_F (passengers/flight) x F (number of flights/year); all flights are assumed full, so the number of seats on a plane equals the number of passengers

Offsetters calculator [11]

The Offsetters calculator differs from the WRI and GHG Protocol Travel calculators in that it requires the input of departure and arrival airports (in the form of city names or airport codes). The other two calculators require only input of distance travelled and cannot process input of actual locations. To use the Offsetters calculator, I entered the origin and destination of each route as one-way flights. To calculate emissions, Offsetters uses emissions factors provided by the UK Department of Environment, Food and Rural Affairs (DEFRA), and additionally applied a "radiative forcing factor" suggested by DEFRA to account for non-CO_2 climate change effects. Offsetters argues that this gives a more accurate value for a flight's climate impact. Its CF estimates are generally higher than for equivalent routes using the other two calculators. Offsetters unfortunately does not explain its emission factors when performing a simple flight offset calculation on their website. This may create confusion among consumers if they compare results to other emission calculators. To learn about these factors, one has to read the "Frequently Asked Questions" in the "About Us" section of their website.

I multiplied my results for a one-person, one-way flight by the number of annual flights and by the number of seats available on the aircraft to derive a total annual CF for a given route for a given airline. A problem encountered with Offsetters was that the CF calculator does not recognize a significant number of destinations.[12] This meant that, in total, Offsetters could not provide values for 31 routes (out of a total of 96 routes), which together

[11] The Offsetters CF calculator can be found on the Offsetters website: www.offsetters.ca.

[12] The destinations not recognized were Trail, Anahim Lake, Bella Coola, Powell River, Masset, Bella Bella, Klemptu, Gold River, Kyuquot, Ganges, Maple Bay, Bedwell Harbour, Langley, Sechelt, Qualicum Beach, Gillies Bay, Port Alberni, Vernon, Gabriola Island, Seymour Inlet, North Pender Island, Thetis Island, Saturna Island, Miner's Bay, and Galiano Island.

account for 4,749,212 km, or 14.2% of the distance of all BC-internal flights. These are generally routes to small airports/airstrips, sometimes floatplane landing strips, which are not serviced by the major commercial airlines. This issue was not encountered with the two other calculators because they require only distance travelled.

To compensate for the inability of the Offsetters calculator to determine the CF of certain routes, I averaged the WRI and GHG Protocol Travel calculator values for all routes for which Offsetters provides a value. I then compared this average to the average of the Offsetters value for these routes. The Offsetters average value was higher by a factor of 1.44. Consequently, for those routes for which Offsetters was unable to provide a value, I averaged the results as determined by the WRI and GHG Protocol Travel calculators and multiplied by 1.44 to approximate the Offsetters value for the missing routes. In summary, the formulae I used were as follows:

$$Offsetters\ CF_R = EF_R\ x\ F\ x\ P$$

Where,

Offsetters CF_R = annual GHG emissions for a given route for a given airline (tonnes CO_2e/year/route)

EF_R = Offsetters emissions factor for a one-way, one-person trip for a selected route (R) (tonnes CO_2e/flight/person)

F = number of flights per year on the selected route

P = total annual number of passengers on the route = P_F (passengers/flight) x F (number of flights/year); all flights are assumed full, so the number of seats on a plane equals the number of passengers

Offsetters CF for routes that Offsetters did not recognize:

$$Offsetters\ CF_R = \frac{WRI\ CF_R + GHG\ Protocol\ Travel\ CF_R}{2}\ x\ 1.44$$

3.2.2 Collecting BC data for CF route calculations

To calculate the CF of BC civil aviation, it was first necessary to establish an inventory of all routes that remain entirely within the province. To accomplish this, I compiled a list of the airlines serving BC, the routes they serve, the number of flights in an average week, the flight distances for all individual flights, and the number of passengers that can be carried on these flights. These steps are explained in more detail below.

Step 1: Airlines serving BC

The first step of data collection was determining all airlines that fly within BC. Two lists of airlines were consulted, one from Transport Canada and the other from British Columbia.com (Transport Canada 2009; Shangaan Webservices Inc. 2010). A total of 20 airline companies[13] offer scheduled intra-provincial flights in BC. The schedules of three small float plane operators—Corilair, North Pacific Seaplanes, and Salt Spring Air—were excluded from the project. These carriers conduct small float plane operations with many stopovers, so calculating emissions between a route's origin and final destination is complicated. Because of this and their small size, and hence comparatively low overall contribution to the CF, I chose not to include these carriers. In addition, Harbour Air and Westcoast Air are now a single company and thus were treated as one airline. In the end, I considered 16 airline companies.

Note: On 1 June 2011, Air Canada Jazz officially became Air Canada Express as part of an Air Canada initiative to streamline their regional services (Air Canada 2011). This has

[13] These airlines are, in alphabetical order, Airspeed Aviation, Air Canada Jazz, Air Nootka, Central Mountain Air, Corilair, Harbour Air, Hawkair, Helijet, KD Air, Northern Hawk, North Pacific Seaplanes, Orca Air, Pacific Coastal Airlines, Salt Spring Air, Seair, Swanberg Air, Tofino Air, Vancouver Island Air, Westcoast Air, and Westjet.

not had operational impacts in BC. Because the airline was known as Air Canada Jazz during the time of my research, it is referred to as Air Canada Jazz in this thesis.

Step 2: Routes and number of flights

The respective airlines' websites were consulted to determine which routes they serve that are entirely within BC, and how many weekly round-trip flights they operate.[14] The number of weekly flights for each airline and each route was multiplied by 52 to obtain an estimate of the yearly round-trip flights per airline per route.

Step 2.5: Average week

I based my flight inventory on the week of 25 October 2010. This week was chosen because it is an 'average' travel week that contains no peak travel days such as holidays. Since the end of October is an off-peak travel season and airlines might schedule more flights during the busier summer months, it is reasonable to assume that the scheduled number of weekly flights throughout the year will be at least as high as during the week chosen for this research. Thus, basing the yearly estimates on this week represents a conservative estimate of annual emissions.

Step 3: Route distances

The next step was determining the distance between departure and arrival locations for each route. For Air Canada Jazz routes, distances were obtained through the Star Alliance TravelDesk software. For most other routes, distances were obtained using the Great Circle

---

[14] In the case of Air Canada Jazz, instead of the Air Canada Jazz website, the Star Alliance TravelDesk software was used to obtain weekly schedules. The Star Alliance Travel Desk software is a free, downloadable program compiled by the Star Alliance airline group that has schedules and flight information on member airlines such as Air Canada and its subsidiary Air Canada Jazz. It is available at http://www.staralliance.com/en/services/tools-and-downloads/timetables/.

Mapper website.[15] Where destinations were not assigned official airport codes (mostly in the case of small float plane destinations), distances between origin and destination were estimated based on Google Maps. While it is generally impossible for an airplane to fly exactly the shortest distance between two points because flying conditions (e.g., weather) and operational requirements (e.g., air traffic congestion) may necessitate flying a longer path, no adjustments were made for this in these calculations. Basing the yearly estimates on the shortest distance between to cities represents a conservative estimate of annual emissions. To calculate the distance travelled per year, I multiplied the stage length of an individual one-way flight between two destinations by the annual number of one-way flights.

Step 4: Number of passengers

The number of seats available per plane was obtained either as an exact figure from airline seat maps, or as an average when different plane types are used interchangeably on a route. Although unrealistic, a load factor[16] of 100% was assumed for all flights. However, the overall GHG emissions per flight vary only slightly whether all seats are occupied or not because the weight of the airplane is greater than the collective weight of the passengers.

3.2.3 Determining the CF of routes in BC

After I compiled the raw data, I processed it in Excel spreadsheets. I first determined the average value for individual flights and the aggregate CF of BC aviation. I then calculated a "route carbon intensity" (i.e., CO_2e emissions per unit distance travelled for a given route), and a "passenger carbon intensity" (i.e., CO_2e emissions per passenger for a

[15] The Great Circle Mapper calculates the shortest distance between any two points in the world. It is available online at http://www.gcmap.com/dist.
[16] The term "load factor" denotes the percentage of seats on an airplane that are occupied on any given flight.

given route). Finally, I calculated the CO_2e emissions for city-pairs to illustrate the distribution of emissions within the province, and calculated the passenger carbon intensity flying between city pairs. The steps and formulas for these calculations are discussed.

Step 1: CF for individual routes

To obtain an average carbon emissions value for a given route, each of the values for that route obtained from the three CF calculators were added and divided by three. In total, there are 96 scheduled airline routes in BC. This number refers to routes that individual airlines operate. Thus, if two airlines operate between the same two cities, this counts as two "airline routes".

$$CF_R = \frac{(WRI\ CF_R + GHG\ Protocol\ Travel\ CF_R + Offsetters\ CF_R)}{3}$$

Where,

CF_R = average CF of the three calculators for a given route (R) for a given airline (tonnes CO_2e/year/route)

R = 1:96

Step 2: Total CF of civil aviation in BC

To determine the total CF of civil aviation in BC, the above-calculated route CFs was summed over all routes in BC.

$$\text{Total BC aviation CF} = \sum_{R=1}^{96} CF_R$$

Where,

Total BC aviation CF = annual GHG emissions for all routes (R) for all airlines in BC (tonnes CO_2e/year). There are a total of 96 BC-internal airline routes considered in this thesis.

Step 3: CF by airline

To calculate the total CF for each individual airline in BC, I added the average CF values of all routes in BC for that airline.

$$Airline\ CF = \sum_{R=1}^{n} CF_R$$

Where,

Airline CF = total GHG emissions for all routes for a given airline (tonnes CO_2e/year)

CF_R = CF for a given route (R) for a given airline (tonnes CO_2e/year/route)

n = the number of intra-provincial routes flown by the airline

Step 4: Route carbon intensity

In order to calculate the CF per unit distance travelled for each individual route, the total emissions for that route per year were divided by the total distance flown per year on that route. This value is referred to in this thesis as the "route carbon intensity". The objective of these calculations was to be able to compare the route carbon intensity of airlines.

$$CI_R = \frac{CF_R}{D}$$

Where,

CI_R = route carbon intensity (tonnes CO_2e/100 km/route)

CF_R = CF for a given route for a given airline (tonnes CO_2e/year/route)

D = D_R x F = distance of a given route (D_R) times the number of annual flights on that route (F) (km)

Step 5: Passenger carbon intensity

In order to calculate the CF per passenger for each individual route, the total emissions for that route per year were divided by the total number of passenger flying that route, which, since I assumed all seats were occupied, is equivalent to the total number of seats on the planes serving that route. This is a minimum passenger carbon intensity because the passenger carbon intensity goes up slightly when a plane is not full. The objective of these calculations was to was to be able to compare the passenger carbon intensity of airlines.

$$CI_P = \frac{CF_R}{P}$$

Where,

CI_P = passenger carbon intensity (tonnes CO_2e/passenger/route)

CF_R = CF for a given route for a given airline (tonnes CO_2e/year/route)

P = total annual number of passengers on the route
= P_F (passengers/flight) x F (number of flights/year); all flights are assumed full, so the number of seats on a plane equals the number of passengers

Step 6: CF of city-pairs

Lastly, in order to calculate city-pair emissions, all routes between two cities, including identical routes served by multiple airlines, as well as similar routes between metropolitan areas (e.g., all flights between Greater Vancouver and Greater Victoria) were summed to obtain the overall CF of all flights between the city-pair.

$$\begin{aligned}&City\text{-}pair\ CF\\&= Airline\ 1\ city\text{-}pair\ route\ 1\ CF + Airline\ 2\ city\text{-}pair\ 1\ CF\ + \cdots\\&+\ Airline\ n\ city\text{-}pair\ 1\ CF\end{aligned}$$

Where,

City-pair CF = total annual GHG emissions for all airlines serving routes between two cities (tonnes CO_2e/year)

City-pair route = all routes between two cities

City-pair route carbon intensity was calculated by dividing the aggregate city-pair CF by the yearly distance between the two cities.

$$CI_{CP-R} = \frac{City\text{-}pair\ CF}{D}$$

Where,

$CI_{CP\text{-}R}$ = city-pair route carbon intensity (tonnes CO_2e/100 km/route)

City-pair CF = total annual GHG emissions for all airlines serving routes between two cities (tonnes CO_2e/year)

D = total annual distance flown on the route
= D_R (distance for a given city-pair route) x F (number of annual flights on that route

City-pair passenger carbon intensity was calculated by dividing the aggregate city-pair CF by the total annual number of passengers flying that city-pair route.

$$CI_{CP-P} = \frac{city\text{-}pair\ CF}{P}$$

Where

CI_{CP-P} =	city-pair passenger carbon intensity (tonnes CO_2e/passenger/route)
City-pair CF =	total annual GHG emissions for all airlines serving routes between two cities (tonnes CO_2e/year)
P =	total annual number of passengers on the route = P_F (passengers/flight) x F (number of flights/year); assume all flights are full, so number of seats on a plane equals the number of passengers

3.2.4 Determining the CF of airports BC

I calculated the CF for 53 airports in BC. For these calculations, I distinguished between two components associated with "airports": (1) airport operations and (2) passenger travel to and from airports. Furthermore, I put Vancouver International Airport (YVR) in a separate category from all other airports in BC.

Step 1: CF for all airports in BC except Vancouver International Airport

For all airports in BC except Vancouver International Airport, I performed calculations based on the Prince George Airport GHG Report (Prince George Airport Authority 2008) and passenger statistics from Transport Canada (Transport Canada 2009, A124). While the Prince George data is from 2007, and the Transport Canada data from 2008, these were the most up-to-date sets of data available at the time of my research. The Prince George inventory lists emissions for three different categories: Airport authority emissions (which includes employee commuting), tenant/airline emissions (airline emissions in the inventory are those emitted by planes while on the ground), and "public emissions", which consists solely of passengers commuting to and from the airport.

I combined the first and second emission categories from the Prince George Airport GHG Report and called these “airport operations”. The value for Prince George was approximately 2330 tonnes of CO_2e per year. I consequently divided this value by the number of annual passengers at the Prince George airport in 2008 (409,929), which I obtained from Transport Canada. This yielded an emission factor of 0.00569 tonnes of CO_2e for airport operations per passenger processed at the airport. To obtain an estimate of the annual airport operations emissions for other BC airports, I multiplied this factor by the annual number of passengers at these airports (also obtained from Transport Canada). While the Transport Canada report does not publish passenger numbers for all individual airports in BC, it lists the major airports in the province and summarizes the remaining 91 small airports under “Other Airports”. Most of these small airports do not have scheduled airline service. All 44 small airports in the “other airports” category with scheduled service were included in my research. My calculations therefore encompass all airports in the province that have scheduled airline service.

To calculate BC airport emissions for passenger travel to and from airports, I divided the public emissions value for Prince George in 2007 (3,982.5 tonnes of CO_2e) by the annual passenger number in 2008 (409,929) to obtain a factor of 0.00972 tonnes of CO_2e per passenger to access the airport. To obtain an estimate of the annual passenger travel emissions, I multiplied this factor by the annual number of passengers at each airports. Again, Vancouver International Airport was considered separately. The equations used for my airport calculations were as follows:

$$Airport\ operations\ CF = \frac{0.00569\ tonnes\ of\ CO_2e}{passenger}\ x\ annual\ passengers$$

$$Airport\ access\ CF = \frac{0.00972\ tonnes\ of\ CO_2e}{passenger}\ x\ annual\ passengers$$

Where,

Airport operations CF =	total annual GHG emissions of an airport due to its operations (tonnes CO_2e/year)
Airport access CF =	total annual GHG emissions of an airport due to passenger travel to and from the airport (tonnes CO_2e/year)
passengers =	number of passengers processed at the airport in a year

Step 2: CF for Vancouver International Airport

There are two reasons why Vancouver International Airport (also commonly referred to by its airport code, YVR) belongs in a class by itself. First, it is by far the dominant airport in BC. It is the province's main hub airport. In 2008, it processed over 17 million passengers. The next closest airport, Victoria International Airport, processed only 1.5 million. Second, Vancouver International Airport has completed the most detailed GHG emissions inventory of any airport in BC. I used data from the airport's "community & environment" website (http://www.yvr.ca/en/community-environment.aspx) and information obtained during an interview and through personal communication with Jennifer Alderson, Environmental Analyst with the Vancouver Airport Authority. YVR data was obtained in two emission categories: those associated with the airport authority and its tenants, and overall emissions on Sea Island. Sea Island is the name given to the land area where the airport is located.

For airport operations emissions, I used the value provided by the airport (11,632 tonnes of CO_2e (personal communication, Jennifer Alderson)), but also added emissions from employee commuting to make the result congruent with that for my method used for the other airports in BC. I assumed that the airport's figure of 23,614 employees for the year

2010 (Vancouver International Airport 2011) also applies for the year 2008. I then assumed that every employee would travel to/from the airport five times a week, 48 weeks a year (240 round trips per year, or equivalently, 480 one-way trips per year). When multiplied by the total number of employees, this yielded the annual trips taken by all employees. From this, I subtracted 9% to account for those employees who commuted by public bus (personal communication, Jennifer Alderson). I multiplied this value by the Prince George airport passenger access factor of 0.00972 tonnes of CO_2e, (thereby assuming that this is a reasonable approximate of the CF for one trip for one YVR employee) to determine the annual employee airport access emissions.

The second category, overall Sea Island emissions (285,214 tonnes of CO_2e), comprises vehicle use on Sea Island and airplanes taking off and landing. It includes vehicle emissions only on Sea Island, but also airplane emissions which my calculations for the other airports in BC do not include. The value is therefore incompatible with my airport CF calculation methodology and was not used.

Instead, to calculate overall passenger access emissions (as opposed to employee access emissions), I obtained the fraction of passengers who transited at the Vancouver International Airport in 2008 (27%) and subtracted it from the total number of passengers processed because, since transit passengers do not leave the airport terminal, they do not generate airport access emissions. I then subtracted 3% from this value to account for the number of passengers who used public busses to access the airport (personal communication, Jennifer Alderson), and assumed for simplicity sake that emissions from bus travel were zero. Finally, I multiplied the remaining number of passengers by the factor of 0.00972 tonnes of CO_2e per passenger described in Step 1 to calculate airport access emissions. The equations used for my YVR calculations were as follows:

$$YVR\ operations\ CF = CF\ YVR + (YVR\ employee\ trips\ x \frac{0.00972\ tonnes\ of\ CO_2e}{employee\ trip})$$

Where,

VYR operations CF = total annual YVR GHG emissions due to operations under airport authority control plus employee commuting (tonnes CO_2e/year)

CF YVR = value obtained directly from the airport for airport operations

YVR employee trips 480 annual round trips/employee x 23,614 employees x 91%

$$YVR\ airport\ access\ CF = \frac{0.00972\ tonnes\ of\ CO_2e}{passenger\ trip}\ x\ YVR\ passenger\ trips$$

Where,

VYR airport access CF = total annual YVR GHG emissions due to passenger travel to and from the airport (tonnes CO_2e/year)

YVR passenger trips = annual number of passengers x NT (% of non-transit passengers = 73%) x NB (non-bus commuting passengers = 97%)

3.2.5 Data limitations

My calculation of BC's civil aviation CF is subject to a number of limitations, as follows.

1) The calculators used in this research were often vague as to the underlying parameters and factors used for their calculations. For instance, neither the WRI nor GHG Protocol Travel calculators mention whether H_2O or contrails are included. It seems not.
2) The inventory includes only scheduled civilian airline routes within BC. Private, charter, military, and agricultural flights are not included in my research.

3) While most airlines serving BC are included in the inventory, three small floatplane airlines were omitted because of calculation difficulties. The CF results for civilian routes within BC would be slightly higher if these three had been included.
4) The inventory was compiled based on an average off-season week. Each week of the year was not considered separately even though the flights per week may vary somewhat. The CF results for civilian routes within BC would be higher if each week had been considered separately since more flights are often scheduled during peak travel seasons.
5) I calculated the shortest route between each individual departure and destination airport. The CF results would be higher if actual flight distances had been considered because planes are often required to fly longer routes because of conditions such as weather, air space congestion, or navigational requirements.
6) I calculated the CF assuming a 100% load factor (i.e., all seats on the plane are occupied). The CF results would be somewhat lower if the actual number of passengers has been considered. However, since the weight of the plane, not the weight of the passengers, is more significant, the introduced error will not be large.
7) I used a factor of 1.44 to adjust Offsetters emissions for those routes for which Offsetters does not recognize the airports in question. I do not know if this adjustment over- or under-estimates actual values.
8) CF data from Vancouver International Airport is based on all flights using the airport, including intra-province, inter-province, and international flights. The CF for BC-internal routes only would consequently be lower than the value obtained from YVR because these data include all types of flights.

9) I assumed that passenger airport access patterns at the Prince George Airport are applicable to all other airports in BC except YVR (e.g., that the same access distances and vehicle choices hold true). Specific values for individual airports in BC may be higher or lower.

10) I assumed Prince George airport operations data are applicable to all other BC airports except YVR. This is probably a reasonable for assumption for the other larger airports in the province. The number of passengers processed for the eight largest airports after Vancouver International Airport are between 1.5 and 0.2 million. The Prince George values is in the mid-range at 0.4 million.

11) The year for which I obtained various data sets varies. Flight data, for example, was for 2010, emission data for Vancouver International Airport was 2007, Prince George Airport data was 2007, and Transport Canada data was 2008. The values of relevant date, however, do not seem to fluctuate dramatically from year to year.

12) I assumed that Vancouver International Airport's figure of 23,614 employees in 2010 also applies to 2008. Because the airport had 26,000 employees in 2005, the actual number of employees in 2008 was likely slightly higher than 23,614, but I could not locate the exact number. Further, I assumed that every employee worked five days a week, 48 weeks per year. The actual number of work days is likely somewhat lower.

In summary, my flight emissions and airport inventories are subject to numerous limitations; however, each seems relatively minor. Moreover, since some of the limitations results in a lower CF values and some in higher CF values, to a degree they will likely cancel one another out.

3.3 Methodology for Question 2

Question 2: What actions have BC-connected airlines and airports taken in the past or are they taking now to mitigate their CF in BC, and why were these actions taken?

A qualitative approach was chosen to answer this question. The two methods employed were document analysis and interviews with experts in the field of aviation. Each method is explained.

3.3.1 Document analysis

Two types of documents were analyzed: (1) government reports and (2) airline and airport documents. Government documents consisted of reports from the BC provincial government. The BC government has undertaken significant efforts to reduce carbon emissions in the province. None directly targets the aviation industry, however some indirectly affect it. The BC Carbon Tax, for instance, taxes aviation fuel for BC-domestic flights. Airline and airport documents were generally obtained from the Internet, although some were sent to me in response to information requests.

3.3.2 Interviews

The second major component for answering Question 2 was interviews with experts. Representatives from airports and airlines, and select aviation experts were contacted. Table 3.1 contains a list of the 16 airlines and 30 airports contacted. While BC airlines offer flights between 53 airports in the province, the remainder of the destinations served was not contacted because they are float plane destinations and as such aspects of land-based airports such as tarmac infrastructure do not apply. Moreover, because of the very limited scope of operations at most of these destinations, their overall CF is likely very low.

Table 3.1: Airlines and airports contacted

Airlines contacted	Airports contacted
Airspeed Aviation	QBC – Bella Coola
Air Canada Jazz	XQU – Qualicum Beach
Air Nootka	YAA – Anahim Lake
Central Mountain Air	YAZ – Tofino
Harbour Air / Westcoast Air	YBL – Campbell River
Hawkair	YCD – Nanaimo
Helijet Airways	YDQ – Dawson Creek
K.D. Air	YHS – Sechelt
Northern Hawk Aviation	YKA – Kamloops
Orca Airways	YLW – Kelowna
Pacific Coastal Airlines	YPR – Prince Rupert
Seair	YQQ – Comox
Swanberg Air	YQZ – Quesnel
Tofino Air	YVE – Vernon
Vancouver Island Air	YVR – Vancouver International Airport
Westjet	YWL – Wiliams Lake
	YPW – Powell River
	YXC – Cranbrook
	YXJ – Fort St. John
	YXS – Prince George
	YXT – Terrace
	YXX – Abbotsford
	YYD – Smithers
	YYE – Fort Nelson
	YYF – Penticton
	YYJ – Victoria
	YZP – Sandspit
	YZT – Port Hardy
	YZZ – Trail
	ZMT – Masset

The 16 airlines were contacted either by email or through submissions on an airline's website. Only three airlines responded to this first contact attempt, and of these only one airline, Hawkair, agreed to an interview. Harbour Air/Westcoast Air emailed relevant environmental information. An interview with Westjet was scheduled through a third party.

A second attempt to contact those airlines that had not responded was made by telephone. Contact information for each airline's head office was obtained from their website. Two of these phone calls, to Air Nootka and Swanberg Aviation, resulted in interviews. Orca Airways declined because they were in a merger process and did not have time for an interview. Northern Hawk Aviation could not be reached through the phone numbers listed on their website, or any other numbers found on the Internet. Voicemail messages were left with the environmental specialist at Air Canada Jazz, the president of Central Mountain Air, an operations expert at Helijet Airways, the Chief Pilot of K.D. Air, an operations expert at Pacific Coastal Airlines, Seair Seaplanes, the VP of Operations at Tofino Air, and the General Manager of Vancouver Island Air. However, none of these airlines returned the calls.

The commercial airports in BC that are served by airlines in the inventory were contacted as well, mostly by email submission through the airport website. Vancouver International Airport, Quesnel Airport, Victoria International Airport, and Prince George Airport responded and interviews were set up. Bella Coola responded and referred questions to Pacific Coastal Airlines, the airport's only commercial carrier. Qualicum Beach Airport sent links to environmental information on the city's website. Sechelt deferred the interview request to a later time, but did not respond to follow up requests. T. Burtig, the manager of Powell River airport, informed me by phone that there were no GHG reduction programs as the city is too small. Sandspit's airport agreed to an interview, but never replied to a specific scheduling request. Transport Canada was to provide information about the three airports under their authority in BC, but did not do so. A representative from one airport agreed to an interview but requested that neither the airport name nor interviewee's name be used.

