The Impact of Active Transportation Infrastructure on Travel-based Greenhouse Gas Emissions and Energy

A Longitudinal Before-After Study of Vancouver's Comox-Helmcken Greenway

April 2016

Professional Master's Project Report

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The Impact of Active Transportation Infrastructure on Travel-based Greenhouse Gas Emissions and Energy: A Longitudinal Before-After Study of Vancouver's Comox-Helmcken Greenway

by

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MASTER OF ARTS (PLANNING)

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We accept this project as conforming
to the required standard

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THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

April 2016

Abstract

Objectives: This study investigated the transportation greenhouse gas (GHG) emissions, motorized energy consumption, and physical energy expenditure impacts of an urban greenway for residents in a walkable, mixed-use urban neighbourhood. Researchers have documented positive associations between the built environment and travel patterns, including environmental and health outcomes such as reductions in vehicle kilometres travelled (VKT) and higher levels of physical activity (PA). However, there is limited evidence to date of a causal impact of how changes in community design and transportation infrastructure affect emissions and energy, as the majority of existing studies are cross-sectional. For this reason, longitudinal natural experiments are currently a priority among researchers to establish causality between the built environment and travel-related outcomes.

Methods: This study uses a Canadian case study of the Comox-Helmcken Greenway, a two-kilometre pedestrian and bicycle pathway in the West End neighbourhood of downtown Vancouver, British Columbia. It represents the first known longitudinal before-after controlled study of an urban greenway in Canada, conducted over a period of four years from 2012 to 2015. The sample consisted of 207 participants divided into two groups: 135 participants living within one-block of the Greenway (treatment group), and 72 participants living at least half a kilometre away from the Greenway (control group). A two-day personal Trip Diary Survey was administered to participants in order to track their travel patterns. Using data from the Trip Diary Survey, two models were used to estimate average daily motorized GHG emissions, motorized energy consumption, and physical energy expenditure.

Results: Positive benefits were found for motorized GHG emissions, with a statistically significant reduction of −22.9% for average daily motorized GHG emissions (before: 1.1 kg CO_2e; after: 0.9 kg CO2e). Likewise, average daily motorized energy consumption saw a statistically significant reduction of −23.7% (before: 16.0 MJ; after: 12.2 MJ). Average daily physical energy expenditure equivalent by motorized travel saw a statistically significant reduction of −22.9% (before: 14,129.6 kcal; after: 10,891.1 kcal). However, energy expenditure by active travel saw a non-significant decrease of −2.0% (before: 88.9 kcal; after: 87.1 kcal).

Conclusion: The study's findings lend evidence to support the claim that active transportation improvement projects may have a beneficial causal impact on improved environmental outcomes. The Comox-Helmcken Greenway yielded significant reductions in transportation GHG emissions and energy consumption for residents living within one-block of the Greenway, highlighting the important contributions active transportation infrastructure can make for climate change policy and emission reductions. However, there were mixed results for changes in health energy outcomes; more research with improved methods is needed to better understand the impact of greenways on physical energy expenditure.

Preface

This professional master's project is original and independent work by the author (VN). The primary supervisor was Dr. Lawrence Frank (LF) from the School of Population and Public Health and the School of Community and Regional Planning, and the secondary supervisor/reader was Dr. Alex Bigazzi (AB) from the Department of Civil Engineering and the School of Community and Regional Planning.

This master's project is an outcome of a larger research project, *Study of Travel, Health, and Activity Patterns Before and After the Redesign of the Comox-Helmcken Corridor*, led by principal investigator, Dr. Lawrence Frank. The City of Vancouver retained Dr. Frank and his research team at the UBC Health & Community Design Lab to conduct the study from 2012 to 2015. The author joined the lab in 2015 to conduct data analysis and writing of the final report for the City of Vancouver. This resulted in further research in the form of a master's professional project, presented here in this report, to fulfill the graduation requirements for the School of Community and Regional Planning.

LF conceived of the larger study, its research design, and led its execution. Mustel Group Market Research conducted the data collection for the larger study. Permission was granted for the author (VN) to use the larger study's dataset to conduct independent analysis. VN was responsible for all aspects of the present study, including development of the methodology, additional data collection, data analysis, and all writing. LF advised on the overall research, and AB advised on the GHG emissions modeling component of the methodology. Hind Sbihi (HS) from the School of Population and Public Health provided technical assistance on the implementation of the statistical methods.

The larger study received approval from the UBC Behavioural Research Ethics Board (Ethics Certificate H12-01801). All participants gave written informed consent.

This research was conducted independently with no influence from the City of Vancouver. The contents of this publication are solely the responsibility of the author, and do not necessarily reflect the official views of the City of Vancouver, The University of British Columbia, the School of Community and Regional Planning, or the School of Population and Public Health.

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List of Acronyms and Abbreviations

AAA	All ages and abilities
ANOVA	Analysis of variance
BC	British Columbia
CEEI	Community Energy and Emissions Inventory
CEEP	Community Energy and Emissions Plan
CHG	Comox-Helmcken Greenway
CoV	City of Vancouver
CO_2e	Carbon dioxide equivalent
EPA	Environmental Protection Agency
FCM	Federation of Canadian Municipalities
GHG	Greenhouse gas emissions
GIS	Geographic information system
GPS	Global Positioning System
ICBC	Insurance Corporation of British Columbia
Kcal	Kilocalories
Kg	Kilogram
Km	Kilometre
L	Litre
MET	Metabolic equivalent
MJ	Megajoules
NEB	National Energy Board
NIR	National Inventory Report
NRCan	Natural Resources Canada
PA	Physical activity
PCP	Partners for Climate Protection
Psg-km	Passenger-kilometre
SCARP	School of Community and Regional Planning
UBC	The University of British Columbia
Veh	Vehicle
VKT	Vehicle kilometres travelled
WRI	World Resources Institute

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Section 1
Introduction and Background

1.1 Study Purpose

This report presents findings from the study, ***The Impact of Active Transportation Infrastructure on Travel-Based Greenhouse Gas Emissions and Energy: A Longitudinal Before-After Study of Vancouver's Comox-Helmcken Greenway***. The study was conducted in 2016, evaluating the environmental and health impacts of the City of Vancouver's Comox-Helmcken Greenway. The study measured changes in five transportation emission and energy outcomes for residents living within one-block of the Greenway from 2012 to 2015:

- Average daily motorized GHG emissions (kg CO_2e);
- Average daily motorized energy consumption (MJ);
- Average daily physical energy expenditure equivalent by motorized travel (kcal);
- Average daily physical energy expenditure by active travel (kcal); and
- Transport energy index (active kcal/motorized kcal).

"Motorized GHG emissions" is defined as greenhouse gas emissions from fossil fuel combustion from motorized vehicles, **"motorized energy consumption"** refers to energy consumption by fossil fuel combustion from motorized vehicles, and **"physical energy expenditure"** refers to energy measured in kilocalories expended from human physical activity (**"by active travel"**), and the equivalent human energy used in motorized transportation expressed as a unit conversion from fossil fuel combustion (**"equivalent by motorized travel"**).

Greenways are landscaped and traffic-calmed pathways for pedestrians and cyclists. Also known as bicycle boulevards or neighbourhood greenways, urban greenways help link major open spaces, parks, public facilities, and neighbourhood centres together. According to the City of Vancouver's greenways program, greenways are intended to:[1]

- Expand the opportunities for urban recreation;
- Encourage people to travel by foot and by bike; and
- Enhance the experience of nature and city life.

This research uses a case study of the Comox-Helmcken Greenway ("Greenway"), an important east-west connection through the West End neighbourhood in downtown Vancouver from False Creek to Stanley Park. Constructed in 2013 for pedestrians and cyclists of all ages and abilities (AAA), Section 1 of the Comox-Helmcken Greenway included improvements to Comox and Helmcken Street between Stanley Park Lane and Hornby Street. The future Section 2 will see the completion of the remainder of the Greenway, and include improvements to Helmcken Street from Hornby Street to False Creek. The study's scope evaluated changes in outcomes only for Section 1 of the Greenway.

The present study is part of a larger study, *Study of Travel, Health, and Activity Patterns Before and After the Redesign of the Comox-Helmcken Greenway Corridor*, led by principal investigator, Dr. Lawrence Frank. The City of Vancouver retained Dr. Frank and his research team at the UBC Health & Community Design Lab to conduct the study from 2012 to 2015. The City of Vancouver commissioned the study in order to validate that their active transportation improvements were realizing their intended purpose, and to better understand how future projects may be better designed.

[1] City of Vancouver. (2015). Greenways: Making Vancouver a More Walkable, Bikeable City. Vancouver, BC: City of Vancouver. Retrieved from: http://vancouver.ca/streets-transportation/greenways-for-walking-and-cycling.aspx

1.2 Research Background

Researchers have documented positive associations between the built environment and travel patterns, including environmental and health outcomes such as reductions in vehicle kilometres travelled (VKT) and higher levels of physical activity (PA). However, there is limited evidence to date of a causal impact of how changes in community design and transportation infrastructure affect emissions and energy, as the majority of existing studies are cross-sectional. For this reason, longitudinal natural experiments are currently a priority among researchers to establish causality between the built environment and travel-related outcomes.[2]

The research agenda for causal evidence is made more urgent due to the need for accelerated action on a confluence of issues, particularly human-caused (anthropogenic) climate change, energy security and resilience, and sedentary behaviour and physical inactivity. With respect to climate change and energy security, municipalities in British Columbia (BC) have developed ambitious targets, policies, and actions to reduce GHG emissions through land use and transportation planning efforts in response to a provincial climate action mandate, the 2008 Local Government "Green Communities" Act (Bill 27). In BC, transportation-sector emissions represent 40% of GHG emissions, forming the second largest share of municipal GHG emissions. Researchers have identified how the reduction of transportation-related emissions should thus be a policy priority for local governments in order to meet their legislated GHG reduction targets.[3] In response, BC municipalities have begun to develop Community Energy and Emissions Plans (CEEP) in order to reduce community-wide energy and emissions from various sectors, including transportation. These plans provide an integrated way for municipalities to address both energy use and emissions for a given locality.