Consent, however, was given to use the data received. In another case, a representative from one airport agreed to an interview; however, the material could not be used because the representative did not wish to sign the required consent sheet for the research project.

A number of other experts in the field of aviation, such as airplane manufacturers, environmental policy officers, climate lawyers, scholars, International Air Transport Association (IATA) and ICAO representatives, BC Ministry of Environment representatives, and offset companies were also contacted for interviews. A few of these requests resulted in interviews; the majority emailed information relevant to the thesis.

In total, 14 interviews—four airlines, four airports, two offset company representatives, one carbon lawyer, and three transportation experts—were conducted. All interviews were conducted in the period between September 2010 and March 2011. Eleven were conducted by telephone, two in person, and one through Skype. Interview questions were semi-structured (see Appendix 1 for a list of interview questions).

3.4 Methodology for Question 3

Question 3: What recommendations can be made to further reduce the CF of aviation in BC?

Answers to Question 3 emerged organically throughout the course of my research, but primarily through my analysis of the CF in Chapter 4 and on the results of my interviews and research in Chapter 5. With these pieces of information, I deduced recommendations to further reduce the CF of BC aviation.

3.5 Conclusion

In this chapter, I outlined the methodologies used to answer each of my research questions. In Chapter 4, the first research question—What is the CF of civil aviation in

BC?—is answered using the approach described in Section 3.2 above. In Chapter 5, the second research question—What are airlines and airports doing to reduced their CF?—is answered using the approach described in Section 3.3 above. And in Chapter 6, the recommendations for further reductions, answering the third research question and using the approach outlined in Section 3.4, are presented.

CHAPTER 4: A PORTRAIT OF BC's CIVIL AVIATION CARBON FOOTPRINT

4.1 Introduction

The purpose of this chapter is to provide a detailed snapshot of BC's civil aviation CF around the year 2010. BC's total CF is comprised of (1) the CF of all scheduled flights within the province and (2) the CF of all airports in the province. The CF of BC-internal flights is analysed by airline, by flight route, and by city-pair. The CF of airports is analysed in terms of the CF of airport operations and of passenger travel to and from airports. Calculation results are summarized in this chapter. Detailed numerical results for all calculations can be found in the tables in Appendix 2. Calculations are discussed in the following order: (1) total CF of civil aviation in BC, (2) CF by airline, (3) CF by route for a given airline, (4) CF by route per unit distance flown for a given airline, (5) CF by route per passenger for a given airline, (6) CF by city-pair, (7) CF per passenger travelling on BC flights, and (8) CF of airports in BC.

4.2 Total CF of civil aviation in BC

To determine the total CF for all scheduled flights within BC, the CO_2e emission value for these flights was first computed using each of the three calculators and then the average value of the three determined. Total CO_2e emissions for the year 2010 were as follows: 171,510 tonnes using the WRI calculator, 173,681 tonnes using the GHG Protocol Travel calculator, and 247,748 tonnes using the Offsetters calculator. The average of these three values is 197,646 tonnes. Rounding to the nearest thousand tonnes, for simplicity sake, yields an estimate of the CF of flights in BC of 198,000 tonnes of CO_2e. This value is the product of 181,272 annual flights within BC covering a total distance of 33,454,356 km (roughly 836 trips around the world). Compared to the BC aviation value of 1.50 Mt CO_2e

for the year 2008 listed in the British Columbia Greenhouse Gas Inventory (British Columbia Ministry of Environment 2010), BC-internal routes thus account for 13.2% of these emissions. However, as mentioned in footnote 5, the BC Ministry of Environment data includes all Canadian domestic flights which originate in BC, and includes all branches of aviation—commercial, military, charter, and agricultural. The calculations presented in this thesis are only for commercial aviation and only flights that lie entirely within BC.

The total CF determined by the Offsetters calculator is significantly higher than those for the WRI and GHG Protocol Travel calculators. In particular, the CF for longer-distance routes (flights of more than 450 km) was often significantly higher. Values were sometimes more than twice as high. Overall, Offsetters was 43.5% higher than the average value of the two other methods, both of which had almost identical totals. This is in part because Offsetters uses a multiplier value of 1.9 for flights over 464 km long.

Despite divergent results for longer routes, the emission calculations for short routes were generally similar for all three calculators. For only one route, Harbour Air's Vancouver–Victoria route, was the value obtained through Offsetters significantly lower than that of the other two methods. Offsetters provides a value of 0.01 tonnes of CO_2e per person per individual flight for this route, which may have been rounded down because only two significant figures were considered. The WRI and GHG Protocol Travel calculators, by comparison, calculated values of 0.0188 tonnes of CO_2e per person per individual flight and 0.0147 tonnes of CO_2e per person per individual flight for this route, respectively.

Total CO_2e emissions from BC airports for the year 2008 (the last year for which Transport Canada statistical data is available; 2007/2008 for Vancouver International Airport) was 326,928 tonnes. Rounding to the nearest thousand tonnes, this results in an airport CF of 327,000 tonnes of CO_2e for the year 2008. Therefore, the overall annual civil aviation CF in BC (for both flights and airports) around the year 2010 was 525,000 tonnes of CO_2e.

4.3 CF of BC airlines

A total of 16 airlines were included in this study. For each of these airlines, the total number of flights internal to BC (Table 4.1) and the total CF for each airline (Table 4.2) was calculated for the year 2010, and ranked by airline.

Table 4.1: 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 Jazz	45032	24.8
2	Harbour Air/Westcoast Air	40976	22.6
3	Pacific Coastal Airlines	19760	10.9
4	Helijet	17264	9.5
5	Seair	14560	8.0
6	Central Mountain Air	11076	6.1
7	KD Air	8112	4.5
8	Tofino Air	5824	3.2
9	Orca Airways	5200	2.9
10	Westjet	4888	2.7
11	Northern Hawk	3172	1.7
12	Hawkair	2704	1.5
13	Airspeed Aviation	1040	0.6
14	Swanberg Air	1040	0.6
15	Air Nootka	312	0.2
16	Vancouver Island Air	312	0.2
	TOTAL	181272	100

Table 4.2: Ranking of airlines by total annual CF

Rank	Airline	Annual CF (tonnes of CO_2e)	% of total CF
1	Air Canada Jazz	101625	51.3
2	Westjet	43684	22.1
3	Pacific Coastal	18363	9.3
4	Central Mountain Air	9561	4.8
5	Hawkair	8952	4.5
6	Harbour Air/Westcoast Air	7339	3.7
7	Helijet	3347	1.7
8	Northern Hawk	1273	0.64
9	Orca Air	856	0.43
10	Seair	747	0.38
11	KD Air	579	0.29
12	Tofino Air	492	0.25
13	Swanberg Aviation	355	0.18
14	Airspeed Aviation	349	0.18
15	Vancouver Island Air	97	0.05
16	Air Nootka	29	0.015
	TOTAL	197648	100

Within the BC-internal civil aviation sector, Air Canada Jazz offered the most annual internal flights and had the highest total annual emissions in BC in 2010—45,032 annual BC-internal flights or 24.8% of total flights, and 101,625 tonnes of CO_2e or 51.3% of the total BC CF. Harbour Air/Westcoast Air had the second most flights with 40,976 (22.6% of total flights), but ranked sixth in annual emissions with 7,339 tonnes of CO_2e (3.7% of the total BC CF). Pacific Coastal Airlines had the third most flights 19,760 (10.9% of total flights), and also ranked third in annual emissions with 18,363 tonnes of CO_2e (9.3% of the total BC CF).

Westjet was only the tenth largest BC civilian carrier in terms of number of flights with 4,888 (2.7% of total flights), but ranked second in annual emissions with 43,684 tonnes of CO_2e (22.1% of the total BC CF). Westjet is the only airline that operates large Boeing

737 jet aircraft on BC-internal routes. Although Westjet uses Boeing 737 Next Generation models, which are more efficient than older variants, these planes still emit more CO_2 overall than the other, smaller aircraft used in BC. For example, a Boeing 737-600 produces 7.214 kg CO_2/km (Pohling 2007) and a Boeing 737-800 produces 9.432 kg CO_2/km (based on a replication of Pohling's calculation method with data from Boeing (2009) while a Dash 8-300, the largest turboprop used in BC, produces only 5.418 kg CO_2/km (Mongu 2003). Emissions of a Boeing 737-600 per km are therefore 33.1% higher than those of a Dash 8-300, and emissions of a Boeing 737-800 are 74.0% higher than those of a Dash 8-300. Because of Air Canada Jazz's large number of annual flights and Westjet's large aircraft these two airlines have the largest aggregate CF of all airlines for BC-internal flights.

In the next two sections, I examine the geographical distribution of contributions to BC's total civil aviation CF. In Section 4.4, I analyze the CF of individual routes by airline and in Section 4.5, the CF of city-pairs.

4.4 CF of routes by airline

In this section, I first discuss the individual routes that make the greatest contribution to CF of routes in BC; second, the route carbon intensity; and third, the passenger carbon intensity. As always, results are based on averages for the three calculation methods.

4.4.1 CF of airline routes

In total, there are 96 scheduled airline routes in BC. Table 4.3 below contains a list of the top 20 individual routes by airline in BC for 2010 ranked by total CO_2e emission value. (See Appendix 2, Table A2.2 for all routes, and Appendix 2, Table A2.1 for an explanation of aircraft type abbreviations.)

Table 4.3: CF rank by airline route

Rank	Airline	Route and aircraft used	Total distance per year (km)	CF (tonnes of CO_2e per year)	Percent of total CF
1	Westjet	Vancouver–Prince George 737	1029496	21316	10.8
2	Air Canada Jazz	Vancouver–Fort St. John CRJ	2483520	16928	8.6
3	Westjet	Vancouver–Kelowna 737	238784	16112	8.2
4	Air Canada Jazz	Vancouver–Kelowna DH3	1397968	12020	6.1
5	Air Canada Jazz	Vancouver–Terrace DH3	1437280	10175	5.1
6	Air Canada Jazz	Vancouver–Prince George CRJ	1246232	8600	4.4
7	Air Canada Jazz	Vancouver–Kamloops DH3	781144	6954	3.5
8	Air Canada Jazz	Vancouver–Prince Rupert DH3	1016704	6904	3.5
9	Air Canada Jazz	Vancouver–Smithers DH3	919360	6558	3.3
10	Westjet	Victoria–Kelowna 737	238784	6256	3.2
11	Air Canada Jazz	Vancouver–Castlegar DH3	790400	5956	3.0
12	Air Canada Jazz	Vancouver–Cranbrook DH3	777504	5548	2.8
13	Air Canada Jazz	Vancouver–Prince George DH3	758576	5235	2.6

14	Hawkair	Vancouver–Terrace DH1	934232	4894	2.5
15	Air Canada Jazz	Vancouver–Penticton DH3	538720	4796	2.4
16	Air Canada Jazz	Vancouver–Victoria DH1	573872	3556	1.8
17	Pacific Coastal Airlines	Port Hardy–Bella Bella Saab340a	521976	3079	1.6
18	Harbour Air	Vancouver–Victoria DeHavilland Beaver and Otter	1386112	3071	1.6
19	Air Canada Jazz	Vancouver–Port Hardy DH3	544544	2743	1.4
20	Pacific Coastal Airlines	Vancouver–Cranbrook B1900 and Saab340	999648	2711	1.4

Overall, BC civil aviation is dominated by Air Canada Jazz routes. Air Canada Jazz operates 13 of the 20 most carbon-intensive routes in BC. Westjet's three BC-internal routes are among the ten most carbon-intensive routes (#1, #3, #10). Vancouver appears in 18 of the 20 most carbon-intensive routes. These results reflect the structure of the civil aviation system in BC. First, that Air Canada Jazz and Westjet are the two dominant carriers, and second, that Vancouver is the dominant hub city. Many smaller cities, rather than being connected between each other, are routed through Vancouver. Analysis of individual routes illuminates factors that contribute to a high CF. I discuss and analyze the top five routes. Examining these five is sufficient to highlight the main factors contributing to a high CF.

The individual route with the single highest CF in BC is Westjet's Vancouver–Prince George route, which generates approximately 21,316 tonnes of CO_2e per year. Assuming an overall CF of 198,000 tonnes of CO_2e per year, this route accounts for 10.8% of the entire CF of BC-internal civil aviation. This result is very high considering Westjet operates a maximum of only three daily return flights (for a total of 19 weekly return flights) between these two cities. It is the only airline that operates Boeing 737 jets on flights within BC. These planes feature 150+ seats and are by far the largest airplanes used on commercial BC-internal routes, compared with a maximum of 50 seats on other airlines serving BC. The use of these comparatively large airplanes is likely the main contributing factor to Westjet's large CF. The route with the second highest CF is Air Canada Jazz's Vancouver–Fort St. John route, which generates 16,928 tonnes of CO_2e per year. This route features 30 weekly return flights on 50-seat regional jets. In this case, the comparatively long distance travelled combined with the high volume of flights results in a large aggregate value, although the relative emissions per unit distance travelled are average for BC-internal routes.

The route with the third highest CF is Westjet's Vancouver–Kelowna route, which generates 16,112 tonnes of CO_2e per year. This route features over 21 weekly return flights using 150-seat Boeing 737 aircraft. The large CF most likely is due to the large aircraft used for a short route. The short route means that the plane's inefficient take-off and landing portions of the flight are contributing to its CF. In other words, more fuel is required for these portions than for the cruise section of the flight. The route with the fourth highest CF is Air Canada Jazz's Vancouver–Kelowna route, which generates 12,020 tonnes of CO_2e per year. Air Canada Jazz operates 47 weekly return flights using 50-seat Dash 8-300 aircraft on this route. While these turboprop aircraft generate lower emissions than jet aircraft, the large number of flights contributed to the large CF for this route. The route with the fifth highest CF is Air Canada Jazz's Vancouver–Terrace route, which generates 10,174 tonnes of CO_2e per year. Air Canada Jazz operates 20 weekly return flights using Dash 8-300 aircraft on this route. In this case, the comparatively long distances travelled result in the large CF.

In summary, the three main factors that seem to contribute to a high CF for an individual airline route are: first, type of aircraft (large jet aircraft have higher total emissions than regional jets or turboprops); second, travel distance (the greater the distance, the greater the emissions); and third, frequency of service (the greater the number of flights, the greater the emissions). These factors interact in a variety of ways to determine the rankings by airline route.

4.4.2 Route carbon intensity

To calculate the route carbon intensity, I divided the annual CF per airline route by the total distance travelled per year on the route, then multiplied by 100. I chose to display the results as "per 100 km flown" as this is easier to visualize than per km flown, and more aptly describes distances travelled by airplanes. Table 4.4 contains a list of the top 20 routes by airline in BC in 2010 ranked by CO_2e emissions per 100 km travelled.

Table 4.4: Rank by airline route carbon intensity

Rank	Airline	Route and aircraft used	CF (tonnes of CO_2e per year)	Total distance per year (km)	CI_R (tonnes of CO_2e per 100 km flown)
1	Westjet	Victoria–Kelowna 737	6256	238784	2.62
2	Westjet	Vancouver–Kelowna 737	16112	624624	2.58
3	Westjet	Vancouver–Prince George 737	21316	1029496	2.07
4	Air Canada Jazz	Vancouver–Kamloops DH3	6954	781144	0.89

5	Air Canada Jazz	Vancouver–Penticton DH3	4796	538720	0.89
6	Air Canada Jazz	Vancouver–Nanaimo DH3	2266	258336	0.88
7	Air Canada Jazz	Vancouver–Kelowna DH3	12020	1397968	0.86
8	Air Canada Jazz	Vancouver–Victoria DH3	2321	277264	0.84
9	Air Canada Jazz	Vancouver–Castlegar DH3	5956	790400	0.75
10	Air Canada Jazz	Vancouver–Cranbrook DH3	5548	777504	0.71
11	Air Canada Jazz	Vancouver–Smithers DH3	6558	919360	0.71
12	Air Canada Jazz	Vancouver–Terrace DH3	10175	1437280	0.71
13	Air Canada Jazz	Vancouver–Prince George CRJ	8600	1246232	0.69
14	Air Canada Jazz	Vancouver–Prince George DH3	5235	758576	0.69
15	Air Canada Jazz	Vancouver–Fort St. John CRJ	16928	2483520	0.68
16	Air Canada Jazz	Vancouver–Prince Rupert DH3	6904	1016704	0.68
17	Hawkair	Terrace–Smithers DH1	69	10192	0.67
18	Air Canada Jazz	Vancouver–Kamloops DH1	1065	161616	0.66
19	Air Canada Jazz	Vancouver–Victoria DH1	3556	573872	0.62
20	Hawkair	Vancouver–Prince Rupert DH1	1572	29952	0.59

Westjet, which flies only three routes that are entirely within BC, occupied the top three routes in terms of route carbon intensity (emissions per unit distance travelled). Air Canada Jazz accounts for 15 out of the 20 most carbon-intensive routes. In addition, the top 20 spots are dominated by routes to and from Vancouver, similar to Table 4.3. Again, these results reflect the structure of the BC aviation system—the dominance of Air Canada Jazz and Westjet airlines and of Vancouver International Airport. Analysis of individual routes illuminates those factors that contribute to a high CF per unit distance flown. I discuss and analyze the top five routes. Examining these five is sufficient to highlight the main factors contributing to a high CF per unit distance flown.

The airline route with the highest CF per unit distance flown is Westjet's Victoria–Kelowna route, producing 2.620 tonnes of CO_2e per 100 km flown (a value that is approximately four to five times higher than the CF per 100 km flown by most propeller-powered planes). This high value can likely be attributed to the use of a comparatively large aircraft on a short route. The route with the second highest CF per unit distance flown is Westjet's Vancouver–Kelowna route, which generates 2.580 tonnes of CO_2e per 100 km flown. Again, the use of a comparatively large airplane on an even shorter route likely significantly contributes to this large CF per unit distance travelled. The route with BC's highest total airline CF, Westjet's Vancouver–Prince George route, has the third highest CF per unit distance flown, generating 2.070 tonnes of CO_2e per 100 km flown. This was, to me, a surprising result as this route is fairly long with a relatively long cruise phase that should not be as emission-intensive as a short flight that mostly consists of the airplane climbing out from the departure airport and then approaching the destination airport. The high emissions can likely be attributed to the comparatively large aircraft type, especially since Air Canada

Jazz's flights on the same route (with two different, smaller aircraft types) only ranked #13 and #14.

The next 13 places in the ranking are occupied by Air Canada Jazz routes. The fourth most carbon-intensive route per unit distance flown is Air Canada Jazz's Vancouver–Kamloops route using a Dash 8-300 aircraft, which results in 0.890 tonnes CO_2e per 100 km flown. Air Canada Jazz also operates smaller Dash 8-100 aircraft on this route, which result in only 0.659 tonnes CO_2e per 100 km flown (#18 ranking). This is a short route and much of the flight is the inefficient take-off and landing phase, which contributes to the high relative CF per unit distance travelled. The fifth most carbon-intensive airline route per unit distance flown is Air Canada Jazz's Vancouver–Penticton route, which generates 0.890 tonnes CO_2e per 100 km flown. This is almost the same value as the Vancouver–Kamloops route discussed above. Vancouver–Penticton is almost identical in distance to Vancouver–Kamloops, which resulted in similar relative CF values. Again, on such a short flight a plane spends a significant portion of the flight on the inefficient take-off and landing phases.

The airline route with the lowest CF per 100 km flown in BC (not shown in Table 4.4; see Appendix 2, Table A2.2) is Air Nootka's Gold River–Kyuquot Sound route, which generates only 0.068 tonnes CO_2e per 100 km flown. This is a short route flown by a small floatplane, which likely explains why the CF is so low. Although the CF is very low, this type of flight does not provide a 'low CF per unit distance flown' template for civil aviation due to the limited number of seats (up to 5) and short distance travelled (approximately 120 km).

In summary, flights operated by Westjet using Boeing 737 jet aircraft have a significantly route carbon intensity compared to routes using turboprop aircraft or regional jets. For airline routes with turboprops or regional jets, it is the short flights with a significant portion of the flight in the take-off and landing phase that have the highest CF per unit distance flown. Westjet routes have the highest route carbon intensity, occupying the top three spots in the ranking, and Air Canada Jazz routes hold 15 out of the top 20 spots. Routes to and from Vancouver have the highest carbon intensity, occupying 18 out of the top 20 spots.

4.4.3 Passenger carbon intensity

To calculate passenger carbon intensity, I divided the annual CF per route by the total number of passengers flying the route. Table 4.5 contains a list of the top 20 routes by airline in BC in 2010 ranked by CO_2e emissions per passenger (i.e., passenger carbon intensity). The values are minimum values because I assumed a maximum passenger load.

Table 4.5: Rank by passenger carbon intensity

Rank	Airline	Route	Annual CF (tonnes of CO_2e)	Seats per plane	Annual flights	Annual seats per route	CI_P (tonnes of CO_2e per passenger)
1	Pacific Coastal Airlines	Port Hardy–Bella Bella Saab340a	3079	30	728	21840	0.14098
2	Air Canada Jazz	Vancouver–Fort St. John CRJ	16928	50	3120	156000	0.10851
3	Hawkair	Vancouver–Prince Rupert DH1	1572	37	416	15392	0.10213
4	Air Canada Jazz	Vancouver–Prince Rupert DH3	6904	50	1352	67600	0.10213
5	Air Canada Jazz	Vancouver–Terrace DH3	10175	50	2080	104000	0.09784
6	Hawkair	Vancouver–Terrace DH1	4894	37	1352	50024	0.09783

7	Pacific Coastal Airlines	Vancouver–Masset Saab340a	1828	30	624	18720	0.09765
8	Hawkair	Vancouver–Smithers DH1	2240	37	624	23088	0.09702
9	Air Canada Jazz	Vancouver–Smithers DH3	6558	50	1352	67600	0.09701
10	Central Mountain Air	Vancouver–Dawson Creek DH1	1415	37	416	15392	0.09193
11	Air Canada Jazz	Vancouver–Cranbrook DH3	5548	50	1456	72800	0.07621
12	Pacific Coastal Airlines	Vancouver–Cranbrook B1900 and Saab340	2710	19	1872	35568	0.07619
13	Air Canada Jazz	Vancouver–Sandspit DH3	2743	50	728	36400	0.07536
14	Central Mountain Air	Prince George–Kelowna B1900	839	18	624	11232	0.0747
15	Westjet	Vancouver–Prince George 737	21316	150	1976	296400	0.07192
16	Air Canada Jazz	Vancouver–Prince George DH3	5235	50	1456	72800	0.07191
17	Air Canada Jazz	Vancouver–Prince George CRJ	8600	50	2392	119600	0.07191
18	Central Mountain Air	Vancouver–Quesnel B1900	647	18	572	10296	0.06284
19	Pacific Coastal Airlines	Vancouver–Bella Coola B1900	859	19	728	13832	0.0621
20	Air Canada Jazz	Vancouver–Castlegar DH3	5956	50	1976	98800	0.06028

The results in Table 4.5 are significantly different from those in Table 4.4. Some routes that ranked highest for the overall CF per unit distance flown, especially Westjet routes, are not among the 20 highest routes for CF per passenger. While the overall emissions of larger planes, especially Westjet planes, are high, their comparatively high seating capacity means that emissions per passenger can be lower than for other routes. Analysis of individual routes illuminates those factors that contribute to a high CF per passenger. I discuss and analyze the top five routes. Examining these five is sufficient to highlight the main factors contributing to a high CF per passenger.

The route with the highest CF per passenger is Pacific Coastal Airline's Port Hardy–Bella Bella route, which generates 0.141 tonnes of CO_2e per passenger. This is a very short flight using a comparatively small aircraft. Because a large part of the flight is the inefficient take-off and landing and because of the limited number of passengers that can be carried, the CF per passenger is high.

The route with the second highest CF per passenger is Air Canada Jazz's Vancouver–Fort St. John route, which generates 0.109 tonnes of CO_2e per passenger. Although this flight has a fairly long and comparatively efficient cruise phase, the CF per passenger is high because of the long distance flown and moderate seating capacity of the plane used.

The routes with the third and fourth highest CF per passenger are for the same geographic route—Vancouver–Prince Rupert—operated by Hawkair and Air Canada Jazz, which generate 0.102 tonnes of CO_2e per passenger. As with the route above, the long distance flown and moderate seating capacity of the plane used seems to explain the high CF per passenger.

The route with the fifth highest CF per passenger is Air Canada Jazz's Vancouver–Terrace route, which generates 0.98 tonnes of CO_2e per passenger. The high emissions for this route as well are likely caused by the long flight distance and moderate seating capacity of the plane.

In summary, I found two basic patterns. First, very short routes using small aircraft have a high CF per unit passenger even though their overall emissions are low, and second, long routes on small or medium-sized planes have a high CF per passenger because of the long distances flown. Long flights on large airplanes have a lower CF per passenger because emissions are distributed between more passengers.

4.5 CF of routes by city-pairs

There are 56 destinations served by the 16 airlines considered in this study. In order to obtain a deeper understanding of the geographical distribution of civil aviation emissions in BC, I considered city-pairs. A city-pair includes all airlines serving a route and all airports within the two cities. For example, the Vancouver–Prince George route is served by Air Canada Jazz and Westjet, so the city-pair includes all Air Canada Jazz 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 this section, I first discuss city-pairs in BC with the highest aviation CF; second, the route carbon intensity of city-pairs; and third, the passenger carbon intensity of city-pairs.

4.5.1 CF of city-pairs

The city-pair CF is the total CF in 2010 for all flights by all airlines that operate between any airports in the two cities of the pair. There are 19 city-pairs in BC in this study. Table 4.6 contains a list of these city-pairs ranked by total CO_2e emissions.