However, meaningful progress on climate change action has been difficult to achieve, in part due to the political infeasibility of the rapid change needed to transition towards and design low-carbon and resilient communities that are less auto-dependent and more energy-efficient.[4] One possible approach for advancing current planning and public engagement efforts is the recognition of the host of co-benefits for communities from action on climate change. In other words, addressing climate change can also simultaneously address many other concerns, such as public health concerns.[5] For example, researchers have noted how

[2] Sallis, J.F., Story, M., & Lou, D. (2009). Study designs and analytic strategies for environmental and policy research on obesity, PA, and diet: recommendations from a meeting of experts. *American Journal of Preventive Medicine, 36*(2S): S72–S77.

[3] Baynham, M., & Stevens, M. (2013). Are we planning effectively for climate change? An evaluation of Official Community Plans in British Columbia. *Journal of Environmental Planning and Management, 57*(4), 557–587.

[4] Senbel, M., & Church, S.P. (2011). Design empowerment: the limits of accessible visualization media in neighborhood densification. *Journal of Planning Education and Research, 31*(4), 423–437.

[5] Krause, R. M. (2013). The motivations behind municipal climate engagement: an empirical assessment of how local objectives shape the production of a public good. *Cityscape: A Journal of Policy Development and Research, 15*(1), 125–142.

climate change and health policy agendas have recently begun to converge, where planners, engineers, (landscape) architects, doctors, public health officials, and other allied professions have an opportunity to unite to create more sustainable *and* healthier communities.[6] This is because climate change mitigation strategies affect transportation-related determinants of health, such as physical activity. Energy used for motorized travel (by motor vehicle) contribute to GHG emissions and provide health disbenefits, while energy used for active modes (by walking and cycling) help reduce GHG emissions and provide health benefits.

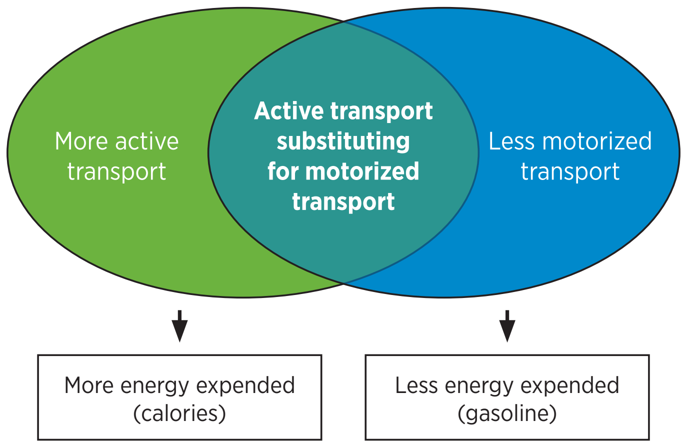


Figure 1. Conceptual transport energy model.

This transportation energy relationship (see Figure 1) has significant salience given that 85% of Canadian adults do not currently meet the recommended guideline of at least 150 minutes per week of moderate-to-vigorous physical activity. Canadians as a whole have become less active in recent years, prompting significant concerns from the public health and medical community.[7] Sedentary behaviour can lead to chronic conditions such as cardiovascular disease and diabetes, both of which have a tremendous impact on overall population health and the healthcare system.[8] Climate change will further exacerbate cardiac health among vulnerable populations, with particular attention directed towards increased heat exposure due to an increase in the frequency and intensity of extremely hot weather.[9][10]

[6] Frank, L. D., Greenwald, M. J., Winkelman, S., Chapman, J., & Kavage, S. (2010). Carbonless footprints: promoting health and climate stabilization through active transportation. *Preventive Medicine, 50*, S99–105.

[7] Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Reports, 22*(1), 1–8.

[8] Owen, N., Bauman, A., Brown, W. (2009). Too much sitting: a novel and important predictor of chronic disease risk? *British Journal of Sports Medicine, 43*(2): 8–83.

[9] De Blois, J., Kjellstrom, T., Agewall, S., Ezekowitz, J.A., Armstrong, P.W., & Atar, D. (2015). The effects of climate change on cardiac health. *Cardiology, 131*: 209–217.

[10] Ho, H.C., Knudby, A., Walker, B.B., & Henderson, S.B. (2017). Delineation of spatial variability in the temperature-mortality relationship on extremely hot days in Greater Vancouver, Canada. *Environmental Health Perspectives, 125*(1): 66–75.

Due to the important role sustainable transportation investment plays in climate change mitigation activities, climate change policy must consider health more systematically under the wider umbrella of sustainability. Considering co-benefits such as health can offer an important framework for decision-making and public engagement to help counter the paralysis of climate action, while sustainable transportation promotion offers important pathways for the prevention and treatment of physical inactivity and chronic diseases.[11] Finding efficiencies and synergies of disparate transportation and health funding streams would yield marked benefits for communities and help advance climate change planning priorities, a monumental task that requires a coordinated effort across multiple sectors for meaningful movement towards synergistic GHG emissions reduction.