Table 4.6: CF rank by city-pair

Rank	City-pair	Total yearly flights	Total distance per year (km)	Total CF (tonnes CO_2e per year)	Percent of total CF
1	Vancouver–Prince George	5824	3034304	35151	17.8
2	Vancouver–Kelowna	7072	2022592	28132	14.2
3	Vancouver–Terrace	3432	2371512	15068	7.6
4	Vancouver–Victoria	53248	4348448	13639	6.9
5	Vancouver–Smithers	1976	1343680	8798	4.5
6	Vancouver–Prince Rupert	1768	1329536	8476	4.3
7	Vancouver–Cranbrook	3328	1777152	8259	4.2
8	Vancouver–Kamloops	3640	942760	8019	4.1
9	Vancouver–Nanaimo	19396	1089036	4156	2.1
10	Vancouver–Williams Lake	2444	833404	2336	1.2
11	Vancouver–Port Hardy	1768	606424	1980	1
12	Fort Nelson–Fort St. John	1664	516360	1923	1
13	Vancouver–Campbell River	3224	554528	1807	0.9
14	Vancouver–Comox	2808	384696	1373	0.7
15	Vancouver–Trail	1352	550264	1270	0.6
16	Vancouver–Tofino	3120	592800	937	0.5
17	Abbotsford–Victoria	2184	194376	503	0.3
18	Comox–Campbell River	3224	125736	475	0.2
19	Terrace–Smithers	624	61152	236	0.1
	TOTAL	**122096**	**22678760**	**142538**	**72.2**

Similar to Tables 4.3 and 4.4, Table 4.6 is dominated by routes to and from Vancouver. Analysis of city-pairs illuminates those factors that contribute to a high city-pair CF. I discuss and analyze the top five city-pair routes. Examining these five is sufficient to highlight the main factors contributing to a high city-pair CF.

The city-pair with the highest aggregate CF is Vancouver–Prince George. The 5,824 annual flights on this route generate 35,151 tonnes of CO_2e over a distance of 3,034,304 km, roughly 17.8% of total BC civil aviation emissions, even though the route accounts for only 9% of total distance flown within BC. The comparatively long flight distance, large aircraft used by Westjet, and comparatively high frequency of flights (by both Air Canada Jazz and Westjet) result in a high aggregate CF.

The second most carbon-intensive city-pair is Vancouver–Kelowna. The 7,072 annual flights on this route generate 28,132 tonnes of CO_2e over a distance of 2,022,592 km, or 14.2% of total emissions over 6.1% of total distance travelled, making this the highest ratio of total emissions to total distance travelled. The results can be explained by the high frequency of flights (by both Air Canada Jazz and Westjet) and the large aircraft used by Westjet.

The third most carbon-intensive city-pair in BC is Vancouver–Terrace. The 3,432 annual flights on this route generate 15,068 tonnes of CO_2e over a distance of 2,371,512 km, or 7.6% of total emissions over 7.1% of total distance travelled. The long distance travelled and comparatively high number of annual flights (by Air Canada Jazz and Hawkair) result in a high aggregate CF.

The fourth most carbon-intensive city-pair in BC is Greater Vancouver–Greater Victoria. I was surprised by this result. I expected it to be in first place because of the large number of flights (almost 75 daily return flights) and the short distance (approximately 62 km). The short distance means that a significant portion of a flight consists of the inefficient take-off and landing phases. The 53,248 annual flights between this city-pair generate 13,639 tonnes of CO_2e over a total distance of 4,348,448 km, which is approximately 6.9% of total

BC aviation emissions over 13% of total distance travelled by BC-internal flights. I don't entirely trust this result because it is not clear to me how well calculator parameters capture emissions for very short flights. The emissions factors used by the calculators are averages for flights under roughly 500 km. Such factors may not accurately reflect emissions on very short flights with high volumes of flight traffic.

The fifth most carbon-intensive city-pair is Vancouver–Smithers. The 1,976 annual flights on this route generate 8,798 tonnes of CO_2e over a distance of 1,343,680 km, or 4.4% of total emissions over 4.0% of total distance travelled. This route, similar to the Vancouver–Terrace route, has a high aggregate CF because of the comparatively high number of annual flights (by Air Canada Jazz and Hawkair) travelling long distances between the two cities.

On both routes in the top five that Westjet serves (Vancouver–Prince George and Vancouver–Kelowna), the percentage of total BC aviation emissions generated is much larger than the percentage of total distance travelled, whereas in the case of Vancouver–Terrace, as well as Vancouver–Smithers, the percentage values are almost identical. This indicates that the Westjet routes, which are served by large jet aircraft, are much less carbon-efficient than other routes which feature turboprop or regional jet service.

In summary, long distance city-pairs tend to have large CFs. Those city-pairs for which Westjet operates Boeing 737 jets also have large CFs (for both long and short routes). Finally, a high frequency of flights also contributes to a high city-pair CF.

4.5.2 City-pair route carbon intensity

Table 4.7 below contains a ranked list of the 19 city-pairs in BC with their respective CO_2e emissions per unit distance (i.e., their city-pair route carbon intensity). Again, results are displayed as "per 100 km flown" for easier visualization.

Table 4.7: Rank by city-pair route carbon intensity

Rank	City-pair	Total yearly flights	Total distance per year (km)	CI_{CP-R} (tonnes of CO_2e per 100 km flown)
1	Vancouver–Kelowna	7072	2022592	1.391
2	Vancouver–Prince George	5824	3034304	1.158
3	Vancouver–Kamloops	3640	942760	0.851
4	Vancouver–Smithers	1976	1343680	0.655
5	Vancouver–Prince Rupert	1768	1329536	0.638
6	Vancouver–Terrace	3432	2371512	0.635
7	Vancouver–Cranbrook	3328	1777152	0.465
8	Terrace-Smithers	624	61152	0.386
9	Vancouver–Nanaimo	19396	1089036	0.382
10	Comox-Campbell River	3224	125736	0.378
11	Fort Nelson–Fort St. John	1664	516360	0.372
12	Vancouver–Comox	2808	384696	0.357
13	Vancouver–Port Hardy	1768	606424	0.327
14	Vancouver-Campbell River	3224	554528	0.326
15	Vancouver-Victoria	53248	4348448	0.314
16	Vancouver–Williams Lake	2444	833404	0.280
17	Abbotsford-Victoria	2184	194376	0.259
18	Vancouver–Trail	1352	550264	0.231
19	Vancouver–Tofino	3120	592800	0.158

Table 4.7, just as Tables 4.3, 4.4 and 4.6, is dominated by routes to and from Vancouver, but several short routes not involving Vancouver also rank fairly high. Routes on which large jet aircraft are used or which are short in distance have the highest relative CF. Analysis of city-pairs illuminates those factors that contribute to a high city-pair CF per unit distance flown. Examining the top three routes is sufficient to highlight the main factors contributing to a high city-pair CF per unit distance flown. However, I also discuss the Vancouver–Victoria city-pair, which ranked only #15, because of the large number of flights between the two cities.

The city-pair with the highest CF per unit distance flown is Vancouver–Kelowna, with 1.391 tonnes of CO_2e per 100 km flown. Flights between these cities are short, meaning that a large portion of a flight consists of the inefficient take-off and landing phases. Moreover, Westjet uses large Boeing 737 jets on this route. The city-pair with the second highest CF per unit distance flown is Vancouver–Prince George with 1.158 tonnes of CO_2e per 100 km flown. Although this route is fairly long and includes a comparatively lengthy cruise phase, Westjet's use of large Boeing 737 jets on this route means that overall this city-pair has a high CF per unit distance flown. Vancouver and Kamloops is the third most carbon-intensive city-pair per unit distance travelled, with 0.851 tonnes of CO_2e generated per 100 km flown. This city-pair is served only by Air Canada Jazz, and only with turboprop aircraft, making the high value somewhat surprising. However, the large portion of flights that is the take-off and landing phase on this short route, combined with the use of large turboprops (Air Canada Jazz uses, among others, Dash 8-300s on this route, which are the largest turboprops used in BC) seems to result in a high route carbon intensity.

Again, a completely unexpected result was the #15 rank of Vancouver–Victoria, generating an average 0.314 tonnes of CO_2e per 100 km flown. While many of the values towards the bottom of Table 4.6 are similar and the ranking close, I expected that the large number of flights on the short route between Vancouver and Victoria would make this city-pair much more carbon-intensive per unit distance travelled. Again, I am suspicious of the accuracy of this result.

By contrast, the city-pair with the lowest CF per unit distance travelled is Vancouver–Tofino, which generates only 0.158 tonnes of CO_2e per 100 km flown. It appears that for this city-pair, the relatively long distance covered by small airplanes resulted in the value.

However, although the value is very low, this type of flight does not provide a ‘low CF per unit distance flown’ template for civil aviation due to the limited number of seats available (between 5-13, depending on whether the aircraft is a Beech King Air, Piper Chieftain, Piper Navajo, DeHavilland Otter, DeHavilland Beaver, or Cessna) and the slow speed of these small airplanes (for example, a Piper Navajo cruises at about 400 km/hr (Airliners.net, "The Piper PA-31 Navajo/Pressurized Navajo", n.d.), while Westjet’s Boeing 737s cruise at up to 950 km/hr (Airliners.net, "The Boeing 737-600/700", n.d.)).

In summary, city-pairs served by Westjet Boeing 737 jets have the highest CF per unit distance travelled. This holds true for both short and long routes, but short routes have an even higher CF per unit distance travelled. For city-pairs on which airlines operate smaller regional jets or turboprops, short routes have a higher CF per unit distance travelled than do long routes.

4.5.3: City-pair passenger carbon intensity

Table 4.8 ranks the CF of a single passenger taking a one-way flight between BC city-pairs. This represents a minimum value because I have assumed in all of my calculations a full plane. If a plane is not full then the carbon emission per passenger will be somewhat higher. The table includes the city-pairs listed in the tables above as well as five additional routes (Port Hardy–Bella Bella, Vancouver–Fort St. John, Vancouver–Castlegar, Victoria–Kelowna, Vancouver–Penticton). Although these routes are only served by one airline, they were added because together with the city-pairs they account for more than 90% of the total annual BC flight CF. To calculate the CF per passenger per flight, I divided the CF of a given route by the total annual number of seats available on all flights of all airlines serving that route.

Table 4.8: Rank by city-pair passenger carbon intensity

Rank	City-pair	CF (tonnes CO_2e per year)	Total seats available	CI_{CP-P} (tonnes of CO_2e per passenger)
1	Port Hardy–Bella Bella	3079	21840	0.1410
2	Vancouver–Fort St. John	16928	156000	0.1085
3	Vancouver–Prince Rupert	8476	82992	0.1021
4	Vancouver–Terrace	15068	154024	0.0978
5	Vancouver–Smithers	8798	90688	0.0970
6	Vancouver–Cranbrook	8259	108368	0.0762
7	Vancouver–Prince George	35151	488800	0.0719
8	Vancouver–Castlegar	5956	98800	0.0603
9	Victoria–Kelowna	6256	109200	0.0573
10	Fort Nelson–Fort St. John	1923	34320	0.0560
11	Vancouver–Port Hardy	1980	37960	0.0522
12	Vancouver–Trail	1270	24752	0.0513
13	Vancouver–Williams Lake	2336	45864	0.0509
14	Vancouver–Kelowna	28132	572000	0.0492
15	Vancouver–Kamloops	8019	173888	0.0461
16	Vancouver–Penticton	4796	104000	0.0461
17	Vancouver–Tofino	937	26832	0.0349
18	Vancouver–Campbell River	1807	61152	0.0295
19	Vancouver–Comox	1373	53664	0.0256
20	Terrace–Smithers	236	13208	0.0179
21	Abbotsford–Victoria	503	29952	0.0168
22	Vancouver–Victoria	13639	1145768	0.0119
23	Vancouver–Nanaimo	4156	430872	0.0096
24	Comox–Campbell River	475	61152	0.0078

Analysis of city-pair passenger carbon intensity illuminates those factors that contribute to a high CF per passenger. Examining the top five routes is sufficient to highlight the main factors contributing to a high minimum CF per passenger. However, I also discuss the very low ranking of Vancouver–Victoria (#22) because the results again seem counterintuitive.

Table 4.8 is dominated by routes to and from Vancouver International Airport (18 of the 24 routes). The highest CF per passenger is found on the Port Hardy–Bella Bella route, which generates at least 0.141 tonnes of CO_2e per passenger. This route was also the third highest route in terms of CF per unit distance travelled per passenger. The very short flight distance likely makes the flight very inefficient, which results in a high CF per passenger. This was the only very short route operated by mostly very small planes that appears in the table. Similar routes would have likely ranked similarly but were not included because they do not account for significant overall emissions.

The city-pair with the second highest CF per passenger is Vancouver–Fort St. John, which generates at least 0.1085 tonnes of CO_2e per passenger. The long flight distance combined with use of relatively small aircraft with fewer seats likely contributed to the high passenger carbon intensity. The cities served by Westjet are not the top rated in Table 4.8. The city-pair with the third highest CF per passenger is Vancouver–Prince Rupert, which generates at least 0.1021 tonnes of CO_2e per passenger. As in the example above, the long flight distance and small aircraft likely contributed to the high aggregate CF per passenger. The city-pairs with the fourth and fifth highest CF per passenger are Vancouver–Terrace and Vancouver–Smithers, which generates at least 0.0978 tonnes of CO_2e per passenger and .097 tonnes of CO_2e per passenger, respectively. Again, it is likely the long flight distances that contribute to a high aggregate CF per passenger.

Vancouver–Victoria ranks only 22^{nd} in Table 4.8. Other very short routes, such as Vancouver–Nanaimo, also rank very low in the table. Even though the routes are carbon-inefficient because of the large portion dedicated to the take-off and landing phase, the comparatively large number of available seats on the planes (on average more than 30) means that the passenger carbon intensity is low.

In summary, very short routes on small airplanes have a high CF per passenger because a large portion of the flight is the inefficient take-off and landing phase. Very short routes on larger aircraft have a lower CF per passenger because the CF is distributed among more passengers. Long routes tend to have a high CF per passenger because of emission aggregation over the longer distances flown.

4.6 CF of BC airports

As previously discussed, the CF of BC airports is divided into a CF of airport operations (emissions from the airport authority and tenants) and a CF of passenger airport access (emissions from travel to and from an airport). Each is discussed.

4.6.1 CF of airport operations

Table 4.9 displays a ranking of the CFs of BC airports for airport operations.

Table 4.9: CF of airport operations

Airport	Passengers in 2008	CF (tonnes CO_2e)	Percentage of total emissions
Vancouver (International)	17,057,968	111890	75.6
Victoria (International)	1,501,189	8542	5.8
Kelowna	1,359,619	7736	5.2
Abbotsford	498,359	2836	1.9
Prince George	409,929	2331	1.6
Vancouver (Harbour)	374,483	2131	1.4
Victoria (Harbour)	313,953	1786	1.2
Comox	297,911	1695	1.1
Kamloops	219,461	1249	0.8
Other (91 airports)	1,360,926	7744	5.2
TOTAL	**23,393,798**	**147940**	**100.0**

Not surprisingly, Vancouver International Airport has the largest airport operations CF in BC with 111,890 tonnes of CO_2e, or 75.6% of the total for airport operations. This is expected given its size and role as the main hub for BC passenger travel. The other commercial airports rank according to passengers processed. This is also not surprising given that the CF calculation was based on passenger numbers. Victoria International Airport has the second largest CF with 8,542 tonnes of CO_2e, or 5.8% of the total. Kelowna has the third largest CF with 7,736 tonnes of CO_2e, or 5.2% of the total airport authority and tenant CF.

4.6.2 CF of passenger airport access

Table 4.10 displays a ranking of the CF of passenger access to and from BC airports. The passenger number for Vancouver International Airport represents the number of passengers who were traveling to or from the airport. It does not include transit passengers. Of the total number of passengers processed at the airport, 73% were non-transit and 27% were transit). Of the non-transit figure, 3% used public transportation to access the airport; they were not included in my calculations.

Table 4.10: CF of passenger airport access

Airport	**Passengers in 2008**	**CF (tonnes CO_2e)**	**Percentage of total emissions**
Vancouver (International)	12,078,747	117405	65.6
Victoria (International)	1,501,189	14592	8.2
Kelowna	1,359,619	13215	7.4
Abbotsford	498,359	4844	2.7
Prince George	409,929	3983	2.2
Vancouver (Harbour)	374,483	3640	2.0
Victoria (Harbour)	313,953	3052	1.7
Comox	297,911	2896	1.6
Kamloops	219,461	2133	1.2
Other (91 airports)	1,360,926	13228	7.4
TOTAL	**23,393,798**	**178988**	**100.0**

Vancouver International Airport has by far the highest passenger airport access CF with 117,405 tonnes of CO_2e, or 65.6% of total passenger airport access emissions. Victoria International Airport has the second highest passenger airport access CF with 14,592 tonnes of CO_2e, or 8.2% of total passenger airport access emissions. And Kelowna has the third highest passenger airport access CF with 13,215 tonnes of CO_2e, or 7.4% of total passenger airport access emissions.

4.7 Validation of results

How do my CF calculations compare to 'real world' emission values? There are at least two ways to verify the validity of my calculations. The first method would be to use data from airline companies who had actually measured GHG emissions for their flights. To the best of my knowledge, such information has not been published by the airlines serving BC. A second method would be to use engineering data from airplane manufacturers and calculate emissions from 'first principles', so to speak. Using data such as emissions for a given engine type, range and fuel capacity of an aircraft (and keeping in mind that a plane's fuel consumption varies depending on whether it is climbing, cruising, or descending), I could calculate GHGs emitted. Previously in this thesis (page 60), I gave a figure for CO_2 emitted per kilometre for a Boeing 737-800 aircraft (9.432 kg CO_2/km), the type used by Westjet. I used this factor and multiplied it by the distance on various routes to determine CO_2 emitted for the route. The results are generally less than one-half of the value I obtained by using the three CF calculators. However, this value is for CO_2 only; it seems to be based on the plane's cruising mode; and it does not include any type of radiative forcing factor (such as used by Offsetters). Adjusting for these missing elements would likely result in an emission value closer to those that I calculated. This is a very crude validation of my results.

While external and independent validation of my results would enhance their credibility, there unfortunately does not seem to be such data available to accomplish this.

4.8 Summary of results

In this chapter, I answered my first research question: What is the CF of civil aviation in BC? I presented a portrait of BC's civilian aviation CF around the year 2010. The total annual CF of BC-internal aviation is approximately 525,000 tonnes of CO_2e, of which 198,000 tonnes are produced by more than 180,000 annual flights by the 16 airlines I included in my research, travelling a total distance of more than 33,000,000 km; 148,000 tonnes are produced by airport operations; and 179,000 tonnes are produced by passenger airport access at 101 airports (while only 53 of these have scheduled air service, the rest had to be included because of lacking specific data availability but likely have a very low CF because they are very small).

The airline routes with the highest CF by are, in order, Westjet's Vancouver–Prince George, Air Canada Jazz's Vancouver–Fort St. John, Westjet's Vancouver–Kelowna, Air Canada Jazz's Vancouver–Kelowna, and Air Canada Jazz's Vancouver–Terrace. Together, these five routes account for almost 40% of the total BC civil aviation CF while travelling only 21% of the distance of all BC domestic flights. The airline routes with the highest CF per unit distance travelled are, in order, Westjet's Victoria–Kelowna, Westjet's Vancouver–Kelowna, Westjet's Vancouver–Prince George, Air Canada Jazz's Vancouver–Kamloops, and Air Canada Jazz's Vancouver–Penticton. The airline routes with the highest CF per passenger are, in order, Pacific Coastal Airlines' Port Hardy–Bella Bella, Air Canada Jazz's Vancouver–Fort St. John, Hawkair's Vancouver–Prince Rupert, Air Canada Jazz's Vancouver–Prince Rupert, and Air Canada Jazz's Vancouver–Terrace.

The city-pairs with the highest CF are, in order, Vancouver and Prince George, Vancouver and Kelowna, Vancouver and Terrace, Vancouver and Victoria, and Vancouver and Smithers. The city-pairs with the highest CF per unit distance travelled are, in order, Vancouver and Kelowna, Vancouver and Prince George, Vancouver and Kamloops, Vancouver and Smithers, and Vancouver and Prince Rupert. The city-pairs with the highest CF per passenger per flight are, in order, Port Hardy and Bella Bella, Vancouver and Fort St. John, Vancouver and Prince Rupert, Vancouver and Terrace, and Vancouver and Smithers.

The three key factors that explain the airline route rankings are aircraft size, flight distance, and flight frequency. Based on my calculations, the airline routes with the highest CF are, not surprisingly, those that are flown with large aircraft, that traverse long distances, and/or that have high flight frequencies. For route carbon intensity, it is short routes or those which are served by large jet aircraft that have the highest results. Westjet routes have by far the highest route carbon intensity.

In the case of city-pairs, Westjet's large jets contribute to the high CF of the Vancouver–Prince George route, while high frequencies or long distances resulted in the high CF of the other discussed city-pairs. For city-pair route carbon intensity, it is those city-pairs which are located close to one another (i.e., a large portion of the flight is the inefficient take-off and landing), or those which are served by large jet aircraft that have the highest results. Very short flights on small airplanes have a high passenger carbon intensity. Longer flights tend to have a high passenger carbon intensity. While my expectation was to find that the large number of daily flights between Greater Vancouver and Greater Victoria would both be a significant contributor to the overall CF of BC aviation and have a high CF per unit distance travelled, the results for both were much lower than I expected. As already stated, I suspect that this result is not accurate.

The airports with the highest airport operations CFs are, in order, Vancouver, Victoria, and Kelowna. These airports have the highest passenger volumes. Similarly, the airports with the highest passenger airport access CFs are, in order, Vancouver, Victoria, and Kelowna.

Now that a picture of the CF of civil aviation in BC has been constructed, I turn to GHG reduction strategies that BC airlines and airports have undertaken to reduce this CF. This is the focus of the next chapter.

CHAPTER 5: AIRLINE INDUSTRY CF REDUCTION EFFORTS

5.1 Introduction

Airlines and airports in BC are active in reducing their GHG emissions. In this chapter, I answer my second research question: What actions have BC-connected airlines and airports taken to mitigate their CF in BC, and why have they taken these actions? The purpose of this chapter is to create a rough picture of past and current mitigation efforts by airline companies and airports operating in BC. I report on and analyze what airlines and airports have done and are currently doing to reduce their CF, and why they have engaged or are engaging in these efforts. Section 5.2 contains a description of airline actions and motivations, and Section 5.3 a description of airport actions and motivations. Section 5.4 presents a summary and analysis of these actions and motivations.

Research Question #2 was answered by means of document analysis and interviews. The documents analyzed were primarily websites and company reports. I also conducted 14 interviews. Table 5.1 contains a list the interviewees, in alphabetical order. All but one agreed to have their names used in this thesis. The person who chose not to have their name used is listed as “Anonymous”. The interviewee’s airport is referred to in this chapter as “a small airport in BC”.

Table 5.1: List of interviewees

Interviewee	Position
Alderson, Jennifer	Environmental Analyst, Vancouver Airport Authority
Anonymous	Operations Manager, small airport in BC
Caldwell, Ian	Senior Pilot, Westjet
Deacon, John	Carbon-trading lawyer
Green, Cuyler	Director of Operations, Prince George Airport
Hayward, Rod	General Manager, Hawkair
Hunt, Harlene	Transportation Manager, City of Quesnel
Janssen, Tony	Operations Manager, Swanberg Air
Killian, Doug	Chief Pilot, Air Nootka
Killkelly, Brian	Director, Supply Origination, *Native*Energy Inc.
Mazzi, Eric	Power Smart® Instructor, Demand-Side Energy Efficiency & Conservation
Paradine, Dennis	Senior Climate Change Policy Analyst, Climate Action Secretariat, BC Ministry of Environment
Reynolds, Conor	UBC Bridge Program Fellow, Institute for Resources, Environment & Sustainability, University of British Columbia
Stein, Jacob	Business Development Specialist, Pacific Carbon Trust

5.2 CF reduction efforts by airlines

In this section, I discuss the CF reduction efforts of seven airlines in order of their contribution to the BC airline CF, starting with the largest contributor, as follows: Air Canada Jazz, Westjet, Hawkair, Westcoast Air/Harbour Air, Helijet, Swanberg Air, and Air Nootka. For each airline, I first introduce the company and state where I obtained the information about it. I then discuss the CF reduction efforts, followed by the company's motivations for taking these actions.

5.2.1 Air Canada Jazz

Air Canada is the largest airline in Canada, and all of its BC-internal routes are operated by its subsidiary, Air Canada Jazz. Air Canada Jazz flights account for 51.3% of the

CF of all BC-internal flights, which means that its stance towards GHG mitigation has significant implications for the CF of aviation in BC, and Canada in general. Unfortunately, interview and information requests to Air Canada Jazz were not returned. Therefore, the information presented here is based solely on the airline's website.

According to the Air Canada Jazz website (http://www.flyjazz.ca/en/home/default.aspx), the company is "committed to safeguarding the environment and minimizing or reducing adverse environmental impacts of its operations" (Air Canada Jazz, "The Environment", n.d.). The website goes on to list a number of environmental commitments, such as using resources efficiently and minimizing waste and emissions. While such commitments are laudable, there is no indication on the website of the extent to which these commitments have been implemented. Specifically, there is no information on GHG reduction measures.