Evidence is needed to identify and determine which built environment strategies can yield positive (co-)benefits to respond to the parallel urgency for action on climate change and public health. These two contextual threads of climate change action and physical activity promotion through sustainable transportation investment will thus form the basis of this research.

[11] Younger, M., Morrow-Almeida, H. R., Vindigni, S. M., & Dannenberg, A. L. (2008). The built environment, climate change, and health: opportunities for co-benefits. *American Journal of Preventive Medicine, 35*, 517–526.

1.3 Research Questions

The aim of this research is to assess the associations between community design, motorized GHG emissions and energy consumption, and physical energy expenditure in order to improve planning and decision-making for evidence-based transportation investment, and accelerate action on climate change and public health concerns (see Figure 2 for an overview of the study's research methodology).

The study asks the following research questions for residents living within one-block of the Comox-Helmcken Greenway (treatment group) with respect to a control group:

Q1A. What is the effect of the Comox-Helmcken Greenway on average daily motorized GHG emissions (kg CO_2e)?
Q1B. What is the effect of the Comox-Helmcken Greenway on average daily motorized energy consumption (MJ)?
Q2A. What is the effect of the Comox-Helmcken Greenway on average daily physical energy expenditure equivalent by motorized travel (kcal)?
Q2B. What is the effect of the Comox-Helmcken Greenway on average daily physical energy expenditure by active travel (kcal)?
Q2C. What is the effect of the Comox-Helmcken Greenway on the transport energy index (active kcal/motorized kcal)?

The study poses the following hypotheses:

H1A. Average daily motorized GHG emissions (kg CO_2e) will decrease for the treatment group after the construction of the Greenway.
H1B. Average daily motorized energy consumption (MJ) will decrease for the treatment group after the construction of the Greenway.
H2A. Average daily physical motorized expenditure by motorized travel (kcal) will decrease for the treatment group after the construction of the Greenway.
H2B. Average daily physical energy expenditure by active travel (kcal) will increase for the treatment group after the construction of the Greenway.
H2C. The transport energy index (active kcal/motorized kcal) will increase for the treatment group after the construction of the Greenway.

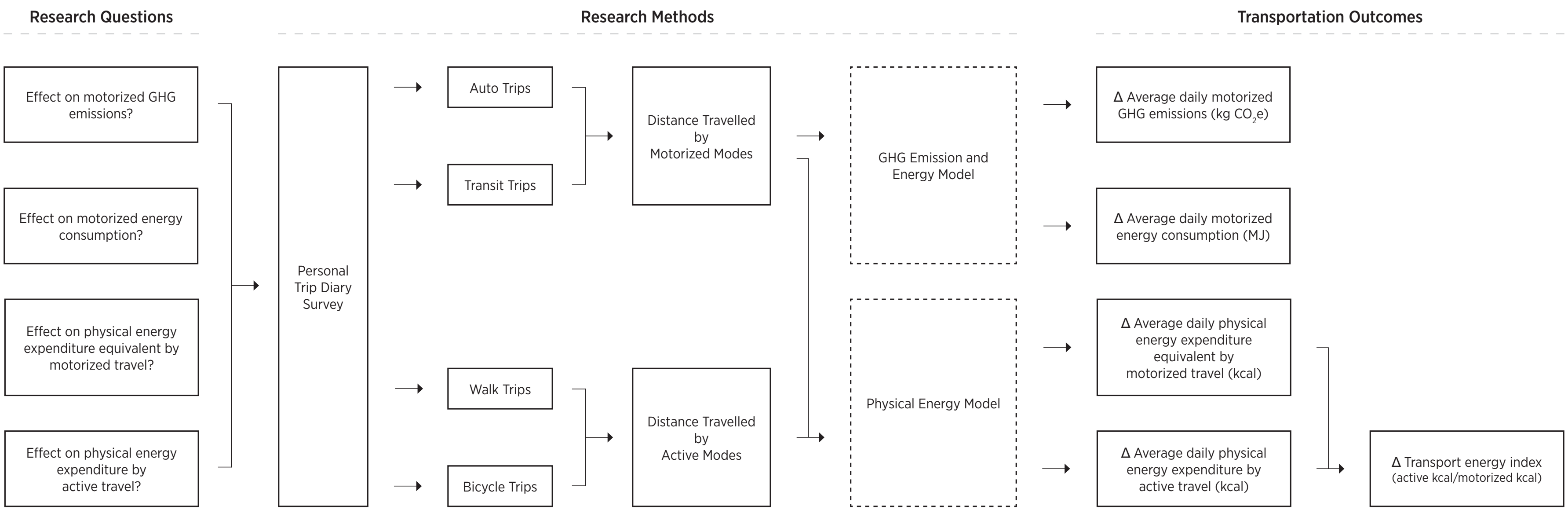


Figure 2. Overview of research methodology.