However, passengers buying tickets for Air Canada Jazz flights on the Air Canada website are given the option of purchasing carbon offsets for the emissions generated during their flight through the Zerofootprint program. The Air Canada website states that "Each flight you take produces carbon dioxide (CO_2), which contributes to climate change. At Air Canada we believe customers should have the option of offsetting the effects of their flight" (Air Canada, "Carbon Offset Program", n.d.). No educational information is provided as to why passengers should engage in offsetting. Moreover, the offsetting information is not very visible on the airline's website. This may be because Air Canada, as Canada's largest carrier, does not want to highlight the climate impact of aviation. Or, it may be because Zerofootprint achieved only a "weak performance" rating in a carbon offset company ranking by the David Suzuki Foundation. Zerofootprint scored only 53/100, compared to scores of up to 85/100 among Zerofootprint's competitors (scores of 80/100 and above resulted in a "strong performance" rating) (David Suzuki Foundation 2009, 10).

For the Prince George to Vancouver route, the Zerofootprint website dedicated to Air Canada offsets (https://aircanada.zerofootprintoffsets.com) calculates emissions of 0.11 tonnes of CO_2—not CO_2e—per passenger compared to 0.05 tonnes of CO_2e per passenger for the WRI calculator, 0.06 tonnes of CO_2e per passenger for the GHG Protocol Travel calculator, and 0.10 tonnes of CO_2e per passenger for the Offsetters calculator. Zerofootprint does not discuss how it calculates carbon emissions, so it is not possible to compare it to Offsetters' methodology. Air Canada states that between the launch of the Zerofootprint partnership in May 2007 and September 2010, 16,414 tonnes of CO_2 were offset for *all* Air Canada flights—BC-domestic, Canadian-domestic, and international, including those for Air Canada Jazz (Air Canada, "Carbon Offset Program", n.d.). This value is extremely low compared to the annual 198,000 tonnes of CO_2e generated by BC-internal flights alone, of which 102,000 tonnes are generated by Air Canada Jazz flights. Thus, in approximately 3.5 years, Zerofootprint has offset for the entire Air Canada system the equivalent of only about 16% of Air Canada Jazz's emissions for one year in BC.

In summary, I had a difficult time determining what efforts Air Canada and Air Canada Jazz have made to reduce their CF in BC. If the minimal statements on the Air Canada website, and its relationship with the questionable offset company, Zerofootprint, are any indication, it seems that its efforts are modest at best. Furthermore, web documents gave little indication of motivations for Air Canada's CF reduction actions.

5.2.2 Westjet

Westjet is Canada's second-largest airline and is responsible for 22.1% of the BC airline CF. As such, like Air Canada Jazz, its stance towards GHG mitigation has significant implications for the CF of aviation in BC, and Canada in general. The data presented in this section were obtained from information found on the Westjet corporate website and from an interview with Ian Caldwell, a Senior Pilot with Westjet.

Westjet has one of the youngest, most fuel-efficient fleets in North America, which, after extensive upgrades, has 30% lower emissions than its previous fleet. This was achieved by using a combination of blended winglet technology[17], modern engines, flying with less potable water, using more direct, precision landing approaches, and incorporating other up-to-date technical developments (Westjet, "Environmental commitment", n.d.). Westjet promotes single-engine taxi when appropriate to reduce emissions generated during a plane's transit from the runway to its parking position. It has also removed some of the cockpit manuals that are rarely used during flights and that can just as easily be accessed through radio uplink. While each manual weighs only five to six pounds, overall weight reduction for all the aircraft in Westjet's fleet and roughly 400 flights per day adds up to significant fuel savings and thus emission reductions. Similar fuel savings are achieved by avoiding what is called double-catering, meaning that instead of loading beverages for a flight and the corresponding return flight at the same time, catering is loaded for each individual flight before that flight. Again, this weight reduction adds up to considerable fuel and emission reductions. However, planes in fact often double-cater because of cost-savings associated

[17] Winglets are wing tip extensions that curve upward and reduce drag and provide extra lift. Among other benefits, they enable the plane to climb and cruise at lower thrust, thereby reducing fuel consumption and emissions (Brady 1999).

with purchasing all catering at large airports, and to speed up a plane's turnaround time for the next flight. Westjet does not offer passengers the option to purchase offsets for the emissions generated during their flight.

Based on the interview, the following are some of the influences on Westjet's corporate decisions to reduce its CF. First, financial benefits are the primary motivation for its GHG reduction efforts. In particular, reductions in fuel consumption, which reduce GHG emissions, translate into cost savings. Second, government regulation, in particular the BC Carbon Tax, has had an impact on the airline's operations. Since the introduction of the tax, the operational cost index—the ratio of fuel costs to fixed costs of operating an airplane—has gone up. This means, for instance, that on shorter flights, such as Calgary–Kelowna–Vancouver, it is more economical to tanker the fuel for both flights in Calgary (thereby avoiding the tax), even though 5-7% of the extra fuel is burned just to carry it. In general, though, stricter government environmental regulation will force the airline to become greener. For example, a mandated carbon offset program would likely be more effective at reducing Westjet's CF. However, the airline would be opposed to becoming a de facto tax collector for the government, citing concern that passengers, when purchasing their ticket, would see mandated offsets as money paid to the airline rather than a tax passed on to the government. A third influence on Westjet's corporate decisions is consumer opinion. Consumer opinion or pressure is currently not strong. Westjet's passengers seem to be aware of the CF of aviation but do not pay close attention to it. Westjet currently does not engage in high profile efforts to increase passenger awareness.

In summary, Westjet seems to be proactive in reducing its CF system-wide. None of these efforts are specifically targeted to BC. The primary motivations for reduction efforts seem to be, first and foremost, financial benefits, secondly, government regulation in BC (specifically, the BC Carbon Tax), and, weakly, consumer preferences.

5.2.3 Hawkair

Hawkair is a regional carrier based in Terrace offering service between Northern BC and Vancouver, and is responsible for 4.5% of the BC airline CF. The data presented in this section was obtained through an interview with Rod Hayward, General Manager of Hawkair.

Hayward stated that the CF of aviation has never come up as an issue for his airline, and that the company has never calculated the CF of its operations. Hawkair's situation provides good perspective on influences inhibiting CF reduction efforts. Hawkair's website includes a statement that the company respects and appreciates the environment (Hawkair, "Company Mission and Vision", n.d.). However, as Hayward made clear, the company is in a highly competitive market; thus, it has to be concerned about anything that puts financial stress on the company. Currently, this means its CF is not a priority. Hawkair's customer base also dictates a lower priority for CF reduction efforts. Many of Hawkair's customers come from rural parts of BC. For them, flying can be a necessary part of life, whether for doctor's appointments or leisure travel, because of the very long distances involved. Hawkair believes its turboprop aircraft are more fuel-efficient than driving a car over long distances in rural BC. Hawkair's customers buy tickets with schedule and price in mind; CFs are "the last thing they think about".

In summary, Hawkair does not engage in any direct CF reduction efforts. Influences on its carbon-related decision-making are impact on the company's financial well-being and orientation of its unique customer base.

5.2.4 Westcoast Air/Harbour Air

Westcoast Air and Harbour Air are part of the same company, even though they operate under separate names. The airlines operate flights between Greater Vancouver and southern Vancouver Island and its outlying Gulf Islands, and are responsible for 3.7% of the BC airline CF. Interview requests with these two airlines were not granted. This was unfortunate given their notable CF reduction efforts. In lieu of an interview, the company referred me to their websites, which is where all information in this section was drawn. There are two website, one for each company, but they are for all practical purposes identical.

In 2007 all of Westcoast Air and Harbour Air's flight services and corporate operations became carbon-neutral (Westcoast Air 2007). This sets these companies apart from other airlines serving BC, with the exception of Helijet (discussed below). Carbon-neutrality was achieved by GHG reduction measures and carbon offsets, provided by Offsetters[18], for all flights (Westcoast Air 2007). The cost of the offset per passenger per flight is not stated on the airlines' websites. The airlines claim they provide the most climate-friendly way to travel between downtown Vancouver and Victoria, compared to other airlines, car, ferry, or helicopter (Westcoast Air 2007). Lastly, Harbour Air and Westcoast Air also offset all of their corporate emissions, including heating, cooling and lighting at all facilities, ground transportation services, employee business travel and commuting to work, and paper and commercial printing (Westcoast Air 2007).

The only motivation for embracing corporate environmental change listed on the companies' website is that they are cognisant of the impact aviation has on the environment (Westcoast Air 2007). However, it can be surmised that the significant reduction in energy

[18] Offsetters' carbon credits are third-party verified and additional, meaning that they result from projects that would not have taken place without the Offsetters program (Westcoast Air 2007).

consumption also presented a financial incentive for the airlines, and that, in contrast to Hawkair's customer base, Westcoast Air and Harbour Air's business is centered in the more environmentally-conscious Vancouver and Victoria metropolitan areas.

In summary, Westcoast Air/Harbour Air provide an outstanding example of how small airlines can achieve carbon neutrality while still providing a viable business model in a competitive industry. Unfortunately, I was unable to directly, though an interview, determine the motivations behind their CF reduction efforts.

5.2.5 Helijet

Helijet provides scheduled helicopter service between Vancouver and Victoria, and is responsible for 1.7% of the BC airline CF. The data presented in this section was obtained from the company's website on carbon neutrality. Interview requests went unanswered.

Helijet was not the first airline in BC to become carbon-neutral (this honour belongs to Westcoast/Harbour Air), but it is currently the only airline to partner with the Pacific Carbon Trust (PCT)[19] to offer carbon-neutral flights, starting in March 2009. This decision was made so that all offsets would go towards projects in BC (Helijet, "Fly Carbon Neutral", n.d.). To achieve carbon neutrality, Helijet began charging a carbon offset contribution of $1.37 per flight between Vancouver to Victoria starting in 2009. The company has offset a total of 4,215 tonnes of carbon up to the end of 2010 (Helijet, "Fly Carbon Neutral", n.d.). This value, over a period of less than two years, is in accordance with my estimate of annual emissions of 3,347 tonnes of carbon produced by Helijet flights. The airline has also installed smokeless engine liners on its helicopters to increase efficiency and reduce the amount of

---

[19] The PCT is a Crown Corporation of the BC provincial government created to deliver quality made-in-BC GHG offsets (Pacific Carbon Trust, "About Pacific Carbon Trust", n.d.). It invests only in BC projects that will result in GHG reductions.

particulate matter emitted (Helijet, "Fly Carbon Neutral", n.d.). Lastly, Helijet has made a commitment to single source suppliers[20], uses local or environmentally-responsible products such as ethically-sourced coffee and eco-friendly cups and bowls whenever possible, and has partnered with the shipping company, Costless Express, which is also a carbon-neutral company (Helijet, "Fly Carbon Neutral", n.d.).

Helijet states: “Respect for our environment has become more important than ever to all of us and we trust you will join us as we strive to develop new and sustainable business practices while continuing to offer you the safe, fast and reliable service you expect” (Helijet, "Fly Carbon Neutral", n.d.). The company seems to be stating that for both company-internal reasons and social-external reasons, it has made its corporate decisions. Helijet’s clientele is very similar to that of Westcoast Air/Harbour Air, both serving the same environmentally-conscious geographic region (i.e., the Vancouver and Victoria metropolitan areas).

In summary, Helijet is also an outstanding example of how small airlines can achieve carbon neutrality while still providing a viable business model in a competitive industry. It is unfortunate I was unable to interview the company. Both Helijet and Westcoast Air/Harbour Air are proactively engaged in reducing their CF, and they prominently emphasize their environmental credentials on their websites. As far as I could ascertain, the influences on these companies’ corporate decision-making was similar.

5.2.6 Swanberg Air

Swanberg Air is a small regional carrier operating flights within northern BC and between northern BC and northern Alberta, and is responsible for 0.2% of the BC airline CF.

---

[20] Helijet states that single source suppliers help reduce environmental impact by reducing the number of warehouses being shipped to and the number of delivery trucks transporting supplies (Helijet, "Fly Carbon Neutral", n.d.).

It is similar to Hawkair, but smaller. The data presented in this section were obtained through an interview with Tony Janssen, Operations Manager at Swanberg Air. The airline's website does not contain any environmental information.

Like Hawkair, the CF of aviation has not been a high priority issue for Swanberg Air. It has come up only in terms of reducing fuel consumption and thus cost savings. The airline has never calculated its CF, does not participate in any offset programs for corporate operations, and does not offer its customers the opportunity to offset their flight emissions. However, it has been involved in the Calgary International Airport's long-term planning, and acknowledges that while the emphasis has been on safety and efficiency, emission reductions are a beneficial by-product of such improvements. Government regulation, such as the BC Carbon Tax, may in the future motivate Swanberg Air to engage in GHG reduction efforts, but at its current level, the tax is passed on to the customer. There is no customer demand for the airline to reduce its CF. This can in part be explained by the nature of Swanberg's clientele, the majority of whom work in the oil fields of Northern BC and northern Alberta.

In summary, Swanberg Air has not taken explicit steps to reduce its CF. Influences on its lack of CF reduction measures seem to be similar to those of Hawkair; namely, potential negative impact on the company's financial state, low level of government regulation, and disposition of its customer base.

5.2.7 Air Nootka

Air Nootka is a small carrier conducting operations in remote, rural parts of BC, and is responsible for a mere 29 tonnes of CO_2e per year, or 0.015% of the total BC airline CF of 198,000 tonnes. The company is similar to Hawkair and Swanberg Air, but smaller than both. The data presented in this section were obtained from an interview with Doug Killian, a

Senior Pilot with Air Nootka. The airline's website does not contain any environmental information.

The CF of aviation is not a major concern for Air Nootka. The company has not attempted to calculate the CF of its operations, primarily because of the small size and limited scope of operations. The airline does, however, use GPS units in its airplanes which allow for more precise and hence more efficient navigation. Air Nootka does not participate in any offset programs either for corporate operations or for passenger travel. Regarding motivation for engaging in CF reduction efforts, Air Nootka desires to become more environmentally-friendly, but at present it is simply not economically feasible. The airline is not aware of any passengers ever having brought up the topic of aviation's CF as an issue that concerned them. The main driver of future corporate environmental change to reduce its CF would, the company indicated, would likely come from legislation.

In summary, Air Nootka has not taken steps to reduce its CF. The reasons are similar to those for Hawkair and Swanberg Air—cost, lack of government mandates, and lack of pressure from its customer base.

5.3 CF reduction efforts by airports

In this section I discuss the CF reduction efforts of six airports in order of their contribution to the BC airport CF, starting with the largest contributor, as follows: Vancouver International Airport, a small airport in BC, Prince George, Quesnel, Powell River, and Qualicum Beach. For each airport, I first introduce the airport and state where I obtained the information about it, then discuss its CF reduction efforts, followed by the influences on its decisions or non-decisions.

5.3.1 Vancouver International Airport

Vancouver International Airport (YVR) is by far the province's largest airport in terms of operations and CF (it accounts for about 70% of total BC airport emissions or 229,000 tonnes), and as such has a significant impact on the CF of civil aviation in BC. Vancouver is the only airport in BC that has its own environmental sustainability team and that engages in a wide range of GHG reduction efforts. The data presented in this section were obtained through an interview with Jennifer Alderson, Environmental Analyst with the Vancouver Airport Authority, and the airport's "Community & Environment" webpage (http://www.yvr.ca/en/community-environment.aspx).

The airport completed two separate emission inventories in 2007. The first tallied emissions from stationary and mobile sources that were associated with either the airport authority or its tenants. The second tallied emissions for Sea Island, the name of the land area where the airport is located, and included stationary sources such as generators, boilers, space-heating furnaces and the like, and mobile sources such as landing and departing aircraft, vehicles (both ground support equipment and vehicles entering or leaving Sea Island on access roads), and airfield maintenance equipment. Airplane take-off and landing emissions were included in the inventory for informational purposes even though they are not under the airport's direct control. These two inventories provided the airport with its first GHG emissions benchmark.

Vancouver International Airport's CF philosophy is to reduce emissions rather than to offset them. It states on its website: "Vancouver Airport Authority's primary objective is to build, operate and maintain a safe, secure and environmentally sustainable airport for our employees and customers alike." Consequently, the airport's strategic priorities are to reduce emissions; reduce energy usage; reduce waste; communication, awareness, recognition and education; and continuous improvement of core environmental programs (Vancouver International Airport, "Our Environmental Management Plan", n.d.). Since many emission sources are out of its control, the airport does not use any carbon offset programs. Rather it focuses on reducing the emissions it can control.

YVR airport operations

The airport was an early leader in instituting energy reduction measures. It joined BC Hydro's Power Smart program[21] in 1999 and became the first organization to become a Power Smart Certified business (Vancouver International Airport, "History", n.d.). It reduces energy usage in building through such measures as turning off lights when areas are not being used and shutting down monitors when not in use. Its international terminal was designed to be a power-smart facility. This has resulted energy savings (by the end of 2010) of about 212 gigawatt-hours and over $8 million since the program started (interview, Jennifer Alderson, Environmental Analyst, Vancouver Airport Authority). The airport also uses solar panels for hot water heating, which has led to a 25% decrease in natural gas consumption at the airport's domestic terminal since 2001 and which results in energy savings of $110,000 annually (Vancouver International Airport, "Sustainability Stories", n.d.). The airport further has an incentive program for alternative fuel taxis serving the airport, which has improved average taxi fuel economy by 47% between 2004 and 2009, resulting in annual CO_2e reductions of 8,422 tonnes; is the first airport in Canada to install a living wall, which is home to almost 30,000 plants which offsets some emissions; and

[21] BC Hydro is a BC crown corporation that supplies electricity for the province. Its Power Smart program was established in 1989 to support energy conservation measures as an alternative to constructing new electricity generation facilities (http://www.bchydro.com/powersmart/).

installed 450 recycling containers between 2005 and 2009 to encourage recycling throughout the airport (Vancouver International Airport, "Sustainability Stories", n.d.).

The airport found that a major source of GHGs was auxiliary power units (APUs). APUs are generators on airplanes that use the plane's fuel to power functions such as air conditioning while the plane is parked. The airport consequently invested a significant part of the Airport Improvement Fee it collects into gate services that reduce the need for planes to use their APUs. Specifically, movable gates are supplied with a ground power unit using hydroelectric power and preconditioned air units to provide air-conditioning to the aircraft. This resulted in large emission reductions.

Many airport operations are not under the sole authority of the airport such as single-engine taxiing, which is under the control of the airline, and use of high-speed taxiways[22], which is under the control of Navigation Canada. However, it is the airport's responsibility to provide the infrastructure that enables the other actors to engage in these procedures. The airport is currently broadening the pavement of some high-speed taxiways so that they can support newer, wider airplanes to move more efficiently about the airfield.

YVR passenger & employee travel

Regarding passenger and employee travel to and from the airport, Vancouver International Airport is the only airport in BC that has comprehensive public transit access. The City of Vancouver constructed the Canada Line train, which runs from Vancouver's downtown to the airport, for the 2010 Vancouver Olympic Games. The airport authority contributed $300 million to this project. There was an immediate GHG reduction of almost 33,000 tonnes of CO_2e after the train line opened, as roughly 15% of the airport's passengers

---

[22] High-speed taxiways allow airplanes to vacate runways at higher speeds after landing compared to regular taxiways. The runway is then available faster for the next approaching airplane, which reduces congestion.

(out of about 15.5 million non-transit passengers annually in 2010) and 13% of its employees (out of 23,614 in 2010) now use it to travel to and from the airport[23]. To further take advantage of the train line, employee parking has been moved from a variety of lots around the terminal to the closest stop on the Canada Line to Sea Island. From there, employees take the train to the terminal building, which reduces their daily car commute by 5 km and results in an annual emission reduction of 880 tonnes of GHGs.

The airport has a Green Commuter Rebate program to reward airport authority employees who commute via a mode other than single-occupancy vehicles—walking, cycling, taking public transit, or ride sharing, as well as commuting on a motorcycle made in 2006 or later. In recognition of the parking space that they are offsetting, the program offers $50 per month to those who qualify. About one-third of airport employees participate in the program.

YVR education & awareness

Vancouver International Airport has engaged in significant efforts to educate its customers and employees on environmentally-friendly behaviour. At the employee level, the airport promotes a 'green culture' among its employees in the following ways:

- The airport has an internal Green Team that has stewards in all of the airport departments who encourage what the airport calls "on the ground greening".
- The airport publishes a "Clear Skies Bulletin" that promotes environmentally-friendly behaviour.

---

[23] Emission reductions for passengers were obtained by multiplying 75% the airport's 16.8 million passengers in 2010 (those who did not transit at the airport), then by the 15% that took the Canada Line, and then by 0.00972 tonnes of CO_2e per passenger that are saved by not using a car or taxi to access the airport. Emission reductions for employee commuting were obtained by multiplying yearly employee trips (23,614 employees times an average 480 annual trips) to and from the airport by the 13% of employees that took the Canada Line and then by 0.00972 tonnes of CO_2e per person that are saved by not using a car to commute.

- Under the airport's Safety Management System (SMS), workers are encouraged to report environmental hazards.
- The airport also features what it calls the CARE program (Communication Awareness Recognition and Education). It is designed to engage employees in environmental initiatives. Under this program, there are several aspects such as internal training programs and the airport's Clear Skies Award, which recognizes individuals and businesses operating at the airport that are leading the way to environmental sustainability. The airport also launched monthly "Envirotips" that are delivered to the airport's bulletin boards and the Green Team.

In general, airport employees have been receptive to the environmental improvement programs. Great success has been accomplished in the inter-departmental committees as they result in increased pride and sense of ownership in the organization. By reaching employees at the individual level, the airport maximizes the number of people that can report environmental issues and also maximizes the number of people that can individually reduce emissions.

The airport has engaged in significant efforts to educate not only its employees but also its passengers. The airport has constructed an observation area in the domestic terminal building where one of the primary themes is aviation and the environment. The broad availability of environmental information on the airport's website also contributes to raising public awareness of the issue.

The airport is actively involved in a variety of fora to disseminate environmental information. It participates in the National Working Group on Aviation Emissions and also the Canadian Airports Council, which has a subcommittee dedicated to the environment and through which the airport promotes environmental excellence by sharing knowledge, best practices, and emerging technologies. The airport also participates in the Airports Council International–North America with benchmarking surveys. Lastly, the airport has presented at an International Union of Air Pollution Prevention and Environmental Protection Associations conference on why the airport has a sustainability framework and why it is working with its partners to implement different initiatives. By virtue of this, the airport takes on a leadership role that may lead to emission reductions not only in BC but also on a much larger geographical scale.

YVR motivations for change

Based on the interview, the following are influences on Vancouver International Airport's corporate decision to reduce its CF, ranked in terms of greater to lesser influence. First and foremost, the airport obtains significant financial benefits from greening its operations. This is evidenced by cost savings achieved through the PowerSmart partnership. Second, passenger opinion seems to have motivated some of the environmental changes at the airport. These changes were complimented by an increasing airport-internal awareness of the aviation CF, which contributed to the creation of the airport's Sustainability Team. The Sustainability Team is different from the aforementioned Green Team, the former is an overarching subgroup of the Airport Authority, whereas the latter has stewards in the individual airport departments. Third, government regulations have so far not played a significant role in influencing environmental improvements at the airport. The BC Carbon Tax, for instance, not enticed airlines to fly to airports in the United States rather than to Vancouver because of higher fuel costs at Vancouver. Further hikes in the BC Carbon Tax, though, may thus necessitate further environmental improvements to reduce energy consumption and remain competitive in the aviation industry.

In summary, Vancouver is exemplary in terms of CF reduction efforts and has gained international recognition for these efforts through the airport and environmental networks it engages in. Its efforts were motivated by financial objectives, passenger and airport-internal CF awareness and government regulations, and the airport has both significantly reduced its emissions by engaging in these efforts and obtained financial benefits from doing so.

5.3.2 A small airport in BC

This section analyzes a BC airport that chose to remain anonymous. The data presented in this section was obtained through an interview with the airport's Operations Manager.

In 2007 the airport worked with Transport Canada to create a GHGs emissions inventory divided into three categories: activities that the airport controls, activities of the airport's tenants, and emissions generated by airplanes within a 10 mile radius of the airport. The inventory was updated in late 2010.

The airport took several steps to reduce GHG emissions. It provided electrical power at no cost to the ground handling agents to encourage them to use electric tugs[24] rather than diesel-powered tugs. One-half of the major ground handlers at the airport have switched to using electric vehicles at the airport. Moreover, the airport installed two new jet bridges[25], where airplanes can be plugged into the electrical grid while they are being serviced and

---

[24] Tugs at airports are used for various tasks such as pulling carts filled with luggage or maneuvering airplanes from their parking positions in preparing for departure.
[25] A jet bridge is the finger-like extension from the terminal building to an aircraft through which passengers can board the plane.

loaded. Other emission reductions have resulted from an extensive lighting upgrade in the terminal building and installing a solar hot water pre-heating system which reduces gas burn in the terminal building.

Regarding public transit access, the airport currently has public bus service and a shuttle bus company providing service from a park and ride facility to the terminal, both with limited frequency. However, the airport is working with BC Transit and private bus companies to increase the frequency of service. The goal of the airport is to provide half-hourly service to the terminal building.

The airport does not utilize carbon offset programs, but it is looking into the possibility of doing so because an airport in eastern Canada created their own offset project which earned the airport additional carbon credits it could sell, and because there is a growing awareness of the CF and offset programs in the airport community.

The following factors influenced this airport's corporate decisions to reduce its CF. A primary factor was cost savings associated with reduced energy consumption. Awareness of its environmental impact also played a role. Government environmental regulation on the other hand, such as the BC Carbon Tax, does not seem to have affected the airline's decision to engage in environmental change. Moreover, public opinion also seems to have little impact on the airport's environmental stance because concern about aviation's CF has not been raised by its passengers. No concerns about the CF of aviation have been raised by the passengers using the airport.

In summary, this airport is taking a number of steps to reduce its CF, including encouraging the use of electric tugs, providing infrastructure to reduce the usage of APUs, and upgrading its terminal building. Most of these changes were motivated by the financial benefit that results from reduced resource consumption, while passenger opinions or government regulations seem not have been influential. Compared to Vancouver, the airport engages in fewer efforts, but it also processes significantly fewer passengers, which means that not all efforts of the Vancouver Airport would be feasible at this airport.