Section 2
Case Study

2.1 Comox-Helmcken Greenway

The Comox-Helmcken Greenway is an important east-west connection through the West End neighbourhood in downtown Vancouver from False Creek to Stanley Park for pedestrians and cyclists of all ages and abilities (AAA). Section 1 of the Greenway is approximately two-kilometres long and includes improvements to Comox and Helmcken Street between Stanley Park Lane and Hornby Street (see Figure 3).

According to the City of Vancouver, the Greenway offers several benefits for the West End. This includes providing residents and visitors with a faster and more direct alternative through downtown Vancouver compared to the Seawall. The Greenway connects four schools, one regional park, three neighbourhood parks, two mini-parks, and one community centre together, as well as shopping areas, hotels, residential neighbourhoods and a hospital.

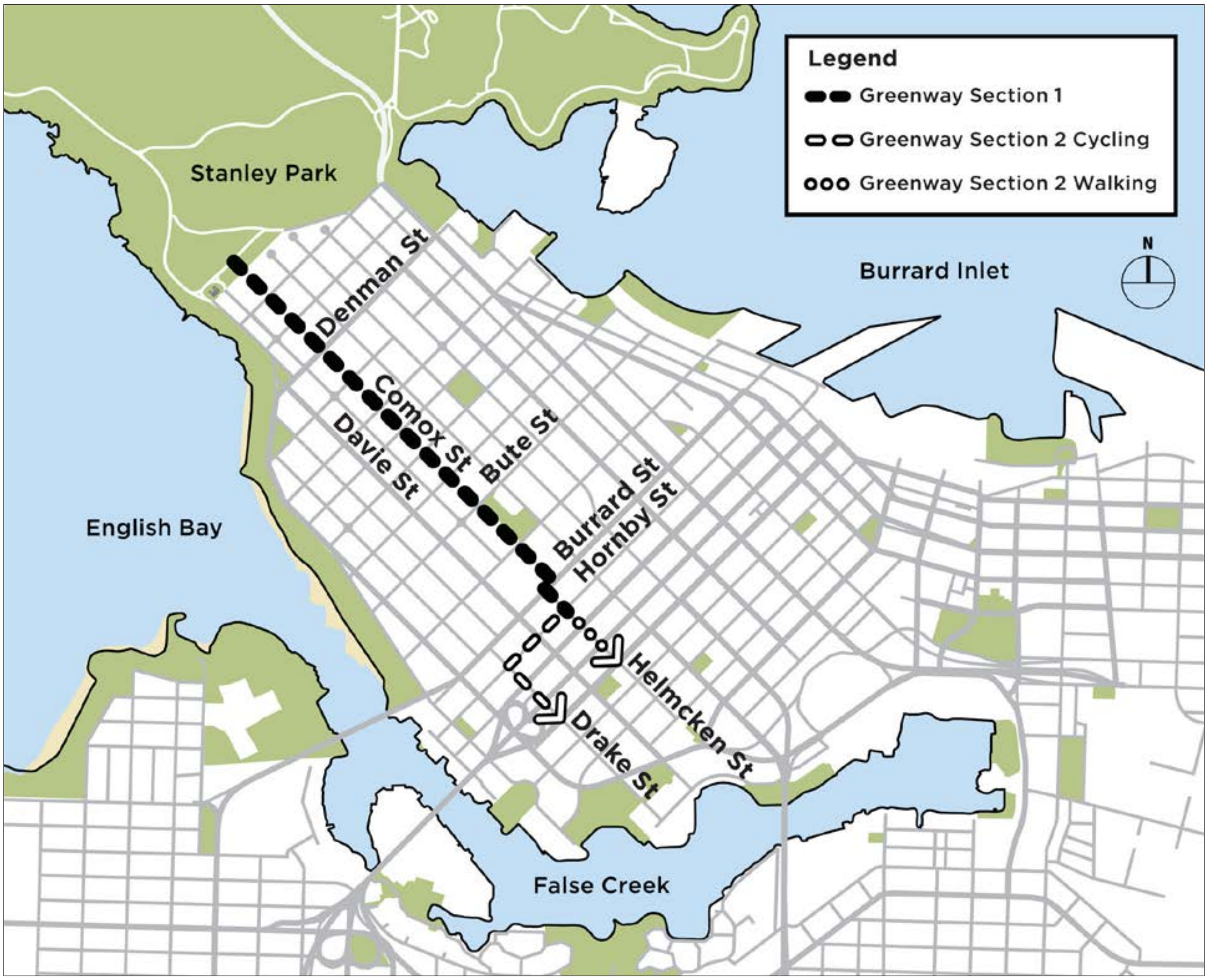


Figure 3. Comox-Helmcken Greenway route alignment map.

With a construction budget of $5,460,000, the following key engineering features characterized the Greenway's design:

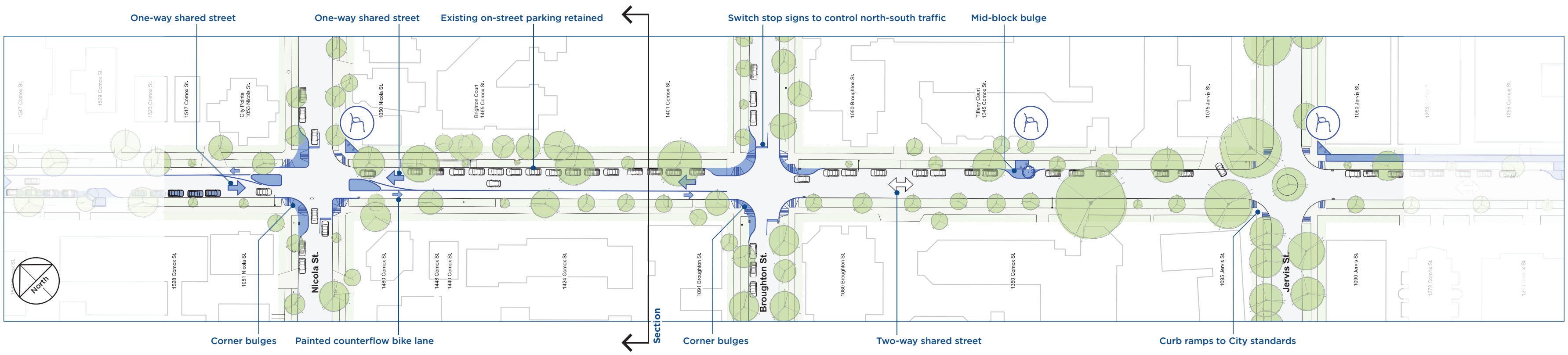
- **Traffic signals:** New and upgraded traffic signals;
- **Streets:** Street paving, concrete medians and curb bulges, catch basins, paint, and signs;
- **Sidewalks:** New sidewalks, curb ramps, and raised crosswalks;
- **Lighting:** Street, sidewalk, and park lighting; and
- **Public realm amenities:** Seating, planting, trees, drinking fountains, and wayfinding.

Figures 4 to 6 show select before and after comparison photos of the Greenway, illustrating some of the new design features for Comox Street. Figure 7 shows the design details for a portion of the Greenway in plan and section from Jervis Street to Thurlow Street.

Figure 4. Before-after photos of Comox Street: counterflow lanes for cyclists.

Figure 5. Before-after photos of Comox Street: protected crossings for cyclists.

Figure 6. Before-after photos of Comox Street: street furniture to promote social interaction.



WHAT IS DIFFERENT?	WHY?
One-way street westbound for vehicles between Nicola and Broughton	• To reduce vehicle volumes while at the same time maintaining access for residents and emergency vehicles
One-way counterflow bike lane eastbound between Nicola and Broughton	• To provide a comfortable cycling environment suitable for people of all ages and abilities • To maintain emergency vehicle access
Corner bulges at Nicola and Broughton	• To provide improved pedestrian crossings
Switch stop signs at Nicola and Broughton	• To give traffic on Comox the priority
Upgrade intersection lighting	• To improve visibility for all road users
New pedestrian lighting	• To improve visibility for all road users
Curb ramps	• To provide accessible pedestrian crossings
Seating areas, including mid-block bulges	• To provide resting opportunities

LEGEND

- Existing two-way street
- Existing one-way street
- Proposed one-way street
- Proposed two-way bicycle lane
- Proposed one-way bicycle lane
- Proposed improvement
- Proposed bicycle parking
- Proposed drinking fountain
- Proposed wayfinding
- Proposed chairs
- Proposed tables and chairs

SECTION

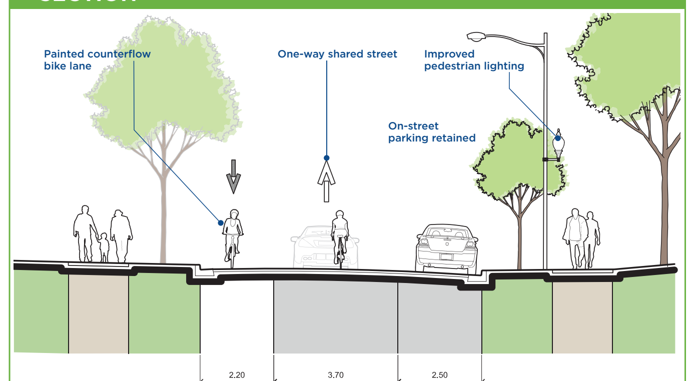


Figure 7. Plan and section view of improvements for Comox Street from Jervis Street to Thurlow Street.

2.2 Planning and Policy Context

The Comox-Helmcken Greenway helps the City of Vancouver meet several of its goals and targets. This research will help assess the City's progress on these goals and targets.

2.2.1 Transportation 2040 Plan

The Transportation 2040 Plan is the City's long-term strategic plan to guide transportation and land use decisions and investments. Greenways can help encourage people to adopt cycling as a safe and convenient transportation option, and help reduce automobile dependency.

Goal: Make cycling safe, convenient, comfortable, and fun for people of all ages and abilities.