5.3.3 Prince George

Prince George Airport accounts for only 1.9% of total BC airport emissions. The data presented in this section was obtained through an interview with Cuyler Green, the airport's Operations Manager, the airport website's environment section[26], and the airport's GHG Report (Prince George Airport Authority 2008).

The Prince George Airport has taken a number of steps to reduce its CF. It created an emissions inventory in 2007. Only 19.6% of emissions in the inventory qualify as those that the airport can control (Prince George Airport Authority 2008, 1). It upgraded its fleet of trucks to more efficient diesel trucks, upgraded its heating, ventilation, and air-conditioning system, installed occupancy sensors where feasible, and uses two electric golf trucks seasonally for baggage transport. The airport also installed plug-ins on the front of the terminal building so that aircraft could be plugged into the grid rather than using their APU, but the plug location on an aircraft is not always on its front, meaning there is potentially a very long cable that can be a hazard for passengers to trip over or for vehicles to damage. As such, airlines generally choose diesel generators because of safety concerns. The airport does not have congestion problems and thus does not need tarmac efficiency improvements. There is currently no public bus service to the Prince George Airport, although Greyhound busses stop there on the Prince George–Quesnel route. There is not enough demand to warrant

---

[26] http://www.pgairport.ca/Airport_Authority/environmental.php.

public bus service. Although the airport's Environmental Report discusses a car-pool board and website for employee commuting (Prince George Airport Authority 2008), this idea appears to have been abandoned. People tend to car pool if they are interested, but employees come in stages, making carpooling difficult. The large land area of Prince George also means it is rare for two or more employees from the same part of town to be coming to the airport at the same time. The airport's latest environmental report said that a decision to purchase carbon offsets was pending (Prince George Airport Authority 2008), but no definitive decision on the matter has been made yet.

The following factors influenced this airport's corporate decisions to reduce its CF. First, financial benefits from reduced energy consumption are a primary motivator for the Prince George Airport to reduce its emissions. Second, the airport is also aware of its environmental impact and tries to mitigate it. A third and more contentious factor is government regulation. The BC Carbon Tax impacts the airport because it is a heavy fuel user, both for machinery and other aspects of running the airport such as heating the terminal building. Because the airport is not a for-profit organization, it cannot write off the tax and thus must pay it. Green also voiced significant concern that the provincial government is taxing aviation without providing any provincial services to aviation, since this is regulated at the federal level. Green felt strongly that the airport was not in the environmental regulation business and that the airport does not want to be a tax collector for the government. Lastly, no passenger had ever brought up the CF of aviation as an issue they were concerned about.

In summary, Prince George is taking multiple measures to reduce its emissions, such upgrades to its airport fleet, building efficiency, and infrastructure to reduce APU usage. These measures were mostly taken because of the financial savings associated with them, but also because of the BC Carbon Tax. Prince George was the only airport that emphasized the influence of the carbon tax on its operation. Other airports indicated it was a minor influence. Prince George is taking fewer CF reduction measures than Vancouver, but its efforts are similar to those of the small airport described above, except that public transit access is not promoted at the Prince George Airport.

5.3.4 Quesnel

Quesnel Airport is a small airport with a small CF. The airport is listed in the "Other" category in Transport Canada statistics, so I was unable to obtain passenger numbers that would allow me to calculate the emissions generated by the airport. The data presented in this section were obtained through an interview with Harlene Hunt, Transportation Manager for the City of Quesnel. The one subsection of the city's website dedicated to the airport [27] does not contain environmental information.

Quesnel has not calculated a GHG inventory for the airport. A few measures undertaken by the city pertain to reducing GHG emissions such as including the airport in the city's anti-idling policy and its recycling program. The airport is considering replacing the current airport runway lights with LED lights. There is no public transit to Quesnel Airport because the low passenger volume simply does not justify such service. Also, there are no incentives for employees to commute in an environmentally-friendly way (such as carpooling) because there are too few employees to make such a project feasible.

Quesnel's environmental improvements were motivated by three main factors. Hunt stated that the biggest incentive for the airport to green its operations is that it is "the right thing to do", both financially and in the interest of environmental conservation for future

[27] http://www.quesnel.ca/Airport.html.

generations. The BC Carbon Tax has increased the cost of doing business for the airport, but this has not prompted any changes in how the airport operates. The CF of the airport has never been raised as an issue by passengers.

In summary, Quesnel is taking a number of steps to reduce its CF as far as its limited means allow, and does so both for financial and sustainability reasons. The BC Carbon Tax has resulted in higher costs for the airport but not motivated it to reduce fuel consumption. There has been no public pressure on the airport to reduce its CF. The airport engages in fewer measures than larger airports such as Vancouver or Prince George, but its measures are proportional to its limited passenger volume.

5.3.5 Powell River

Powell River Airport is another small airport with a small CF. Again, the airport is listed in the "Other" category in Transport Canada statistics, so I was unable to obtain passenger numbers that would allow me to calculate the emissions generated by the airport. I talked with the Operations Manager at the airport; however, a full interview was not conducted. He informed me that his airport did not have any GHG reduction programs as its operations are too small.

5.3.6 Qualicum Beach

Qualicum Beach Airport, like Powell River, is another small airport with a small CF. It is also listed in "Other" in Transport Canada statistics. The data presented in this section were obtained from an online report, "Town of Qualicum Beach Policy Manual, Subject: Qualicum Beach Municipal Airport" (a link to which was sent by email by the City of Qualicum Beach). The report included by-laws concerning the airport, but was unfortunately largely not related to the research for this thesis. The airport has no specific GHG reduction programs.

5.4 Analysis of airline and airport CF reduction efforts

In this section, I synthesize, summarize, and analyze first, the CF reduction efforts of BC airlines and the reasons why airlines engaged in these efforts, and second, the CF reduction efforts of airports and the reasons why airports engaged in these efforts.

5.4.1 Analysis of airline CF reduction efforts

The data presented in Section 5.2 has been organized into two tables, one on airline efforts to reduce their CF (Table 5.2) and the other on reasons these efforts were or were not undertaken (Table 5.3).

To analyze airline efforts, I first synthesized and summarized the data acquired through document analysis and interviews. I distinguished two categories of information related to CF reduction efforts, one an indicator of the airline's engagement in CF reduction activities and the other what activities it was engaged in. The engagement category is labelled "proactive measures to reduce CF". A "Y" indicates an affirmative (yes) response, i.e., the airline is taking proactive measures to reduce its CF; an "N" indicates a negative (no) response. The airlines are grouped by Y and N in the table. There are three categories of reduction activities: "in-the-air" referring to operational in-flight measures (such as reducing superfluous weight on an aircraft), "on-the-ground" referring to efforts such as building efficiency upgrades, and "offset programs". A check mark (√) indicates the activity has been or is being pursued by the airline in a significant way, and a dash (–) indicates it has not been pursued in a significant way.

Table 5.2: Airline efforts to reduce CF

Airline	proactive measures to reduce CF?	in-the-air reductions	on-the-ground reductions	offset programs
Air Canada Jazz	Y	√	–	√
Westjet	Y	√	√	–
Westcoast/Harbour	Y	√	√	√
Helijet	Y	√	√	√
Hawkair	N	–	–	–
Swanberg Air	N	–	–	–
Air Nootka	N	–	–	–

Four out of the seven airlines investigated—Air Canada Jazz, Westjet, Westcoast Air/Harbour Air, and Helijet—are proactively working to reduce their CF. In the case of Air Canada Jazz, not enough information was available to assert whether the airline engages in on-the-ground efforts. The other three airlines are not taking significant measures to reduce their CF both in the air and on the ground. Three of the seven airlines—Air Canada Jazz, Westcoast Air/Harbour Air and Helijet—participate in carbon offset programs. There are two types of offset programs: passenger offsets and airline operation offsets. The former allows passengers to offset the emissions generated by their particular flights, whereas the latter is used by airlines to offset their entire operation, including aspects such as ground operations, supply deliveries and emissions generated by office administration. Air Canada Jazz only engages in a passenger offset program, where carbon offsetting for passengers is optional. Westcoast Air/Harbour Air and Helijet flights include mandatory passenger offsets in every ticket, and the airlines also use offsets to mitigate their entire operational emissions. There are issues with the program that Air Canada Jazz uses, Zerofootprint, as evidenced in its low ranking by the David Suzuki Foundation. There are also issues with Westcoast Air/Harbour Air's program, Offsetters, which are mostly due to lacking information and clarity on the company's website. The David Suzuki Foundation (David Suzuki Foundation 2009, 10) awarded Offsetters a rating of "average performance" with a score of 15/20 for additionality, 20/20 for auditing, 6.2/15 for unique ownership, 20/20 for permanence, 10.5/15 for transparency, and 5/10 for public education, for a total score of 77/100.

Table 5.3 lists only airline reasons for engaging in CF reduction efforts, not reasons that dissuaded them from pursuing such efforts. There are four basic factors influencing corporate decisions to reduce GHG emissions: financial benefits, environmental responsibility, government regulation, and passenger opinion. The table columns for factors are ordered from left to right based on my assessment of the strength of the factors to influence corporate decision-making, with strongest factor on the left. A check mark (√) indicates that a particular factor was a significant reason for the airline in question to engage in CF reduction efforts. A dash mark (–) indicates it was not. Blank indicates lack of information to be able to make a judgement.

Table 5.3: Reasons for airlines to engage in CF reduction efforts

Airline	financial benefits	environmental responsibility	government regulation	passenger opinion
Air Canada Jazz	√	√	√	
Westjet	√	√	√	√
Westcoast/Harbour	√	√	–	
Helijet	–	√	–	√
Hawkair	–	–	–	–
Swanberg Air	–	–	–	–
Air Nootka	–	–	–	–

Financial benefits are the most important reason for airlines to engage in CF reduction efforts. Air Canada Jazz, Westjet, and Westcoast Air/Harbour Air all aim to reduce their emissions for this reason. Air Canada Jazz and Westjet, as large airlines, can achieve economies of scale through these efforts, which makes emission reductions even more viable.

Environmental responsibility is the second most important reason for airlines to engage in CF reduction efforts. Although more of the airlines surveyed —Air Canada Jazz, Westjet, Westcoast Air/Harbour Air, and Helijet—engage in efforts to reduce their emissions because of environmental responsibility than because of financial benefits, the latter is a stronger reason. Environmental responsibility is an altruistic reason to engage in CF reductions, whereas financial benefits are an intrinsic interest to a company's financial well-being.

Government regulation was given as a reason for only two of the airlines surveyed—Air Canada Jazz and Westjet—to engage in CF reduction efforts. Government regulations have the potential to be a strong influence on airline behaviour by mandating changes, but currently such regulations do not seem to be strict enough to force more, and especially smaller, airlines to engage in emission reductions.

The least important reason for engaging in CF reduction efforts is passenger opinion. Only two of the airlines in my sample—Westjet and Helijet—reduced their emissions because of this factor. While for Westjet passenger opinion was only a weak factor influencing its behaviour, it was a major factor for Helijet. However, Helijet's case is atypical for the aviation industry in general, as most airlines are not driven by passenger opinion to reduce their emissions.

The three airlines that are not proactively reducing their CF—Hawkair, Swanberg Air and Air Nootka—take this stance because of their limited size and because accounting for their emissions is seen as an excessive financial burden. None of the airlines are explicitly engaged in measures to reduce their CF. In addition, the clientele of Hawkair and Swanberg Air, both mainly serving northern BC, is very different than that of airlines serving the large metropolitan areas of southern BC.

5.4.2 Analysis of airport CF reduction efforts

Similar to the above section, the data presented in Section 5.3 has been organized into two tables, one on airport efforts to reduce their CF (Table 5.4) and the other on reasons these efforts were or were not undertaken (Table 5.5).

To analyze airport efforts, I first synthesized and summarized the data acquired through document analysis and interviews. I distinguished two categories of information related to CF reduction efforts, one an indicator of the airport's engagement in CF reduction activities and the other what activities it was engaged in. Table 5.4 follows the same principle as Table 5.2, but contains different categories of reduction activities. The engagement category is labelled "proactive measures to reduce CF". A "Y" indicates an affirmative (yes) response, i.e., the airport is taking proactive measures to reduce its CF; an "N" indicates a negative (no) response. The airports are grouped by Y and N in the table. There are five categories of reduction activities: Energy and waste reductions (which include building and tarmac upgrades), airport access emission reductions, promotion of passenger awareness, employee involvement, and offset programs. A check mark (√) indicates the activity has been or is being pursued by the airline in a significant way, and a dash (–) indicates it has not been pursued in a significant way.

Table 5.4: Airport efforts to reduce CF

Airport	proactive measures to reduce CF?	energy and waste reductions	airport access emission reductions	promotion of passenger awareness	employee involve-ment	offset programs
Vancouver International Airport	Y	√	√	√	√	–
Small airport in BC	Y	√	√	–	–	–
Prince George	Y	√	–	–	–	–
Quesnel	Y	√	–	√	–	–
Powell River	N	–	–	–	–	–
Qualicum Beach	N	–	–	–	–	–

Four of the six airports investigated—Vancouver International Airport, a small airport in BC, Prince George, and Quesnel—are taking proactive measures to reduce their CF. These are the four largest airports in my sample. The remaining two airports—Powell River and Qualicum Beach—do not consider their CF to be a concern and are not taking significant measures to address it.

All four of the airports that are taking proactive CF reduction measures engage in energy and waste reductions, although Vancouver does so on a much broader scale than the three other airports. Three of these airports—Vancouver, a small airport in BC, and Prince George—have taken measures to reduce use of emission-intensive APUs. These same airports that have completed building upgrades to reduce their energy consumption.

Only two of the proactive airports—Vancouver and a small airport in BC—are promoting airport access emission reductions. Because of its high passenger volume, Vancouver can promote such reductions in ways that are not feasible for the smaller airports in BC, such as comprehensive public transit access. Promotion of passenger awareness is practiced by two airports—Vancouver and Quesnel. Employee involvement, which can result in “on-the-ground greening”, is only practiced by the Vancouver International Airport.

None of the airports I surveyed used programs to offset their corporate emissions. In most instances, airports answered that they preferred to focus on those things which they can control and reduce emissions rather than offset them later. While offsets are a possible strategy to mitigate those emissions that cannot be prevented, they are currently not used by any airport I investigated.

Table 5.5 lists airport’s reasons for engaging in CF reduction efforts. Airports, just as airlines, can be motivated by a number of reasons to reduce their CF. I grouped factors into the same four categories as for airlines: financial benefits, government regulation, passenger opinion, and environmental responsibility. The table is ordered by the strength of the factors to influence corporate decision-making, with strongest points on the left. A check mark (√) indicates that a particular factor was a significant reason for the airline in question to engage in CF reduction efforts. A dash mark (–) indicates it was not. Blank indicates lack of information to be able to make a judgement.

Table 5.5: Reasons for airports to engage in CF reduction efforts

Airport	financial benefits	environmental responsibility	government regulation	passenger opinions
Vancouver International Airport	√	√		√
Small airport in BC	√	√		
Prince George	√	√	√	
Quesnel	√	√	√	
Powell River				
Qualicum Beach				

The main driver for airports to engage in CF reduction efforts is to obtain financial benefits from reduced resource consumption. This was a reason for four of the six airports—Vancouver International Airport, a small airport in BC, Prince George, and Quesnel—to engage in CF reduction efforts. In other words, every airport which engaged in CF reduction efforts expected to benefit financially from doing so. Environmental responsibility is the second strongest driver of airport CF reduction efforts. Four airports—Vancouver, a small airport in BC, Prince George, and Quesnel—engaged in efforts because of this factor. Awareness of environmental responsibility seems not to be dependent on the size of an airport's operations but rather on its management. Government regulations significantly influenced only two of the airports I studied, Prince George and Quesnel. Regulations resulted in emission reductions not because of forcing the airports to reduce their emissions but by applying a tax burden. Consequently the airports aimed to reduce their emissions to circumvent the imposed tax and obtain financial benefits from doing so. Passenger opinion, just as for airlines, is the weakest factor influencing airport corporate environmental decisions. Only one airport—Vancouver—was influenced by passenger opinions, and even then not significantly. The two airports that are not taking proactive measures to reduce their CF—Powell River and Qualicum Beach—are not motivated by any of the above factors.

5.5 Conclusion

In am now in a position to answer my second research question: What actions have BC-connected airlines and airports taken to mitigate their CF in BC, and why have they taken these actions? Seven airlines and six airports were surveyed as to what measures they have engaged in to reduce their CF and why they have done so. Out of these airlines, the four largest are proactive, and the three smallest are not. Out of the six airports, the four largest are proactive, and the two smallest are not.

To answer the first part of the question, those airlines and airports that have taken CF reduction measures have taken evolutionary measures rather than revolutionary measures. In other words, existing procedures have been improved in ways that result in some emission reductions. These small gains do reduce the CF of aviation, but they do not represent groundbreaking gains that can solve the problem of aviation emissions.

For airlines, in-flight operational measures are the most common CF reduction effort, and are taken by four out of the seven airlines investigated. CF reduction measures on the ground and offset programs (which mitigate emissions rather than reducing them), are tied in second place with three airlines each engaging in these efforts. Offset programs, both for passengers and for airline operations, are offered by large and small airlines, but not all large, environmentally proactive airlines offer them.

For airports, energy and waste reductions are the most common CF reduction efforts, and are pursued by four of the six airports investigated. Airport access emission reductions are only pursued by two of the six airports, and while a large passenger volume makes it more feasible to promote broad public transit access, smaller airports seem not to be entirely precluded from this effort. Promotion of passenger awareness and employee involvement are both not widely used among BC airports. While the only airport that promotes employee involvement is large, one of the airports promoting passenger awareness is small, indicating that airport size may matter for employee involvement but not necessarily for promoting passenger awareness. Offset programs, in contrast to airlines, are used by none of the airport surveyed.

Airports often have less difficulty in reducing their CF than airlines because they can do so by engaging in building efficiency upgrades and other measures that can be accomplished with existing technologies. Also, unlike airlines, energy savings for airports appear to be more proportional and predictable, considering for example that most airlines use different plane types which may result in different fuel consumption reductions or which might not be able to undergo retrofits in some instances.

What airlines and airports have in common is that larger airlines and airports are more likely to engage in CF reduction efforts than smaller ones and obtain greater relative financial benefits from engaging in these efforts because of economies of scale. However, BC's most environmentally proactive airlines are comparatively small. While inactivity of small airlines is likely often caused by the sometimes significant start-up costs of implementing efficiency measures, in some cases it may be related to unawareness of the CF of aviation, or in other cases by lack of knowledge on how to implement CF reduction measures. However, while individually, these entities may not account for a large portion of the BC civil aviation CF, collectively they do have a significant share that should not simply be ignored because it is comprised of small individual contributions.

What sets airlines and airports apart is the degree of environmental cooperation among their peers. In the case of airlines most action seems to be taken on the level of the individual entity. Although other airlines are in the same environmental situation, there is no indication of overarching cooperation and coordination to reduce aviation's CF. Airports also take measures on an individual basis, but have overarching councils that can be used to disseminate information. By virtue of this, knowledge barriers in respect to the environmental impacts of aviation or how to implement CF reduction efforts can be more easily overcome.

To answer the second part of the question, it is in airlines' and airports' best financial interest to reduce their CF because reduced energy consumption reduces operational expenditures. Thus, the aviation industry has a natural tendency to make itself more efficient whenever possible to reduce its costs. This results in environmental benefits even if those are not pursued for their inherent worth but achieved as a secondary goal. Economies of scale do mean that large airlines stand to reap greater profits from engaging in environmental improvements, and it is often only large airlines that can afford the initial costs of these improvements. However, over greater time horizons, it is likely that even small airlines would be able to benefit financially from environmental improvements.

Environmental responsibility drives both airlines and airports to reduce their emissions. However, this is an altruistic motivation that cannot always be reconciled with financial objectives. Airports are less likely than airlines to engage in CF reduction efforts purely because of environmental responsibility when they do not stand to benefit financially from doing so.

Government regulations currently hold little influence on both airlines and airports. This is because there is currently no government regulation in BC that forces airlines or airports to reduce their emissions. Rather, the BC Carbon Tax merely imposes a tax burden on fuel, but airlines pass this burden on to passengers and thus have no incentive to modify their operations. Airports, on the other hand, which do have to pay the tax, merely have an incentive to reduce their energy consumption to avoid the tax, but they are not forced to do so. Airports that cannot or do not want to alter their operational procedures are not forced by government regulations to reduce their emissions, and rather must pay the associated taxes.

Passenger opinion is the last and weakest factor influencing airlines and airports to engage in CF reduction efforts. Passenger awareness of aviation's CF is low, and most airlines and airports (with select notable exceptions) are content with this state of affairs if this means that they will not become subject to mandatory emission reductions because of increased passenger concerns.

CHAPTER 6: CONCLUSION

6.1 Summary of results

The goal of my research was to answer three questions: *What is the CF of civil aviation in BC; What actions have BC-connected airlines and airports taken to mitigate their CF in BC and why have they taken these actions;* and *What recommendations can be made to further reduce the CF of aviation in BC*? Both quantitative and qualitative methods were used including numerical calculations, document analysis, and interviews.

What is the CF of civil aviation in BC? Civil aviation system in this thesis is defined to be airplane flights + airports + passenger travel to and from airports. The annual CF of BC civil aviation is roughly 525,000 tonnes of CO_2e, with 198,000 tonnes contributed by airplane flights (37.7%), 148,000 tonnes by airport operations and airport tenants (28.2%), and 179,000 tonnes by passenger airport access (34.1%).

The greatest contributor to the airline CF is Air Canada Jazz, while the greatest contributor to the airport CF is Vancouver International Airport. A significant share of the airline CF is also generated by Westjet's use of comparatively large jet-powered planes. These routes have the highest flight carbon-intensity in BC, but have lower emissions per passenger than short routes operated by small planes. While I expected that the very high volume of flights between Greater Vancouver and Greater Victoria would result in a high CF and high flight carbon intensity because of the very distance, my research did not substantiate these expectations. Instead, the CF is dominated by longer-distance routes, and high flight carbon intensity by those routes on which Westjet operates Boeing 737 aircraft. Short routes using small aircraft and long routes have a high CF per passenger.

What actions have BC-connected airlines and airports taken to mitigate their CF in BC? BC airlines and airports have mostly pursued incremental, evolutionary changes to reduce their CF. Large airlines have engaged in limited CF reduction efforts to achieve financial benefits from reduced fuel consumption. In BC, a select few small airlines based in the metropolitan areas in the southern portion of the province are most proactive in reducing their CF. Most other small airlines, especially those based in northern BC, are not environmentally proactive. Measures taken by airlines include in-flight operational improvements that reduce fuel consumption, on-the-ground operational improvements such as efficiency upgrades to airline buildings, and using offsets for passenger emissions and/or their entire operations. Large airports are more likely to engage in CF reduction measures than their smaller counterparts. Measures taken by airports are energy and waste reductions, airport access emission reductions, promotion of passenger awareness, and employee involvement. Airports can often achieve emission reductions more easily than airlines through energy efficiency building upgrades and other measures that do not require the kinds of technological leapfrogging that are required to achieve significant emission reductions in airplanes.

Why have they taken these actions? CF reductions are pursued by airlines primarily for financial reasons, and large airlines seem to obtain more relative financial benefits from reducing their CF than small airlines. Nevertheless, the only two carbon-neutral airlines in BC are both small and have remained competitive despite charging a small premium on each ticket to offset the flight's emissions. Environmental responsibility is the second factor driving CF reduction efforts, although these considerations are often outweighed by financial objectives. Airlines and airports are generally not forced by government regulations to reduce their CF, although some airports choose to reduce their emissions to avoid additional taxation. Passenger opinion is the weakest of the drivers, and only marginally influences airlines and airports to reduce their CF.

6.2 Recommendations resulting from research

What recommendations can be made to further reduce the CF of aviation in BC? This section answers my third research question. Based on the analysis contained in chapters 4 and 5, I put forth eight recommendations. They are ordered by my perception of their importance for reducing the aviation CF.

Recommendation 1: Reduce airport access emissions

In my research, passenger transportation to and from airports accounts for 34% of the overall aviation system CF. Most people currently access BC airports individually (i.e., by taxi or private car), rather than through more carbon-efficient alternatives such as public transit. This generates significant emissions that in at least some instances could be avoided. Addressing passenger airport access, both in terms of researching what obstacles passengers face in respect to public transit access and in terms of providing alternative, more carbon-efficient access modes, needs to be a target for CF reduction efforts related to aviation.

Recommendation 2: Promote stakeholder cooperation

Increased cooperation and coordination between stakeholders in the aviation sector is essential to further reducing the CF. Different aspects of the aviation system are controlled by different entities. For example, how airplanes move on an airfield is governed by airlines and Navigation Canada, but also requires airports to provide the necessary infrastructure for procedures such as single-engine taxing or using high-speed taxiways. Increased involvement and an enlarged British Columbia Aviation Council (http://www.bcaviationcouncil.org/), which only has 15 members, or the formation of a forum or working group at the provincial level might facilitate this kind of cooperation. An aviation CF workshop (perhaps in cooperation with the Pacific Institute for Climate Solutions) would be a good way to bring together stakeholders, and such an event could evolve into an annual conference. Knowledge obtained through this working group could result in implementation of best practices. An important result of this cooperation would be knowledge transfer and perhaps access to funding for small airlines and airports in BC to overcome the administrative and financial difficulties they currently face in respect to CF reduction effort implementation. With this kind of assistance, small airlines and airports may be able to benefit financially from reducing their emissions, just as their larger counterparts, over greater time horizons. Another important result would be dissemination of technological improvements (such as LED lighting to replace incandescent bulb lighting) which may help other small airports in BC to upgrade their infrastructure in order to reduce emissions. Disseminating the use of these best practices contributes to a reduced aviation CF.