- C1.1: Build cycling routes that feel comfortable for people of all ages and abilities.
- C1.2: Upgrade and expand the cycling network to efficiently connect people to destinations.

2.2.2 Greenest City 2020 Action Plan

The Greenest City Action Plan aspires for the City of Vancouver to become the greenest city in the world by the year 2020. This includes promoting sustainable transportation options and increasing residents' opportunities for access to nature.

Goal #2: Eliminate dependence on fossil fuels.

- Target 1: Reduce community-based greenhouse gas emissions by 33% from 2007 levels.

Goal #4: Make walking, cycling, and public transit preferred transportation options.

- Target 1: Make at least two thirds of all trips by foot, bike and public transit.

Goal #6: Vancouver residents enjoy incomparable access to green spaces, including the world's most spectacular urban forest.

- Target 1: All Vancouver residents live within a five-minute walk of a park, greenway, or other green space by 2020.

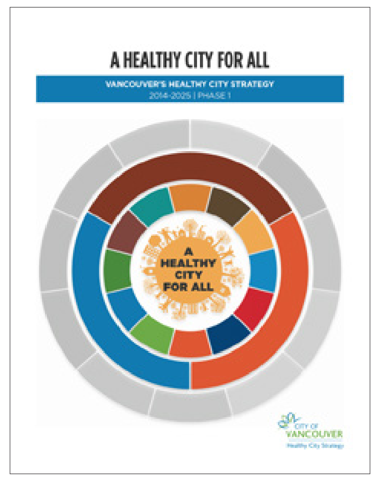
2.2.3 Renewable Energy Strategy

The Renewable Energy Strategy outlines policies and actions the City of Vancouver will take to derive 100% of its energy from renewable energy sources by 2050. The Strategy focuses on two of the city's biggest users of energy—transportation (46%) and buildings (48%), representing 94% of all of Vancouver's GHG emissions.

Renewably Powered Transportation Priorities

- T.1.4: Enhance cycling infrastructure and encourage more bike trips according to the direction set in Transportation 2040.

2.2.3 Healthy City Strategy



The Healthy City Strategy outlines policies and actions to improve the health and well-being of people in the City of Vancouver. Promoting active living is a key component towards improved health and well-being outcomes.

Goal #8: Vancouverites are engaged in active living and have incomparable access to nature.

- Target 1: By 2020, all Vancouver residents live within a five-minute walk of a park, greenway or other green space.
- Target 2: By 2025, increase the percentage of Vancouver residents aged 18 and older who meet the Canadian Physical Activity Guidelines by 25 per cent over 2014 levels.

2.3 Neighbourhood Context

The West End is a high-density mixed residential and commercial neighbourhood in Vancouver's downtown peninsula. It is considered one of Vancouver's most diverse neighbourhoods, having the second-highest number of low-income residents, the third-largest number of recent immigrants, and the third-largest number of seniors in Vancouver. It is also home to the largest LGBTQ community in Western Canada.

The West End neighbourhood ranks high on traditional measures of walkability (see Figure 8). The UBC Health & Community Design Lab's Walkability Index is a tool that measures characteristics of the physical environment that contribute to walkable neighbourhood design.[12] The Walkability Index was calculated for a 500-metre area around Comox Street. Table 1 shows the results for the Comox Corridor and other areas of Metro Vancouver for comparison purposes.