Recommendations 3: Increase passenger education programs

My research suggests that passenger awareness of the negative environmental impacts of aviation is low. Neither airlines nor airports report a high level of pressure from passengers to do more about their CF. Many people seem not to know about the CF of aviation and its consequences or choose not to pay attention to it. In many instances this may be because people do not fly regularly and thus do not feel ‘connected’ to the emissions that are generated when they do travel by air. However, increased passenger awareness may cause passengers to either alter their travel behaviour (e.g., eliminating frivolous trips, telecommuting, travelling with less luggage etc.), or they may choose to offset the emissions generated by their flights. As long as CF offsets are voluntary, passengers can only be encouraged to utilize them, but not be forced to do so. Public exhibits, especially at airports (such as in Vancouver), that illustrate the negative environmental impacts of aviation and what can be done to remedy them may result in increased passenger awareness and action. BC prides itself in its magnificent natural environment. Consequently, it seems reasonable to promote steps to the public that enable conservation of this environment.

Recommendation 4: Increase employee education programs

Vancouver International Airport has not only achieved emission reductions by involving its employees in environmental efforts. Employee involvement requires a dedication on behalf of management to educate and involve employees and together aim to reduce emissions both on an individual level (e.g., through carpooling) and on a corporate level. The experience of Vancouver could be used as a template for other airports in BC on how to create Green Teams and raise environmental awareness among employees. For smaller airports, such Green Teams may not be required for all airport departments, but could still be introduced at a higher level to get employees involved. An increased sense of pride is an additional benefit and reason for airports and airlines to promote employee involvement.

Recommendation 5: Improve quality and transparency of offsets programs

Some airlines are using offset programs, both for their passengers and their entire operations. As Westcoast Air/Harbour Air and Helijet demonstrate, it is possible for an airline to be carbon-neutral and remain competitive in the aviation industry. This approach could serve as a template for other airlines. Westcoast Air/Harbour Air and Helijet serve Greater Vancouver. While offsetting does not reduce emissions, it is a viable strategy for reducing aviation's negative environmental impact in the immediate term. However, there are issues with many carbon offset programs (e.g., lacking transparency) that concern many potential customers, both individual and corporate. Such issues must be resolved before large-scale aviation offsets can be feasibly expected from the corporate and private public. Offsetting all emissions associated with BC aviation would also require additional offsets because providers currently can not offer enough to offset almost 600,000 tonnes of CO_2e per year. The question of whether aviation carbon offsets should become mandatory or remain voluntary will also have to be addressed. Mandatory carbon offsets are problematic because of boundary and ownership issues, which must be solved first before compulsory offsets can be introduced.

Recommendation 6: Increase government regulation and incentives

While the BC Carbon Tax currently has not had a significant impact in reducing emissions in the BC aviation industry, government regulation and incentives do have the potential to encourage both airlines and airports to reduce their CF. However, such measures must be considered carefully, and likely would have to be at the federal level. Aviation is an integral part of the economy and can be necessary to access essential services for residents in rural BC. Mandatory flight carbon offsets should not be implemented at the provincial level, for instance, because they would risk rendering BC aviation uncompetitive, especially as airports in northern Washington State, which are only a short drive from large cities such as Vancouver, are already providing significant competition to BC airlines and airports. The same holds true for increases to the BC Carbon Tax, which have the potential to shift emissions jurisdictionally out of BC rather than to actually reduce emissions. Instead, the provincial government should encourage CF reductions through incentives. For example, any airline or airport that sets an approved CF reduction target and consequently accomplishes this target may be eligible for a full or partial Carbon Tax refund for the fuel the airline or airport did consume. Alternatively, the provincial government may provide funding for knowledge transfers or airline/airport upgrades that result in CF reductions. This funding could, at least in part, be derived from money taken in through the BC Carbon Tax. Through these measures, the provincial government can encourage aviation stakeholders to reduce their CF while at the same time not imposing a financial burden on them that threatens their economic competitiveness.

6.3 Contribution of research

My research contributes to existing knowledge both on a practical and theoretical level. On a practical level, I have provided the first detailed snapshot of civil aviation-generated GHG emissions in BC in terms of emission quantities and their distribution, and of measures the BC aviation industry is making to reduce GHG emissions and reasons for undertaking these measures. This provides a baseline and guidance for future study and efforts to further reduce aviation GHGs in BC.

At the theoretical level, I developed a methodology for calculating an aviation CF portrait on a subnational scale and for inventorying aviation CF reduction efforts. While my research focused on BC, the methodology can used as a template to conduct similar research in other jurisdictions and other geographical scales.

6.4 Limitations of research

The CF calculations in Chapter 4 are subject to a number of limitations. First, my calculations are limited by problems inherent in the calculators I used. This is why I used three CF calculators for my Chapter 4 calculations to obtain averaged CF values. There are also data limitations. For example, I included only scheduled flights in my research; three small airlines were omitted from the inventory; the week chosen for the inventory was in the off-season; I used the shortest route between departure and arrival airport; I assumed a 100% load factor; I used a factor of 1.44 to calculate CF data when the Offsetters website could not recognize specific airports; passenger data from the Vancouver International Airport includes all passengers instead of only BC-domestic passengers; I assumed that the Prince George Airport passenger airport access patterns are applicable to all other airports in BC; emissions data for Vancouver International Airport is based on the years 2007/2008, for Prince George on the year 2007, and for other airports based on Transport Canada data for the year 2008, not 2010; and I assumed that employee numbers at Vancouver International Airport were the same in 2008 as in 2010 and that all employees work five days per week, 48 weeks per year. However, the errors introduced by these limitations is likely small as compared with errors inherent in the emission factors in the calculators that I used, and over which I had no control in my research.

The data on CF reduction efforts and reasons for these efforts in Chapter 5 are also subject to a number of limitations. The most significant limitation is that most airlines and airports did not agree to being interviewed. The sample size on which I am basing my analysis is thus small and results may not represent the remaining airlines and airports in BC. Moreover, especially for airlines, I was in some cases unable to obtain detailed information on reasons for corporate decision-making. The lack of literature regarding reasons for corporate environmental change in the airline industry was also a limitation for my research, and how I worded, ordered, and structured my interview questions may have also influenced the results obtained. Different questions may have resulted in different answers.

6.5 Suggestions for further research

First, rather than new and different research, drawing on the experience acquired while pursuing this research, I could revisit my first two research questions and try to overcome some of the limitations that affected the accuracy of my results. I could, for instance, try to gather more airline and airport specific data, interview more aviation industry stakeholders, and conduct passenger surveys to learn more about passenger travel behaviour and passenger attitudes and how these factors affect the CF of BC aviation. I could compare the emissions generated to those generated by various modes of transportation.

Moreover, several of my interviewees stated that profit margins in the airline industry are narrow and cited this as a reason why many airlines do not pursue CF reduction strategies. Consequently, the cost structure of airlines should be researched relative to their CF. Publicly available information such as the cost of carrying a passenger over a given distance (which is published at least by large airlines such as Air Canada) can be used to calculate the cost of an airline to operate a route. This information can be compared to the cost of offsetting the emissions generated on that route. Because an increase in environmental taxes or fees means that an airline's operating costs increase (unless the cost is passed on to passengers), such research could indicate at what level a tax or fee becomes prohibitive and renders a route financially unviable.

Another important avenue of research is to answer the questions: Why does the (BC) aviation industry behave the way it does? I have determined in this thesis what the industry is doing about its CF and what its motivations are, but I have not determined how these actions fit into the broader concept of corporate environmental change. There is a variety of research on corporate environmental change that suggests I could develop a model of such change in the aviation industry. The work of Van den Bosch and van Riel (1998), Aragon-Correa and Sharma (2003), and Brockhoff, Chakrabarti and Kirchgeorg (1999) suggests approaches to developing such a model. My results indicate that the schemes developed by these authors are applicable to the BC aviation industry. In addition, passenger opinions could be surveyed relative to climate change in general, access to airports, airport operations, etc.

Finally, a next logical step, building off the research in this thesis, would be to expand my research to cover all of Canada. This would entail greatly expanded data gathering, but the template I have provide allows for expanding the geographic scale. Applying this template to a global scale is possible, but would be extremely labour-intensive, time consuming, and costly.

6.6 Final thoughts

Conducting this research illustrated very clearly to me the sheer complexity of effectively reducing the CF of aviation. Aviation is part of everyday life in the 21st century and a vital part of the economy; it is also controlled and influenced by a multitude of stakeholders. While there can be no debate that the CF of aviation is an environmental problem that needs to be addressed, doing so requires not only significant cooperation between the affected stakeholders but also more research, both in the natural and social sciences, on how aviation affects the environment and how its impact can be reduced.

The motto of the Pacific Institute for Climate Solutions, which generously supported my research, is “Knowledge. Insight. Action.” With my research, I hope to have contributed to the knowledge and insight aspects of this motto, and I hope that this knowledge and insight can consequently be translated into the third aspect, action. We do not have to wait for revolutionary technological developments. My research results indicate that many actions have already been taken to reduce GHG emissions but that there is significant room for improvement. The recommendations derived from my analysis are designed to spur more action to reduce the CF of aviation.

WORKS CITED

Air Canada. "Carbon Offset Program." Accessed 11 April 2011. http://www.aircanada.com/en/travelinfo/traveller/zfp.html.

———. 2011. "Jazz begins flying under Air Canada Express banner." Accessed 7 June 2011. http://www.aircanada.com/en/news/110601.html.

Air Canada Jazz. "The Environment." Accessed 24 March 2011. http://www.flyjazz.ca/en/home/aboutjazz/theenvironment.aspx.

Airliners.net. "The Boeing 737-600/700." Accessed 23 June 2011. http://www.airliners.net/aircraft-data/stats.main?id=95.

———. "The Piper PA-31 Navajo/Pressurized Navajo." Accessed 23 June 2011. http://www.airliners.net/aircraft-data/stats.main?id=311.

Airports Council International - North America. 2009. "Position Statement on Climate Change." Accessed 15 September 2010. http://aci-na.org/static/entransit/ACI-NA_Climate_Change_Position_FINAL.pdf.

Akerman, Jonas. 2005. "Sustainable air transport - on track in 2050." *Transportation Research Part D* 10: 111-126.

Akerman, Jonas, and Mattias Hojer. 2006. "How much transport can the climate stand? Sweden on a sustainable path in 2050." *Energy Policy* 34: 1944-1957.

Alberta Environment. 2008. Alberta Air Emissions Trends and Projections. Available from http://environment.gov.ab.ca/info/library/7964.pdf.

Alic, John A., David C. Mowery, and Edward S. Rubin. 1995. US Technology and Innovation Policies: Lessons for Climate Change. Pittsburgh, PA: Department of Engineering and Public Policy, Carnegie Mellon University.

Aragon-Correa, J. Alberto, and Sanjay Sharma. 2003. "A Contingent Resource-Based View of Proactive Corporate Environmental Strategy." *Academy of Management Review* 28 (1): 71-88.

Boeing. 2009. "The Boeing Next Generation 737-800." Accessed 29 June 2011. http://www.boeing.com/AeroIndia2011/pdf/bck-737-800.pdf.

Bradbury, Danny. 2007. "Passenger jets get a radical green makeover." *The Independent*, 14 February.

Brady, Chris. 1999. "Advanced Blended Winglets." Accessed 5 July 2011. http://www.b737.org.uk/winglets.htm.

British Columbia Ministry of Environment. 2010. "British Columbia Greenhouse Gas Inventory Report 2008." Accessed 5 November 2010. http://www.env.gov.bc.ca/cas/mitigation/ghg_inventory/pdf/pir-2008-full-report.pdf.

Brockhoff, Klaus, Alok K. Chakrabarti, and Manfred Kirchgeorg. 1999. "Corporate Strategies in Environmental Management." *Research-Technology Management* 42 (4): 26-30.

Burkhardt, Ulrike, and Bernd Kaercher. 2011. "Global radiative forcing from contrail cirrus." *Nature Climate Change* 1: 54-58.

Chapman, Lee. 2007. "Transport and climate change: a review." *Journal of Transport Geography* 15: 354-367.

CO2 Australia Limited. 2009. "Our Glossary." Accessed 20 November 2010. http://www.co2australia.com.au/index.php?action=help&helpcatID=621&helpID=3552#3552.

Committee on Aeronautics Research and Technology for Environmental Compatibility of the National Research Council. 2002. "Environmental Costs and Benefits." In *For Greener Skies: Reducing Environmental Impacts of Aviation*, 39. National Academy Press; Washington, D.C.

Crass, Mary. 2008. Reducing CO2 Emissions from Urbal Travel: Local Policies and National Plans. In *OECD International Conference*. Milan, Italy.

Daggett, D., O. Hadaller, R. Hendricks, and R. Walther. 2006. Alternative Fuels and Their Potential Impact on Aviation. Cleveland, Ohio: National Aeronautics and Space Administration.

Daggett, David L., Robert C. Hendricks, Rainer Walther, and Edwin Corporan. 2008. Alternate Fuels for Use in Commercial Aircraft. Cleveland, Ohio: National Aeronautics and Space Administration.

David Suzuki Foundation. "Air Travel and Climate Change." Accessed 12 October 2009. http://www.davidsuzuki.org/issues/climate-change/science/climate-change-basics/air-travel-and-climate-change/index.php.

———. 2009. Purchasing Carbon Offsets: A Guide for Canadian Consumers, Businesses, and Organizations. Vancouver, BC: David Suzuki Foundation and The Pembina Institute.

Delzen, A. van, and R.C.N. Wit. 2000. National allocation of international aviation and marine CO2-emissions. Delft: Dutch Civil Aviation Authority.

Department of Energy & Climate Change. 2009. UK Climate Change Sustainable Development Indicator: 2009 Greenhouse Gas Emissions, Final Figures.

Dewes, Winfried, Roger Cottington, Roger Gardner, Francis Hirsinger, Andreas Petzold, Richard Ramaroson, Marli Vogels, and Jan Westerberg. 2000. "The AERONET network -- emissions, atmospheric impact and regulations." *Air & Space Europe* 2 (3): 24-28.

Dictionary.com. "Carbon Footprint." Accessed 20 November 2010. http://dictionary.reference.com/browse/carbon+footprint.

Diederichs, H., and G. B. Upton. 1917. Mufflers for aeronautic engines. National Advisory Committee for Aeronautics.

East, Andrew John. 2008. Vegetable Industry Carbon Footprint Scoping Study. Sydney, Australia: Horticulture Australia Ltd.

Environment Canada. 2010. National Inventory Report: Greenhouse Gas Sources and Sinks in Canada. Environment Canada.

Environmental Defense Fund. 2002. "Nitrogen Oxides: How NOx Emissions Affect Human Health and the Environment." Accessed 18 June 2011. http://www.edf.org/documents/2551_FactSheet_NOx.pdf.

Fahey, David W. 2008. The use of non-CO2 multipliers for the climate impact of aviation: *The scientific basis*. Montreal: ICAO.

Federal Aviation Administration. 2005. Aviation & Emissions: A Primer. Available from http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/media/aeprimer.pdf.

Government of British Columbia. "Carbon-Neutral Government." Accessed 18 November 2010. http://www.gov.bc.ca/yourbc/carbon_neutral/cn_planet.html?src=/planet/cn_planet.html.

Green, J.E. 2003. "Civil aviation and the environmental challenge." *The Aeronautical Journal* (June): 281-299.

Greene, David L., and Michael Wegener. 1997. "Sustainable transport." *Journal of Transport Geography* 5 (3): 177-190.

Greenhouse Gas Protocol Initiative. "About the GHG Protocol." Accessed 14 May 2011. http://www.ghgprotocol.org/about-ghgp.

Hawkair. "Company Mission and Vision." Accessed 9 July 2011. http://www.hawkair.ca/mission-vision.

Helijet. "Fly Carbon Neutral." Accessed 24 March 2011. http://www.helijet.com/fly-carbon-neutral.

Hertwich, Edgar, Hogne N. Larsen, Ida Nilstad Pettersen, and Christian Solli. 2008. Chapter 11 Climate calculators and expert systems: *Design and calculation*. Paper read at 2nd Conference of the Sustainable Consumption Research Exchange (SCORE!) Network, at Brussels, Belgium.

ICAO (International Civil Aviation Organization). 2010a. "Environment Branch." Accessed 31 March 2011. http://www.icao.int/icao/en/env2010/Index.html.

———. 2010b. ICAO Environmental Report 2010. Available at http://www.icao.int/icao/en/env2010/environmentreport_2010.pdf.

———. n.d.-a. "CAEP Structure." Accessed 31 March 2011. http://www.icao.int/icao/en/Env2010/Caep_Structure.pdf.

———. n.d.-b. "Environment Section: Aircraft Engine Emissions." Accessed 11 October 2009. http://www.icao.int/icao/en/env/aee.htm.

———. n.d.-c. "Foundation of the International Civil Aviation Organization." Accessed 16 November 2010. http://www.icao.int/cgi/goto_m.pl?icao/en/hist/history02.htm.

———. n.d.-d. "Strategic Objectives of ICAO." Accessed 16 November 2010. http://www.icao.int/icao/en/strategic_objectives.htm.

IPCC (Intergovernmental Panel on Climate Change) Working Groups I and III. 1999. *Aviation and the Global Atmosphere*. Cambridge, UK: Cambridge University Press. Available from http://www.ipcc.ch/ipccreports/sres/aviation/index.htm. Accessed 3 November 2011.

Janic, Milan. 1999. "Aviation and externalities: the accomplishments and problems." *Transportation Research Part D* 4: 159-180.

Jardine, Christian N. 2009. Calculating the Carbon Dioxide Emissions of Flights. Oxford: Environmental Change Institute.

Jones, Christopher M. 2005. "A Lifecycle Assessment of U.S. Household Consumption: The Methodology and Inspiration Behind the “Consumer Footprint Calculator”." Accessed 21 June 2011. http://escholarship.org/uc/item/1fb4q9bb.

Judd, K.S., S.A. Shankle, A.R. Kora, and K.M. Fowler. 2009. Inventory of Carbon Dioxide (CO2) Emissions at Pacific Northwest National Laboratory.

Kim, Brian Y., Ian A. Waitz, Mary L. Vigilante, and Royce Bassarab. 2009. *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories*. Washington, D.C.: Transportation Research Board Business Office.

Kitzes, Justin, and Mathis Wackernagel. 2009. "Answers to common questions in Ecological Footprint accounting." *Ecological Indicators* 9: 812-817.

Klin, Thomas P., John E. Putnam, Burr Stewart, and Mary L. Vigilante. 2009. "Airports, Nonaircraft Emissions, and Climate Change." *Transportation Research Circular E-C138: Critial Issues in Aviation and the Environment:* 18-23.

Koopman, Gert Jan. 1997. "Long-term challenges for inland transport in the European Union: 1997-2010." *Energy Policy* 25 (14-15): 1151-1161.

Lutsey, Nicholas Paul. 2008. *Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors*. Ph. D. Dissertation, Philosophy, University of California, Davis.

McNeil, Sue, Willam Wallace, and Thomas F. Humphrey. 2000. Developing an Information Technology-Oriented Basic Research Program for Surface Transportation Systems. National Science Foundation and US Department of Transportation.

Miake-Lye, Richard, Ian Waitz, David Fahey, Howard Wesoky, and Chowen Wey. 2000. "Aviation and the Changing Climate." *Aerospace America* (September): 35-39.

Ministry of Finance. "What is a carbon tax?" Accessed 18 November 2010. http://www.fin.gov.bc.ca/tbs/tp/climate/A1.htm.

Miyoshi, C., and K.J. Mason. 2009. "The carbon emissions of selected airlines and aircraft types in three geographic markets." *Journal of Air Transport Management* 15: 138-147.

Mongu. 2003. "Short-haul turboprops." Accessed 8 June 2011. http://forum.keypublishing.com/archive/index.php?t-6470.html.

Murray, Joy, and Christopher Dey. 2009. "The carbon neutral free for all." *International Journal of Greenhouse Gas Control* 3 (2): 237-248.

Natural Resources Canada. 2003. "The Atlas of Canada - Greenhouse Gas Emissions by Sector, 1998." Accessed 5 November 2010. http://atlas.nrcan.gc.ca/auth/english/maps/climatechange/atmospherestress/greenhousegasemissionbysector?scale=10488256.316757&mapxy=2253098.0076470003%20430316.98492033326&mapsize=750%20666&urlappend.

———. 2006. Canada's Energy Outlook: The Reference Case 2006. Available from http://environment.gov.ab.ca/info/library/7964.pdf.

Nederveen, A.J., J.W. Konings, and J.A. Stoop. 2003. "Globalization, International Transport and the Global Environment: Technological Innovation, Policy Making and the Reduction of Transportation Emissions." *Transportation Planning and Technology* 26 (1): 41-67.

Nijkamp, Peter. 2003. "Globalization, International Transport and the Global Environment: A Research and Policy Challenge." *Transportation Planning and Technology* 1: 1-8.

Offsetters. "Frequently Asked Questions." Accessed 23 March 2011. http://offsetters.ca/about-us/frequently-asked-questions/.

Oliver, Rachel. 2007. "All About: Planes." Accessed 12 October 2009. http://edition.cnn.com/2007/WORLD/asiapcf/11/05/eco.about.planes/index.html.

Olsthoorn, Xander. 2001. "Carbon dioxide emissions from international aviation: 1950-2050." *Journal of Air Transport Management* 7: 87-93.

Pacific Carbon Trust. "About Pacific Carbon Trust." Accessed 5 July 2011. http://www.pacificcarbontrust.com/About/tabid/57/Default.aspx.

Padgett, J. Paul, Anne C. Steinemann, James H. Clarke, and Michael P. Vandenbergh. 2008. "A comparison of carbon calculators." *Environmental Impact Assessment Review* 28 (2-3): 106-115.

Pandey, Divya, Madhoolika Agrawal, and Jai Pandey. 2010. "Carbon footprint: current methods of estimation." *Environmental Monitoring and Assessment:* 1-26.

Pohling, Mitch. 2007. "Math! How much CO2 is released by Aeroplane?" Accessed 8 June 2011. http://micpohling.wordpress.com/2007/05/08/math-how-much-co2-released-by-aeroplane/.

Prince George Airport Authority. 2008. Prince George Airport Authority: Greenhouse Gas Report Fiscal Year 2007. Prince George.

Ramanathan, V., and G. Carmichael. 2008. "Global and regional climate changes due to black carbon." *Nature Geosci* 1 (4): 221-227.

Rees, William E., Mathis Wackernagel, and Phil Testemale. 1998. *Our Ecological Footprint: Reducing Human Impact on the Earth*: New Society Publishers.

Reimer, Daniel S., and John E. Putnam. 2007. "The law of aviation-related climate change: The airport proprietor's role in reducing greenhouse gas emissions." *Journal of Airport Management* 2 (1): 82-95.

Remer, Lorraine A. 2007. "Aerosol effects on the Environment." Accessed 18 June 2011. http://aerocenter.gsfc.nasa.gov/ae/effects.php.

Safire, William. 2008. "Footprint." Accessed 15 July 2011. http://www.nytimes.com/2008/02/17/magazine/17wwln-safire-t.html.

Sausen, Robert, Ivar Isaksen, Volker Grewe, Didier Hauglustaine, David S. Lee, Gunnar Myhre, Marcus O. Koehler, Givanni Pitari, Ulrich Schumann, Frode Stordal, and Christos Zerefos. 2005. "Aviation radiative forcing in 2000: An update on IPCC (1999)." *Meteorologische Zeitschrift* 14 (4): 555-561.

Shangaan Webservices Inc. 2010. "Air Travel in British Columbia." Accessed 10 October 2010. http://www.britishcolumbia.com/Transport/details.asp?id=2.

Sierra Research Inc. 2005. Alaska Aviation Emission Inventory. Available from http://www.wrapair.org/forums/ef/inventories/akai/Aviation_EI_Final_Report.pdf. Sacramento, CA.

Smirti, Megan. 2008. Modeling and Measuring Greenhouse Gas Reduction from Low Carbon Airport Access Modes. University of California Transportation Center.

Society of Environmental Journalists. 2007. "Blue Skies and Greenhouse Gases: Is Air Travel Really a Big Deal?" Accessed 12 October 2009. http://www.sej.org/publications/tipsheet/blue-skies-and-greenhouse-gases-is-air-travel-really-a-big-deal.

Solon, Daniel. 2007. "Airlines are defending their record over pollution." *New York Times*, 4 June.

Somerville, Hugh. 1997. "New Directions: Air Quality Issues in the Aviation Industry." *Atmospheric Environment* 31 (12): 1905-1907.

Transport Canada. 2009. Transportation in Canada - Addendum. Available from http://www.tc.gc.ca/media/documents/policy/addendum2009.pdf.

U.S. Environmental Protection Agency. 2011. "Human-Related Sources and Sinks of Carbon Dioxide." Accessed 18 June 2011. http://www.epa.gov/climatechange/emissions/co2_human.html.

Van den Bosch, F.A.J., and C.B.M. van Riel. 1998. "Buffering and Bridging as Environmental Strategies of Firms." *Business Strategy and the Environment* 7: 24-31.

Vancouver International Airport. "History." Accessed 15 July 2011. http://www.yvr.ca/en/about/history.aspx.

———. "Our Environmental Management Plan." Accessed 16 July 2011. http://www.yvr.ca/en/community-environment/Environmental-management/Environmental-goals.aspx.

———. "Sustainability Stories." Accessed 16 July 2011. http://www.yvr.ca/en/community-environment/stories.aspx.

———. 2011. Vancouver International Airport 2010 Economic Impact Report. Available from http://www.yvr.ca/Libraries/2010_Annual_Report/2011_05_12_Economic_Impact_Summary_FINAL.sflb.ashx. Vancouver, BC.

Vedantham, Anu, and Michael Oppenheimer. 1998. "Long-term scenarios for aviation: Demand and emissions of CO2 and NOx." *Energy Policy* 26 (8): 625-641.

Weidema, Bo P., Mikkel Thrane, Per Christensen, Jannick Schmidt, and Soren Lokke. 2008. "Carbon Footprint: A Catalyst for Life Cycle Assessment?" *Journal of Industrial Ecology* 12 (1): 3-6.

Westcoast Air. 2007. "Carbon Neutral." Accessed 24 March 2011. http://www.westcoastair.com/offsetting.php.

Westjet. "Environmental commitment." Accessed 24 March 2011. http://www.westjet.com/guest/en/about/environment/index.shtml.

Whitelegg, John, Nick Williams, and Chris Evans. n.d. The Plane Truth: Aviation and the Environment. London: The Ashden Trust and Transport 2000 Trust.

Williams, Victoria, and Robert B. Noland. 2005. "Variability of contrail formation conditions and the implications for policies to reduce the climate impacts of aviation." *Transportation Research Part D* 10: 269-280.

World Resources Institute. "GHG Emissions by Sector." Accessed 5 November 2010. http://cait.wri.org/cait-unfccc.php?page=sectors.

———. 2010. "Global Emissions of CO2 from Fossil Fuels." Accessed 5 November 2010. http://cait.wri.org/figures.php?page=ntn/1-2.

WWF. 2008. "Climate Pollution from Aviation Increasing." Accessed 12 October 2009. http://www.sciencedaily.com/releases/2008/01/080101201618.htm.

Yang, Christopher, David McCollum, Ryan McCarthy, and Wayne Leighty. 2009. "Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California." *Transportation Research Part D* 14: 147-156.

APPENDIX 1: Interview Questions

General interview questions for airline representatives

- Is the CF of aviation a concern for your airline? Has it ever come up in strategic planning?
- Has your company ever calculated its CF?
- What is your airline doing about its CF? Offset programs? If yes, which program and why? Are you happy with the performance?
- If not doing anything about CF: What do you think what it would take for your airline to do something about its CF? Do you think legislation, or consumer pressure? What might be the biggest incentive for you?
- Does the BC Carbon Tax have a big impact on your operations, for fuel costs etc?
- How does your airline feel about operational improvements such as improved navigation, high-speed taxiways etc? Do you participate in any of these initiatives?
- From your perspective as an airline, do you think that voluntary programs so that customers can offset their CF, or mandated policies would be better to reduce the CF?
- Is the CF an issue for your passengers? Are they sufficiently aware of it?

General interview questions for airport representatives

- Is the carbon footprint (CF) of aviation a concern for your airport? Has it ever come up in strategic planning?
- Has your airport ever calculated the CF of its operations? If so, what activities were included (just aircraft movements, ground activities, ground buildings, supporting infrastructure…)?
- What is your airport doing about its CF? Offset programs? If yes, which program and why? Are you happy with the performance?
- If not doing anything about CF: What do you think what it would take for your airport to do something about its CF? Do you think legislation, or consumer pressure? What might be the biggest incentive for you?
- Does the BC Carbon Tax have a big impact on your operations, for fuel costs etc? Does it have an impact in terms of airlines choosing to fly somewhere else, for example Bellingham?
- How does your airport feel about operational improvements such as improved navigation, high-speed taxiways etc? Do you participate in any of these initiatives?
- What about public transport to and from the airport? Has this been a focus for your airport, and how much of an environmental difference does it make?
- Are there incentives for employees to commute in an environmentally-friendly way?
- From your perspective as an airport, do you think that voluntary programs so that customers can offset their CF, or mandated policies would be better to reduce the CF?
- Is the CF an issue for your passengers? Are they sufficiently aware of it?

APPENDIX 2: CF Calculation Data

Table A2.1: BC flight inventory

Notes:

1. Airports are listed by their official IATA designators. However, for some small airports, the name of the town is listed instead. These airports are Gold River, Kyuquot, Nanaimo float plane airport, Ganges, Maple Bay, Bedwell Harbour, Langley, Sechelt, Comox float plane airport, Gillies Bay, Vernon, Gabriola Island, Tofino, Seymour Inlet, Pender Island, Thesis Island, Miner's Bay, Galiano Island, and Saturna Island.

2. Vancouver International Airport is listed as YVR, and Victoria International Airport as YYJ. “Vancouver” and “Victoria” refer to float plane airports in these cities, and “DT Vancouver” and “DT Victoria” to the downtown heliports in these cities.

3. “SATD” in the source description refers to the Star Alliance TravelDesk software.

Abbreviations

- Airlines
    - CMA: Central Mountain Air
    - HA: Harbour Air
    - HK: Hawkair
    - NH: Northern Hawk Aviation
    - PC: Pacific Coastal Airlines
    - QK: Air Canada Jazz
    - WS: Westjet

- Airport codes
    - DT Vancouver: Downtown Vancouver Heliport
    - DT Victoria: Victoria Heliport
    - QBC: Bella Coola
    - XQU: Qualicum Beach
    - YAA: Anahim Lake
    - YAZ: Tofino
    - YBL: Campbell River
    - YCD: Nanaimo
    - YCG: Castlegar
    - YDQ: Dawson Creek
    - YKA: Kamloops
    - YKT: Klemptu
    - YLW: Kelowna
    - YPB: Port Alberni
    - YPR: Prince Rupert
    - YPW: Power River
    - YQQ: Comox
    - YQZ: Quesnel

- YVR: Vancouver International Airport
- YWL: Williams Lake
- YXC: Cranbrook
- YXJ: Fort St. John
- YXS: Prince George
- YXT: Terrace
- YXX: Abbotsford
- YYD: Smithers
- YYE: Fort Nelson
- YYF: Penticton
- YYJ: Victoria International Airport
- YZP: Sandspit
- YZT: Port Hardy
- YZZ: Trail
- ZEL: Bella Bella
- ZMT: Masset

- Aircraft codes
  - 737: Boeing 737
  - B1900: Beech 1900
  - CRJ: Canadair Regional Jet
  - DH1: Dash 8-100
  - DH3: Dash 8-300

Carrier	Route	Equipment	Stage length	Weekly flights	Yearly flights	Source	Yearly kilometres	Seats
QK	YVR-Victoria	DH1	62km	178	9256	SATD	573872	37
QK	YVR-Victoria	DH3	62km	86	4472	SATD	277264	50
QK	YVR-Nanaimo	DH3	54km	92	4784	SATD	258336	50
QK	YVR-Penticton	DH3	259km	40	2080	SATD	538720	50
QK	YVR-Castlegar	DH3	400km	38	1976	SATD	790400	50
QK	YVR-Kelowna	DH3	286km	94	4888	SATD	1397968	50
QK	YVR-Cranbrook	DH3	534km	28	1456	SATD	777504	50
QK	YVR-Kamloops	DH1	259km	12	624	SATD	161616	37
QK	YVR-Kamloops	DH3	259km	58	3016	SATD	781144	50
QK	YVR-Prince George	DH3	521km	28	1456	SATD	758576	50
QK	YVR-Prince George	CRJ	521km	46	2392	SATD	1246232	50
QK	YVR-Fort St. John	CRJ	796km	60	3120	SATD	2483520	50
QK	YVR-Smithers	DH3	680km	26	1352	SATD	919360	50
QK	YVR-Terrace	DH3	691km	40	2080	SATD	1437280	50
QK	YVR-Prince Rupert	DH3	752km	26	1352	SATD	1016704	50
QK	YVR-Sandspit	DH1	748km	14	728	SATD	544544	37
WJ	YVR-YXS	737NG	521km	38	1976	westjet.com	1029496	150
WJ	Victoria-Kelowna	737NG	328km	14	728	westjet.com	238784	150
WJ	Vancouver-Kelowna	737NG	286km	42	2184	westjet.com	624624	150
CMA	YVR-Comox	B1900	137km	24	1248	flycma.com	170976	18
CMA	Comox-Campbell River	B1900	39km	32	1664	flycma.com	64896	18
CMA	YVR-Campbell River	B1900	172km	32	1664	flycma.com	286208	18
CMA	YVR-Quesnel	B1900	430km	11	572	flycma.com	245960	18
CMA	Williams Lake-Quesnel	B1900	98km	11	572	flycma.com	56056	18
CMA	YVR-Williams Lake	B1900	341km	11	572	flycma.com	195052	18
CMA	YVR-Dawson Creek	DH1	756km	8	416	flycma.com	314496	37
CMA	YXS-Terrace	B1900	391km	10	520	flycma.com	203320	18
CMA	Terrace-Smithers	B1900	98km	10	520	flycma.com	50960	18
CMA	YXS-YKA	B1900	386km	12	624	flycma.com	240864	18
CMA	YXS-YLW	B1900	492km	12	624	flycma.com	307008	18
CMA	YXS-Fort St. John	B1900	290km	10	520	flycma.com	150800	18
CMA	Fort Nelson-Fort St. John	B1900	311km	10	520	flycma.com	161720	18
CMA	Fort Nelson-Fort St. John	Dornier 328	311km	12	624	flycma.com	194064	30

CMA	Fort Nelson-Dawson Creek	DH1	373km	8	416	flycma.com	155168	37
PC	YVR-Trail	B1900	407km	24	1248	pacificcoastal.com	507936	19
PC	YVR-Cranbrook	B1900 and Saab340	534km	36	1872	pacificcoastal.com	999648	19
PC	YVR-Williams Lake	B1900	341km	36	1872	pacificcoastal.com	638352	19
PC	YVR-Anahim Lake	B1900	393km	6	312	pacificcoastal.com	122616	19
PC	YVR-Bella Coola	B1900	430km	14	728	pacificcoastal.com	313040	19
PC	YVR-Powell River	Saab340, Shorts 360, Beech 1900	119km	54	2808	pacificcoastal.com	558792	20
PC	YVR-Comox	Saab340, Shorts 360, Beech 1900	137km	30	1560	pacificcoastal.com	213720	20
PC	Comox-Campbell River	Saab340, Shorts 360, Beech 1900	39km	30	1560	pacificcoastal.com	60840	20
PC	YVR-Campbell River	Saab340, Shorts 360, Beech 1900	172km	30	1560	pacificcoastal.com	268320	20
PC	YVR-Masset	Saab 340a	819km	12	624	pacificcoastal.com	511056	30
PC	YVR-Port Hardy	Saab 340a and Beech 1900	343km	26	1352	pacificcoastal.com	463736	25
PC	Port Hardy-Bella Bella	Saab 340a	171km	14	728	pacificcoastal.com	521976	30
PC	Bella Bella-Klemptu	Grumman Goose	58km	10	520	pacificcoastal.com	30160	8
PC	YVR-Victoria	Beech 1900, Beech King Air, Shorts 360	62km	58	3016	pacificcoastal.com	174928	20
Air Nootka	Gold River-Kyuquot	Float plane	~120km	6	312	airnootka.com/schedule.html	37440	4

Airspeed Aviation	Abbotsford-Victoria	Prop?	89km	20	1040	http://www.airspeed-abby.com/fares.html	92560	20
Harbour Air	Vancouver-Nanaimo	DeHavilland Beaver and Otter	61km	134	6968	http://www.harbour-air.com/schedules.php	425048	15
Harbour Air	Vancouver-Victoria	DeHavilland Beaver and Otter	98km	272	14144	http://www.harbour-air.com/schedules.php	1386112	15
Harbour Air	Vancouver-Ganges	DeHavilland Beaver and Otter	56km	38	1976	http://www.harbour-air.com/schedules.php	110656	15
Harbour Air	Ganges-Maple Bay	DeHavilland Beaver and Otter	10km	38	1976	http://www.harbour-air.com/schedules.php	19760	15
Harbour Air	Ganges-Bedwell Harbour	DeHavilland Beaver and Otter	23km	14	728	http://www.harbour-air.com/schedules.php	16744	15
Harbour Air	YVR-Nanaimo	DeHavilland Beaver and Otter	53km	86	4472	http://www.harbour-air.com/schedules.php	237016	15
Harbour Air	YVR-Victoria	DeHavilland Beaver and Otter	62km	38	1976	http://www.harbour-air.com/schedules.php	122512	15
Harbour Air	Langley-Victoria	DeHavilland Beaver and Otter	77km	30	1560	http://www.harbour-air.com/schedules.php	120120	15

Harbour Air	Vancouver-Sechelt	DeHavilland Beaver and Otter	52km	28	1456	http://www.harbour-air.com/schedules.php	75712	15
Harbour Air	Nanaimo-Sechelt	DeHavilland Beaver and Otter	48km	52	2704	http://www.harbour-air.com/schedules.php	129792	15
Harbour Air	Vancouver-Comox	DeHavilland Beaver and Otter	137km	34	1768	http://www.harbour-air.com/schedules.php	242216	15
Harbour Air	YVR-Sechelt	DeHavilland Beaver and Otter	53km	24	1248	http://www.harbour-air.com/schedules.php	66144	15
Hawkair	YVR-Smithers	DH1?	680km	12	624	http://www.hawkair.ca/schedule	424320	37
Hawkair	YVR-Terrace	DH1?	691km	26	1352	http://www.hawkair.ca/schedule	934232	37
Hawkair	YVR-Prince Rupert	DH1?	752km	8	416	http://www.hawkair.ca/schedule	312832	37
Hawkair	Terrace-Prince Rupert	DH1?	122km	4	208	http://www.hawkair.ca/schedule	29952	37
Hawkair	Terrace-Smithers	DH1?	98km	2	104	http://www.hawkair.ca/schedule	10192	37

Helijet	YVR-DT Victoria	Sikorsky S76 Helicopter	87km	166	8632	http://helijet.com/n/schedule/img/page18/Helijet%20Schedule%20Information%20-%20effective%2012Oct10.pdf	750984	14
Helijet	DT Vancouver - DT Victoria	Sikorsky S76 Helicopter	98km	166	8632	http://helijet.com/n/schedule/img/page18/Helijet%20Schedule%20Information%20-%20effective%2012Oct10.pdf	845936	14
KD Air	Vancouver-Qualicum Beach	Piper PA31 or Cessna	90km	66	3432	http://www.kdair.com/flights/summer_schedule_eng.html	308880	6
KD AIr	Qualicum Beach-Gillies Bay	Piper PA31 or Cessna	40km	38	1976	http://www.kdair.com/flights/summer_schedule_eng.html	79040	6
KD Air	Qualicum Beach-Port Alberni	Piper PA31 or Cessna	39km	52	2704	http://www.kdair.com/flights/summer_schedule_eng.html	105456	6
Northern Hawk	Bella Bella-Port Hardy	Beech King Air, Piper	171km	8	416	http://www.idtrip.com/northernhawk/northcoastsched.pdf	71136	10
Northern Hawk	Port Hardy-YVR	Beech King Air, Piper	343km	8	416	http://www.idtrip.com/northernhawk/northcoastsched.pdf	142688	10

Northern Hawk	YVR-Tofino	Beech King Air, Piper	190km	18	936	http://www.idtrip.com/northernhawk/southcoastsched.pdf	177840	10
Northern Hawk	YVR-Nanaimo	Beech King Air, Piper	55km	5	260	http://www.idtrip.com/northernhawk/southcoastsched.pdf	14300	10
Northern Hawk	YVR-Trail	Beech King Air, Piper	407km	2	104	http://www.idtrip.com/northernhawk/interiorsched.pdf	42328	10
Northern Hawk	Trail-Vernon	Beech King Air, Piper	182km	9	468	http://www.idtrip.com/northernhawk/interiorsched.pdf	85176	10
Northern Hawk	YVR-Vernon	Beech King Air, Piper	301km	11	572	http://www.idtrip.com/northernhawk/interiorsched.pdf	172172	10
Orca Airways	Abbotsford-Nanaimo	Navajo Chieftain	116km	20	1040	http://www.flyorcaair.com/schedule-abbotsford.php	120640	8
Orca Airways	Abbotsford-Victoria	Navajo Chieftain	89km	22	1144	http://www.flyorcaair.com/schedule-abbotsford.php	101816	8
Orca Airways	YVR-Victoria	Navajo Chieftain	62km	30	1560	http://www.flyorcaair.com/schedule-vancouver.php	96720	8
Orca Airways	YVR-Tofino	Navajo Chieftain	190km	28	1456	http://www.flyorcaair.com/schedule-vancouver.php	276640	8

Tofino Air	YVR-Gabriola Island	Otter, Beaver, Cessna	~35km	42	2184	http://www.tofinoair.ca/flights_gab.asp	76440	8
Tofino Air	Sechelt-Nanaimo	Otter, Beaver, Cessna	37km	56	2912	http://www.tofinoair.ca/flights_sec-nan.asp	107744	8
Tofino Air	YVR-Tofino	Otter, Beaver, Cessna	190km	14	728	http://www.tofinoair.ca/flights_sec-yvr-bam-tof.asp	138320	8
Vancouver Island Air	Campbell River-Seymour Inlet	Otter, Beaver, Beech 18	~200km	6	312	http://www.vancouverislandair.com/scheduled.html	62400	8
Westcoast Air	Same as Harbour Air							
Seair	YVR-Nanaimo	Cessna, Beaver	53km	56	2912	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_nanaimo_4	154336	6
Seair	YVR-Ganges	Cessna, Beaver	45km	42	2184	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_saltspring	98280	6
Seair	YVR-North Pender Island	Cessna, Beaver	43km	42	2184	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_pender	93912	6
Seair	YVR-Thetis Island	Cessna, Beaver	42km	42	2184	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_thetis	91728	6

Seair	YVR-Saturna Island	Cessna, Beaver	46km	42	2184	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_saturna	100464	6
Seair	YVR-Miner's Bay	Cessna, Beaver	37km	28	1456	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_mayne	53872	6
Seair	YVR-Galiano Island	Cessna, Beaver	~40km	28	1456	http://seairseaplanes.com/index.php?fuseaction=e4_cms.sched_galiano	58240	6
Swanberg Air	Dawson Creek-Ft. St. John	Jetstream, Nevajo	66km	10	520	http://swanbergair.com/schedule/	34320	12
Swanberg Air	Fort St. John-Fort Nelson	Jetstream, Nevajo	309km	10	520	http://swanbergair.com/schedule/	160576	12

Table A2.2: Full listing of BC Flight CF Average Values

Notes:

1. In the Offsetters column, bolded results indicate that the value was obtained by multiplying the average between the WRI tool and the GHG Protocol Travel calculator by 1.44 to compensate for Offsetters not recognizing the airport in question.

Airline	Route and aircraft used	Total distance per year (km)	WRI tool values (tonnes of CO_2e per year)	GHG Protocol travel calculator values (tonnes of CO_2e per year)	Offsetters values (tonnes of CO_2e per year)	Average CF value (tonnes of CO_2e)	Tonnes of CO_2e per 100 km flown
QK	YVR-YYJ DH1	573872	4057	3185	3425	3556	0.620
QK	YVR-YYJ DH3	277264	2649	2079	2236	2321	0.837
QK	YVR-YCD DH3	258336	2468	1938	2392	2266	0.877
QK	YVR-YYF DH3	538720	5147	4040	5200	4796	0.890
QK	YVR-YCG DH3	790400	4036	5928	7904	5956	0.754
QK	YVR-YLW DH3	1397968	13356	10485	12220	12020	0.860
QK	YVR-YXC DH3	777504	3970	4665	8008	5548	0.714
QK	YVR-YKA DH1	161616	1143	897	1154	1065	0.659
QK	YVR-YKA DH3	781144	7463	5859	7540	6954	0.890
QK	YVR-YXS DH3	758576	3874	4551	7280	5235	0.690
QK	YVR-YXS CRJ	1246232	6364	7477	11960	8600	0.690
QK	YVR-YXJ CRJ	2483520	10923	14901	24960	16928	0.682
QK	YVR-YYD DH3	919360	4695	5516	9464	6558	0.713
QK	YVR-YXT DH3	1437280	7340	8624	14560	10175	0.708
QK	YVR-YPR DH3	1016704	4472	6100	10140	6904	0.679

QK	YVR-YZP DH3	544544	1772	2418	4040	2743	0.504
WS	YVR-YXS 737	1029496	15772	18535	29640	21316	2.070
WS	YYJ-YLW 737	238784	6844	5373	6552	6256	2.620
WS	YVR-YLW 737	624624	17903	14054	16380	16112	2.580
CMA	YVR-YQQ B1900	170976	588	462	674	575	0.336
CMA	YQQ-YBL B1900	64896	223	175	300	233	0.359
CMA	YVR-YBL B1900	286208	984	773	899	885	0.309
CMA	YVR-YQZ B1900	245960	452	664	824	647	0.263
CMA	YQZ-YWL B1900	56056	193	151	206	183	0.327
CMA	YVR-YWL B1900	195052	671	527	618	605	0.310
CMA	YVR-YDQ DH1	314496	541	1396	2309	1415	0.450
CMA	YXS-YXT B1900	203320	374	549	655	526	0.259
CMA	YXY-YYD B1900	50960	175	138	187	167	0.327
CMA	YXS-YKA B1900	240864	443	650	786	626	0.260
CMA	YXS-YLW B1900	307008	564	829	1123	839	0.273
CMA	YXS-YXJ B1900	150800	519	407	468	465	0.308
CMA	YYE-YXJ B1900	161720	556	437	562	518	0.321
CMA	YYE-YXJ Dornier 328	194064	1112	873	1123	1036	0.534
CMA	YYE-YDQ DH1	155168	586	861	1077	841	0.542
PC	YVR-YZZ B1900	507936	986	1448	**1752**	1395	0.275
PC	YVR-YXC B1900 and Saab340	999648	1940	2279	3912	2710	0.271
PC	YVR-YWL B1900	638352	1239	1819	2134	1731	0.271

PC	YVR-YAA B1900	122616	238	349	**423**	337	0.275
PC	YVR-QBC B1900	313040	607	892	**1079**	859	0.275
PC	YVR-YPW Saab, Shorts, B1900	558792	2135	1676	**2344**	2052	0.367
PC	YVR-YQQ Saab, Shorts, B1900	213720	817	641	936	798	0.373
PC	YQQ-YBL Saab, Shorts, B1900	60840	233	183	312	243	0.399
PC	YVR-YBL Saab, Shorts, B1900	268320	1025	805	936	922	0.344
PC	YVR-ZMT Saab340a	511056	1349	1840	**2296**	1828	0.358
PC	YVR-YZT Saab340a and Beech 1900	463736	1184	1739	2366	1763	0.380
PC	YZT-ZEL Saab340a	521976	2992	2379	**3867**	3079	0.590
PC	ZEL-YKT Grumman Goose	30160	46	36	**59**	47	0.156
PC	YVR-YYJ Beech 1900, Beech King Air, Shorts 360	174928	668	525	603	599	0.342
Airspeed Aviation	YXX-YYJ propeller plane	92560	354	278	416	349	0.377
Air Nootka	Gold River-Kyuquot float plane	37440	29	22	**37**	29	0.078

HA	Vancouver-Nanaimo DeHavilland Beaver and Otter	425048	1218	956	1045	1073	0.252
HA	Vancouver-Victoria DeHavilland Beaver and Otter	1386112	3973	3119	2122	3071	0.222
HA	Vancouver-Ganges DeHavilland Beaver and Otter	110656	317	249	**408**	325	0.293
HA	Ganges-Maple Bay DeHavilland Beaver and Otter	19760	57	44	**73**	58	0.294
HA	Ganges-Bedwell Harbour DeHavilland Beaver and Otter	16744	48	38	**62**	49	0.295
HA	YVR-Nanaimo DeHavilland Beaver and Otter	237016	679	533	671	628	0.265
HA	YVR-Victoria DeHavilland Beaver and Otter	122512	351	276	296	308	0.251
HA	Langley-Victoria DeHavilland Beaver and Otter	120120	344	270	**442**	352	0.293
HA	Vancouver-Sechelt DeHavilland Beaver	75712	217	170	**279**	222	0.293

	and Otter						
HA	Nanaimo-Sechelt DeHavilland Beaver and Otter	129792	372	292	**478**	381	0.293
HA	Vancouver-Comox DeHavilland Beaver and Otter	242216	694	545	796	678	0.280
HA	YVR-Sechelt DeHavilland Beaver and Otter	66144	190	149	**244**	194	0.294
HK	YVR-YYD DH1	424320	1603	1884	3232	2240	0.528
HK	YVR-YXT DH1	934232	3530	4148	7003	4894	0.524
HK	YVR-YPR DH1	312832	1018	1389	2309	1572	0.503
HK	YXT-YYD DH1	10192	72	57	77	69	0.674
HK	YXT-YPR DH1	29952	212	166	154	177	0.592
Helijet	YVR-DT Victoria S76	750984	2009	1577	1208	1598	0.213
Helijet	DT Vancouver-DT Victoria S76	845936	2263	1776	1208	1749	0.207
KD Air	YVR-XQU Piper PA31 or Cessna	308880	354	278	**455**	362	0.117

KD Air	XQU-Gillies Bay Beach Piper PA31 or Cessna	79040	91	71	**117**	93	0.118
KD Air	XQU-YPB Beach Piper PA31 or Cessna	105456	121	95	**156**	124	0.118
NH	ZEL-YZT Beech King Air or Piper	71136	136	107	**175**	139	0.196
NH	YVR-YZT Beech King Air or Piper	142688	146	214	291	217	0.152
NH	YVR-YAZ Beech King Air or Piper	177840	340	267	374	327	0.184
NH	YVR-YCD Beech King Air or Piper	14300	27	21	26	25	0.172
NH	YVR-YZZ Beech King Air or Piper	42328	43	63	**76**	61	0.143
NH	YZZ-Vernon Beech King Air or Piper	85176	163	128	**210**	167	0.196
NH	YVR-Vernon Beech King Air or Piper	172172	329	258	**423**	337	0.196
Orca Air	YXX-YCD Navajo	120640	184	145	166	165	0.137
Orca Air	YXX-YYJ Navajo	101816	156	122	183	154	0.151
Orca Air	YVR-YYJ Navajo	96720	148	116	125	130	0.134
Orca Air	YVR-YAZ Navajo	276640	423	332	466	407	0.147

Tofino Air	YVR-Gabriola Island Otter, Beaver, Cessna	76440	117	92	**150**	120	0.157
Tofino Air	Sechelt-Nanaimo Otter, Beaver, Cessna	107744	165	129	**212**	169	0.157
Tofino Air	YVR-Tofino Otter, Beaver, Cessna	138320	211	166	233	203	0.147
Vancouver Island Air	Campbell River-Seymour Inlet Otter, Beaver, Beech 18	62400	95	75	**122**	97	0.156
Seair	YVR-Nanaimo Cessna, Beaver	154336	177	139	175	164	0.106
Seair	YVR-Ganges Cessna, Beaver	98280	113	88	**145**	115	0.117
Seair	YVR-North Pender Island Cessna, Beaver	93912	108	85	**139**	111	0.118
Seair	YVR-Thetis Island Cessna, Beaver	91728	105	83	**135**	108	0.117
Seair	YVR-Saturna Island Cessna, Beaver	100464	115	90	**148**	118	0.117

Seair	YVR-Miner's Bay Cessna, Beaver	53872	62	48	**79**	63	0.117
Seair	YVR-Galiano Island Cessna, Beaver	58240	67	52	**86**	68	0.117
Swanberg Air	YDQ-YXJ Jetstream, Navajo	34320	79	62	62	68	0.197
Swanberg Air	YXJ-YYE Jetstream, Nevajo	160576	197	289	374	287	0.179
Total		**3,345,435**	**171,510**	**173,681**	**247,748**	**197,648**	

A2.3: BC Civil Aviation City-Pair CF Values

Table A2.3.1: Vancouver-Victoria (Total yearly flights: 53248)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-YYJ DH1	573872	3556	0.620
QK	YVR-YYJ DH3	277264	2321	0.837
PC	YVR-YYJ Beech 1900, Beech King Air, Shorts 360	174928	599	0.342
HA	Vancouver-Victoria DeHavilland Beaver and Otter	1386112	3071	0.222
HA	YVR-Victoria DeHavilland Beaver and Otter	122512	308	0.251
HA	Langley-Victoria DeHavilland Beaver and Otter	120120	307	0.256
Helijet	YVR-DT Victoria S76	750984	1598	0.213
Helijet	DT Vancouver-DT Victoria S76	845936	1749	0.207
Orca Air	YVR-YYJ Navajo	96720	130	0.134
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		4348448	**13639**	**0.314**

Table A2.3.2: Vancouver – Nanaimo (Total yearly flights: 19396)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-Nanaimo DH3	258336	2266	0.877
HA	Vancouver-Nanaimo DeHavilland Beaver and Otter	425048	1073	0.253
HA	YVR-Nanaimo DeHavilland Beaver and Otter	237016	628	0.265
NH	YVR-Nanaimo Beech King Air or Piper	14300	25	0.174
Seair	YVR-Nanaimo Cessna, Beaver	154336	164	0.106
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		1089036	**4156**	**0.382**

Table A2.3.3: Vancouver – Kelowna (Total yearly flights: 7072)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-YLW DH3	1397968	12020	0.860
WS	YVR-YLW 737	624624	16112	2.580
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		2022592	**28132**	**1.391**

Table A2.3.4: Vancouver – Cranbrook (Total yearly flights: 3328)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
PC	YVR-Cranbrook B1900 and Saab340	999648	2711	0.271
QK	YVR-Cranbrook DH3	777504	5548	0.714
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		1777152	**8259**	**0.465**

Table A2.3.5: Vancouver – Kamloops (Total yearly flights: 3640)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-YKA DH1	161616	1065	0.659
QK	YVR-YKA DH3	781144	6954	0.890
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		942760	**8019**	**0.851**

Table A2.3.6: Vancouver – Prince George (Total yearly flights: 5824)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-YXS DH3	758576	5235	0.690
QK	YVR-YXS CRJ	1246232	8600	0.690
WS	YVR-YXS 737	1029496	21316	2.071
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		3034304	**35151**	**1.158**

Table A2.3.7: Vancouver – Smithers (Total yearly flights: 1976)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-Smithers DH3	919360	6558	0.713
HK	YVR-Smithers DH1	424320	2240	0.528
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		1343680	**8798**	**0.655**

Table A2.3.8: Vancouver – Terrace (Total yearly flights: 3432)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-Terrace DH3	1437280	10174	0.708
HK	YVR-Terrace DH1	934232	4894	0.524
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		2371512	**15068**	**0.635**

Table A2.3.9: Vancouver – Prince Rupert (Total yearly flights: 1768)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
QK	YVR-YPR DH3	1016704	6904	0.679
HK	YVR-YPR DH1	312832	1572	0.503
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		1329536	**8476**	**0.638**

Table A2.3.10: Vancouver – Comox (Total yearly flights: 2808)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	YVR-Comox B1900	170976	575	0.336
PC	YVR-Comox Saab, Shorts, B1900	213720	798	0.373
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		384696	**1373**	**0.357**

Table A2.3.11: Comox-Campbell River (Total yearly flights: 3224)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	Comox-Campbell River B1900	64896	233	0.359
PC	Comox-Campbell River Saab, Shorts, B1900	60840	242	0.398
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		125736	**475**	**0.378**

Table A2.3.12: Vancouver – Campbell River (Total yearly flights: 3224)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	YVR-Campbell River B1900	286208	885	0.309
PC	YVR-Campbell River Saab, Shorts, B1900	268320	922	0.344
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		554528	**1807**	**0.326**

Table A2.3.13: Vancouver – Williams Lake (Total yearly flights: 2444)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	YVR-YWL B1900	195052	605	0.310
PC	YVR-YWL B1900	638352	1731	0.271
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		833404	**2336**	**0.280**

Table A2.3.14: Terrace-Smithers (Total yearly flights: 624)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	Terrace-Smithers B1900	50960	167	0.327
HK	Terrace-Smithers DH1	10192	69	0.672
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		61152	**236**	**0.386**

Table A2.3.15: Fort Nelson – Fort St. John (Total yearly flights: 1664)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
CMA	Fort Nelson-Fort St. John B1900	161720	518	0.320
CMA	Fort Nelson-Fort St. John Dornier 328	194064	1118	0.576
Swan-berg Air	Fort St. John-Fort Nelson Jetstream, Nevajo	160576	287	0.179
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		516360	**1923**	**0.372**

Table A2.3.16: Vancouver – Trail (Total yearly flights: 1352)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
NH	YVR-Trail Beech King Air or Piper	42328	53	0.126
PC	YVR-Trail B1900	507936	1217	0.240
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		550264	**1270**	**0.231**

Table A2.3.17: Vancouver – Port Hardy (Total yearly flights: 1768)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
PC	YVR-Port Hardy Saab340a and Beech 1900	463736	1763	0.380
NH	YVR-Port Hardy Beech King Air or Piper	142688	217	0.152
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		606424	**1980**	**0.327**

Table A2.3.18: Vancouver – Tofino (Total yearly flights: 3120)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
NH	YVR-Tofino Beech King Air or Piper	177840	327	0.184
Orca Air	YVR-Tofino Navajo	276640	407	0.147
Tofino Air	YVR-Tofino Otter, Beaver, Cessna	138320	203	0.147
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		592800	**937**	**0.158**

Table A2.3.19: Abbotsford-Victoria (Total yearly flights: 2184)

Airline	Route	km per year	Average CF in tonnes of CO_2e	Tonnes of CO_2e per 100 km flown
Orca Air	Abbotsford Victoria Navajo	101816	154	0.151
Airspeed Aviation	Abbotsford-YYJ prop	92560	349	0.377
Total		Total km flown per year	Total tonnes of CO_2e per year	Average tonnes of CO_2e per 100 km flown across airlines
		194376	**503**	**0.259**

Table A2.4: Full listing of CF per unit distance travelled per passenger

Airline	Route and aircraft used	Total distance per year (km)	Average CF value (tonnes of CO_2e)	Tonnes of CO_2e per 100 km flown	Seats on plane	Tonnes of CO_2e per 100 km flown per passenger
QK	YVR-YYJ DH1	573872	3556	0.620	37	0.016757
QK	YVR-YYJ DH3	277264	2321	0.837	50	0.01674
QK	YVR-YCD DH3	258336	2266	0.877	50	0.01754
QK	YVR-YYF DH3	538720	4796	0.890	50	0.0178
QK	YVR-YCG DH3	790400	5956	0.754	50	0.01508
QK	YVR-YLW DH3	1397968	12020	0.860	50	0.0172
QK	YVR-YXC DH3	777504	5548	0.714	50	0.01428
QK	YVR-YKA DH1	161616	1065	0.659	37	0.017811
QK	YVR-YKA DH3	781144	6954	0.890	50	0.0178
QK	YVR-YXS DH3	758576	5235	0.690	50	0.0138
QK	YVR-YXS CRJ	1246232	8600	0.690	50	0.0138
QK	YVR-YXJ CRJ	2483520	16928	0.682	50	0.01364
QK	YVR-YYD DH3	919360	6558	0.713	50	0.01426
QK	YVR-YXT DH3	1437280	10175	0.708	50	0.01416
QK	YVR-YPR DH3	1016704	6904	0.679	50	0.01358
QK	YVR-YZP DH3	544544	2743	0.504	50	0.01008
WS	YVR-YXS 737	1029496	21316	2.070	150	0.0138
WS	YYJ-YLW 737	238784	6256	2.620	150	0.017467
WS	YVR-YLW 737	624624	16112	2.580	150	0.0172
CMA	YVR-YQQ	170976	575	0.336	18	0.018667

	B1900					
CMA	YQQ-YBL B1900	64896	233	0.359	18	0.019944
CMA	YVR-YBL B1900	286208	885	0.309	18	0.017167
CMA	YVR-YQZ B1900	245960	647	0.263	18	0.014611
CMA	YQZ-YWL B1900	56056	183	0.327	18	0.018167
CMA	YVR-YWL B1900	195052	605	0.310	18	0.017222
CMA	YVR-YDQ DH1	314496	1415	0.450	37	0.012162
CMA	YXS-YXT B1900	203320	526	0.259	18	0.014389
CMA	YXY-YYD B1900	50960	167	0.327	18	0.018167
CMA	YXS-YKA B1900	240864	626	0.260	18	0.014444
CMA	YXS-YLW B1900	307008	839	0.273	18	0.015167
CMA	YXS-YXJ B1900	150800	465	0.308	18	0.017111
CMA	YYE-YXJ B1900	161720	518	0.321	18	0.017833
CMA	YYE-YXJ Dornier 328	194064	1036	0.534	30	0.0178
CMA	YYE-YDQ DH1	155168	841	0.542	37	0.014649
PC	YVR-YZZ B1900	507936	1395	0.275	19	0.014474
PC	YVR-YXC B1900 and Saab340	999648	2710	0.271	19	0.014263
PC	YVR-YWL B1900	638352	1731	0.271	19	0.014263
PC	YVR-YAA B1900	122616	337	0.275	19	0.014474
PC	YVR-QBC B1900	313040	859	0.275	19	0.014474
PC	YVR-YPW Saab, Shorts, B1900	558792	2052	0.367	20	0.01835
PC	YVR-YQQ Saab,	213720	798	0.373	20	0.01865

	Shorts, B1900					
PC	YQQ-YBL Saab, Shorts, B1900	60840	243	0.399	20	0.01995
PC	YVR-YBL Saab, Shorts, B1900	268320	922	0.344	20	0.0172
PC	YVR-ZMT Saab340a	511056	1828	0.358	30	0.011933
PC	YVR-YZT Saab340a and Beech 1900	463736	1763	0.380	25	0.0152
PC	YZT-ZEL Saab340a	521976	3079	0.590	30	0.019667
PC	ZEL-YKT Grumman Goose	30160	47	0.156	8	0.0195
PC	YVR-YYJ Beech 1900, Beech King Air, Shorts 360	174928	599	0.342	20	0.0171
Airspeed Aviation	YXX-YYJ propeller plane	92560	349	0.377	20	0.01885
Air Nootka	Gold River-Kyuquot float plane	37440	29	0.078	4	0.0195
HA	Vancouver-Nanaimo DeHavilland Beaver and Otter	425048	1073	0.252	15	0.0168
HA	Vancouver-Victoria DeHavilland Beaver and Otter	1386112	3071	0.222	15	0.0148
HA	Vancouver-Ganges DeHavilland Beaver and	110656	325	0.293	15	0.019533

	Otter					
HA	Ganges-Maple Bay DeHavilland Beaver and Otter	19760	58	0.294	15	0.0196
HA	Ganges-Bedwell Harbour DeHavilland Beaver and Otter	16744	49	0.295	15	0.019667
HA	YVR-Nanaimo DeHavilland Beaver and Otter	237016	628	0.265	15	0.017667
HA	YVR-Victoria DeHavilland Beaver and Otter	122512	308	0.251	15	0.016733
HA	Langley-Victoria DeHavilland Beaver and Otter	120120	352	0.293	15	0.019533
HA	Vancouver-Sechelt DeHavilland Beaver and Otter	75712	222	0.293	15	0.019533
HA	Nanaimo-Sechelt DeHavilland Beaver and Otter	129792	381	0.293	15	0.019533
HA	Vancouver-Comox DeHavilland Beaver and Otter	242216	678	0.280	15	0.018667
HA	YVR-Sechelt DeHavilland Beaver and	66144	194	0.294	15	0.0196

	Otter					
HK	YVR-YYD DH1	424320	2240	0.528	37	0.01427
HK	YVR-YXT DH1	934232	4894	0.524	37	0.014162
HK	YVR-YPR DH1	312832	1572	0.503	37	0.013595
HK	YXT-YYD DH1	10192	69	0.674	37	0.018216
HK	YXT-YPR DH1	29952	177	0.592	37	0.016
Helijet	YVR-DT Victoria S76	750984	1598	0.213	14	0.015214
Helijet	DT Vancouver-DT Victoria S76	845936	1749	0.207	14	0.014786
KD Air	YVR-XQU Piper PA31 or Cessna	308880	362	0.117	6	0.0195
KD Air	XQU-Gillies Bay Beach Piper PA31 or Cessna	79040	93	0.118	6	0.019667
KD Air	XQU-YPB Beach Piper PA31 or Cessna	105456	124	0.118	6	0.019667
NH	ZEL-YZT Beech King Air or Piper	71136	139	0.196	10	0.0196
NH	YVR-YZT Beech King Air or Piper	142688	217	0.152	10	0.0152
NH	YVR-YAZ Beech King Air or Piper	177840	327	0.184	10	0.0184
NH	YVR-YCD Beech King Air or Piper	14300	25	0.172	10	0.0172
NH	YVR-YZZ Beech King Air or Piper	42328	61	0.143	10	0.0143
NH	YZZ-Vernon	85176	167	0.196	10	0.0196

	Beech King Air or Piper					
NH	YVR-Vernon Beech King Air or Piper	172172	337	0.196	10	0.0196
Orca Air	YXX-YCD Navajo	120640	165	0.137	8	0.017125
Orca Air	YXX-YYJ Navajo	101816	154	0.151	8	0.018875
Orca Air	YVR-YYJ Navajo	96720	130	0.134	8	0.01675
Orca Air	YVR-YAZ Navajo	276640	407	0.147	8	0.018375
Tofino Air	YVR-Gabriola Island Otter, Beaver, Cessna	76440	120	0.157	8	0.019625
Tofino Air	Sechelt-Nanaimo Otter, Beaver, Cessna	107744	169	0.157	8	0.019625
Tofino Air	YVR-Tofino Otter, Beaver, Cessna	138320	203	0.147	8	0.018375
Vancouver Island Air	Campbell River-Seymour Inlet Otter, Beaver, Beech 18	62400	97	0.156	8	0.0195
Seair	YVR-Nanaimo Cessna, Beaver	154336	164	0.106	6	0.017667
Seair	YVR-Ganges Cessna, Beaver	98280	115	0.117	6	0.0195
Seair	YVR-North Pender Island	93912	111	0.118	6	0.019667

	Cessna, Beaver					
Seair	YVR-Thetis Island Cessna, Beaver	91728	108	0.117	6	0.0195
Seair	YVR-Saturna Island Cessna, Beaver	100464	118	0.117	6	0.0195
Seair	YVR-Miner’s Bay Cessna, Beaver	53872	63	0.117	6	0.0195
Seair	YVR-Galiano Island Cessna, Beaver	58240	68	0.117	6	0.0195
Swanberg Air	YDQ-YXJ Jetstream, Navajo	34320	68	0.197	12	0.016417
Swanberg Air	YXJ-YYE Jetstream, Nevajo	160576	287	0.179	12	0.014917

Table A2.5: Full ranking of CF per passenger on BC routes

Rank	Airline	Route	Annual CF (tonnes of CO_2e)	Seats per plane	Annual flights	Annual seats per route	CF per passenger (tonnes of CO_2e)
1	PC	YZT-ZEL Saab340a	3079	30	728	21840	0.14098
2	QK	YVR-YXJ CRJ	16928	50	3120	156000	0.10851
3	HK	YVR-YPR DH1	1572	37	416	15392	0.10213
4	QK	YVR-YPR DH3	6904	50	1352	67600	0.10213
5	QK	YVR-YXT DH3	10175	50	2080	104000	0.09784
6	HK	YVR-YXT DH1	4894	37	1352	50024	0.09783
7	PC	YVR-ZMT Saab340a	1828	30	624	18720	0.09765
8	HK	YVR-YYD DH1	2240	37	624	23088	0.09702
9	QK	YVR-YYD DH3	6558	50	1352	67600	0.09701
10	CMA	YVR-YDQ DH1	1415	37	416	15392	0.09193
11	QK	YVR-YXC DH3	5548	50	1456	72800	0.07621
12	PC	YVR-YXC B1900 and Saab340	2710	19	1872	35568	0.07619
13	QK	YVR-YZP DH3	2743	50	728	36400	0.07536
14	CMA	YXS-YLW B1900	839	18	624	11232	0.0747
15	WS	YVR-YXS 737	21316	150	1976	296400	0.07192
16	QK	YVR-YXS DH3	5235	50	1456	72800	0.07191
17	QK	YVR-YXS CRJ	8600	50	2392	119600	0.07191
18	CMA	YVR-YQZ B1900	647	18	572	10296	0.06284
19	PC	YVR-QBC B1900	859	19	728	13832	0.0621
20	QK	YVR-YCG	5956	50	1976	98800	0.06028

		DH3					
21	NH	YVR-Vernon Beech King Air or Piper	337	10	572	5720	0.05892
22	PC	YVR-YZZ B1900	1395	19	1248	23712	0.05883
23	CMA	YVR-YWL B1900	605	18	572	10296	0.05876
24	NH	YVR-YZZ Beech King Air or Piper	61	10	104	1040	0.05865
25	WS	YYJ-YLW 737	6256	150	728	109200	0.05729
26	PC	YVR-YAA B1900	337	19	312	5928	0.05685
27	CMA	YXS-YXT B1900	526	18	520	9360	0.0562
28	CMA	YXS-YKA B1900	626	18	624	11232	0.05573
29	CMA	YYE-YXJ B1900	518	18	520	9360	0.05534
30	CMA	YYE-YXJ Dornier 328	1036	30	624	18720	0.05534
31	CMA	YYE-YDQ DH1	841	37	416	15392	0.05464
32	NH	YVR-YZT Beech King Air or Piper	217	10	416	4160	0.05216
33	PC	YVR-YZT Saab340a and Beech 1900	1763	25	1352	33800	0.05216
34	CMA	YXS-YXJ B1900	465	18	520	9360	0.04968
35	WS	YVR-YLW 737	16112	150	2184	327600	0.04918
36	QK	YVR-YLW DH3	12020	50	4888	244400	0.04918
37	PC	YVR-YWL B1900	1731	19	1872	35568	0.04867
38	QK	YVR-YKA DH1	1065	37	624	23088	0.04613
39	QK	YVR-YYF DH3	4796	50	2080	104000	0.04612
40	QK	YVR-YKA	6954	50	3016	150800	0.04611

		DH3					
41	HK	YXT-YPR DH1	177	37	104	3848	0.046
42	Swanberg Air	YXJ-YYE Jetstream, Nevajo	287	12	520	6240	0.04599
43	Vancouver Island Air	Campbell River-Seymour Inlet Otter, Beaver, Beech 18	97	8	312	2496	0.03886
44	PC	YVR-YPW Saab, Shorts, B1900	2052	20	2808	56160	0.03654
45	NH	YZZ-Vernon Beech King Air or Piper	167	10	468	4680	0.03568
46	Orca Air	YVR-YAZ Navajo	407	8	1456	11648	0.03494
47	NH	YVR-YAZ Beech King Air or Piper	327	10	936	9360	0.03494
48	Tofino Air	YVR-Tofino Otter, Beaver, Cessna	203	8	728	5824	0.03486
49	NH	ZEL-YZT Beech King Air or Piper	139	10	416	4160	0.03341
50	PC	YVR-YBL Saab, Shorts, B1900	922	20	1560	31200	0.02955
51	CMA	YVR-YBL B1900	885	18	1664	29952	0.02955
52	CMA	YVR-YQQ B1900	575	18	1248	22464	0.0256
53	PC	YVR-YQQ Saab, Shorts, B1900	798	20	1560	31200	0.02558
54	HA	Vancouver-	678	15	1768	26520	0.02557

		Comox DeHavilland Beaver and Otter					
55	Air Nootka	Gold River-Kyuquot float plane	29	4	312	1248	0.02324
56	Orca Air	YXX-YCD Navajo	165	8	1040	8320	0.01983
57	CMA	YXY-YYD B1900	167	18	520	9360	0.01784
58	CMA	YQZ-YWL B1900	183	18	572	10296	0.01777
59	KD Air	YVR-XQU Piper PA31 or Cessna	362	6	3432	20592	0.01758
60	Orca Air	YXX-YYJ Navajo	154	8	1144	9152	0.01683
61	Airspeed Aviation	YXX-YYJ propeller plane	349	20	1040	20800	0.01678
62	HA	Langley-Victoria DeHavilland Beaver and Otter	352	15	1560	23400	0.01504
63	HA	Vancouver-Victoria DeHavilland Beaver and Otter	3071	15	14144	212160	0.01448
64	Helijet	DT Vancouver-DT Victoria S76	1749	14	8632	120848	0.01447
65	Helijet	YVR-DT Victoria S76	1598	14	8632	120848	0.01322
66	PC	ZEL-YKT Grumman Goose	47	8	520	4160	0.0113
67	HA	Vancouver-Ganges DeHavilland Beaver and Otter	325	15	1976	29640	0.01097
68	Swanberg	YDQ-YXJ	68	12	520	6240	0.0109

	Air	Jetstream, Navajo					
69	Orca Air	YVR-YYJ Navajo	130	8	1560	12480	0.01042
70	HA	YVR-Victoria DeHavilland Beaver and Otter	308	15	1976	29640	0.01039
71	QK	YVR-YYJ DH1	3556	37	9256	342472	0.01038
72	QK	YVR-YYJ DH3	2321	50	4472	223600	0.01038
73	HA	YVR-Sechelt DeHavilland Beaver and Otter	194	15	1248	18720	0.01036
74	HA	Vancouver-Nanaimo DeHavilland Beaver and Otter	1073	15	6968	104520	0.01027
75	HA	Vancouver-Sechelt DeHavilland Beaver and Otter	222	15	1456	21840	0.01017
76	PC	YVR-YYJ Beech 1900, Beech King Air, Shorts 360	599	20	3016	60320	0.00993
77	NH	YVR-YCD Beech King Air or Piper	25	10	260	2600	0.00962
78	QK	YVR-YCD DH3	2266	50	4784	239200	0.00947
79	HA	Nanaimo-Sechelt DeHavilland Beaver and Otter	381	15	2704	40560	0.00939
80	Seair	YVR-Nanaimo Cessna,	164	6	2912	17472	0.00939

		Beaver					
81	HA	YVR-Nanaimo DeHavilland Beaver and Otter	628	15	4472	67080	0.00936
82	Seair	YVR-Saturna Island Cessna, Beaver	118	6	2184	13104	0.00901
83	HK	YXT-YYD DH1	69	37	208	7696	0.00897
84	Seair	YVR-Ganges Cessna, Beaver	115	6	2184	13104	0.00878
85	Seair	YVR-North Pender Island Cessna, Beaver	111	6	2184	13104	0.00847
86	Seair	YVR-Thetis Island Cessna, Beaver	108	6	2184	13104	0.00824
87	KD Air	XQU-Gillies Bay Beach Piper PA31 or Cessna	93	6	1976	11856	0.00784
88	PC	YQQ-YBL Saab, Shorts, B1900	243	20	1560	31200	0.00779
89	Seair	YVR-Galiano Island Cessna, Beaver	68	6	1456	8736	0.00778
90	CMA	YQQ-YBL B1900	233	18	1664	29952	0.00778
91	KD Air	XQU-YPB Beach Piper PA31 or Cessna	124	6	2704	16224	0.00764

92	Tofino Air	Sechelt-Nanaimo Otter, Beaver, Cessna	169	8	2912	23296	0.00725
93	Seair	YVR-Miner's Bay Cessna, Beaver	63	6	1456	8736	0.00721
94	Tofino Air	YVR-Gabriola Island Otter, Beaver, Cessna	120	8	2184	17472	0.00687
95	HA	Ganges-Bedwell Harbour DeHavilland Beaver and Otter	49	15	728	10920	0.00449
96	HA	Ganges-Maple Bay DeHavilland Beaver and Otter	58	15	1976	29640	0.00196