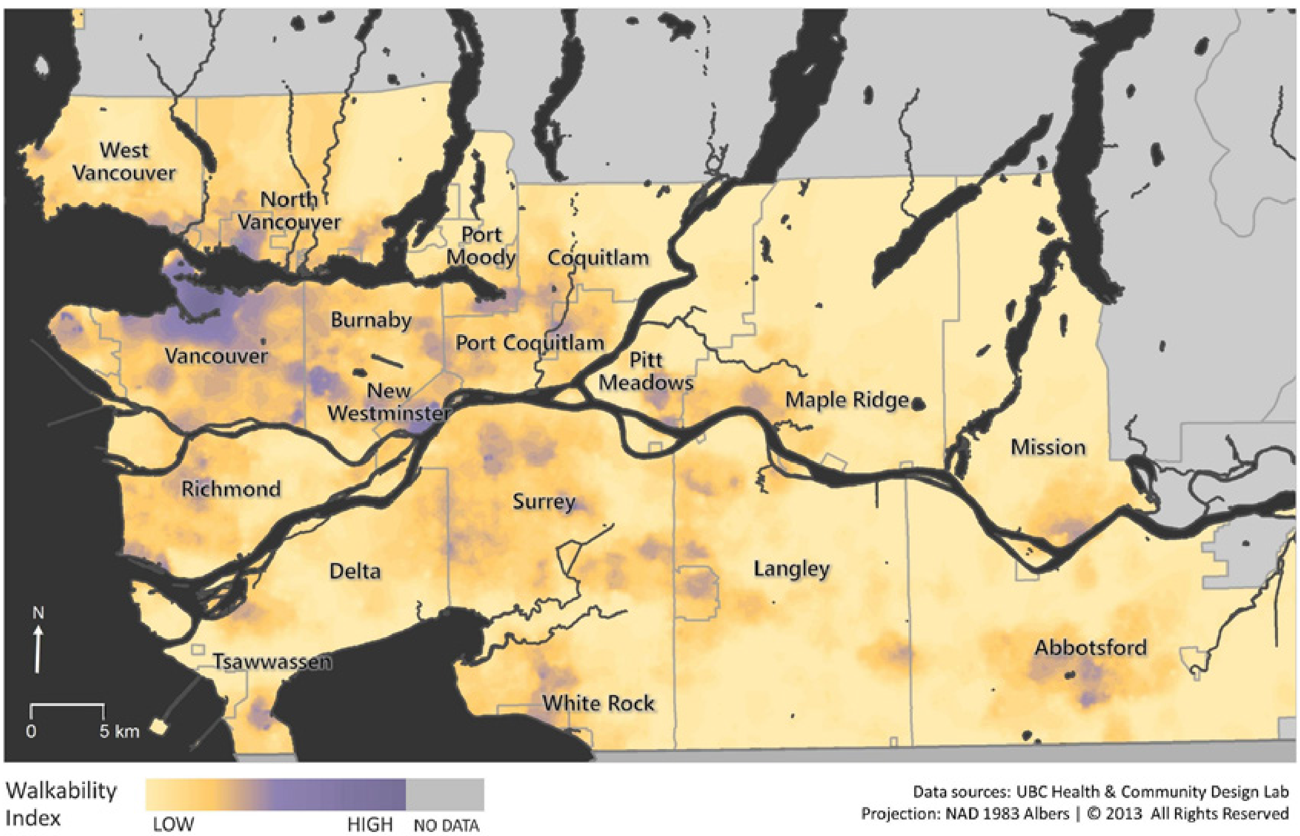


Figure 8. Metro Vancouver Walkability Surface.

[12] Frank, L.D., Devlin, A., Johnstone, S., & van Loon, J. (2010). *Neighbourhood Design, Travel, and Health in Metro Vancouver: Using a Walkability Index*. Vancouver, BC: UBC Health & Community Design Lab. Retrieved from: http://atl.sites.olt.ubc.ca/files/2011/06/WalkReport_ExecSum_Oct2010_HighRes.pdf

The Comox Corridor has a significantly higher walkability measure compared to Downtown New West (New Westminster), Metrotown (Burnaby), and Ambleside (West Vancouver), in part due to the neighbourhood's high residential density. The neighbourhood's walkability in part contributes to a high sustainable mode share. According to the 2006 Census, the West End has the highest walk to work mode share in the City of Vancouver at 40%.[13]

Table 1. Walkability Index measurements for the Comox Corridor.

Area	Net Residential Density (dwelling units/acre)	Commercial Density (retail floor area ratio)	Intersection Density (per square kilometre)	Land Use Mix (0 to 1)	Walkability Index
Comox Corridor City of Vancouver (500 m buffer)	164.6	1.4	68.4	0.6	9.8
Downtown New West City of New Westminster (Columbia St & 6th St)	48.7	1.8	103.4	0.6	5.9
Metrotown City of Burnaby (Kingsway & Sussex Ave)	33.1	2.0	63.3	0.7	3.8
Ambleside District of West Vancouver (Marine Dr & 19th Ave)	18.0	0.9	68.8	0.6	1.6

Note: "Residential density" is the number of residential units per acre designated for residential use within a neighbourhood buffer. Higher densities indicate more people live in the area. "Commercial density" (or Retail Floor Area Ratio) is the amount of area designated for commercial use within a neighbourhood buffer, using a ratio of commercial floor area to commercial land area. Higher ratio numbers indicate higher commercial density. "Intersection Density" is measured by the number of street intersections in a neighbourhood buffer. More intersections suggest a greater degree of network connectivity enabling more direct travel between two points using existing streets and pathways. "Land use mix" is the evenness of square footage distribution across residential, commercial (including retail and services), entertainment, and office development within a neighbourhood buffer. A higher value in this measure indicates a more even distribution of land between the land use types.

[13] City of Vancouver. (2013). *West End Community Plan*. Vancouver, BC: City of Vancouver. Retrieved from: http://vancouver.ca/files/cov/west-end-community-plan.pdf

Section 3 Methodology

3.1 Research Design

3.1.1 Experimental Design

The study employed a quasi-experimental longitudinal before-after controlled research design (see Figure 9). This type of design allowed the study to evaluate the effects of the Comox-Helmcken Greenway on the participants before (Phase 1) and after (Phase 2) relative to a control group.

Only residents living within half a kilometre (500 metres) were considered to have benefitted from the Greenway; this group of individuals constituted the study's target population. Thus, residents living further than half a kilometer formed the control group, as they were assumed to have been unaffected by the Greenway. The use of proximity to define the control group is based on the research design of similar studies.[14][15]

For the purposes of the present study, the analysis examined participants living within one-block within Comox Street, or approximately 120 metres away from Comox Street, for all statistical tests, where the effect of the Greenway would be the greatest.

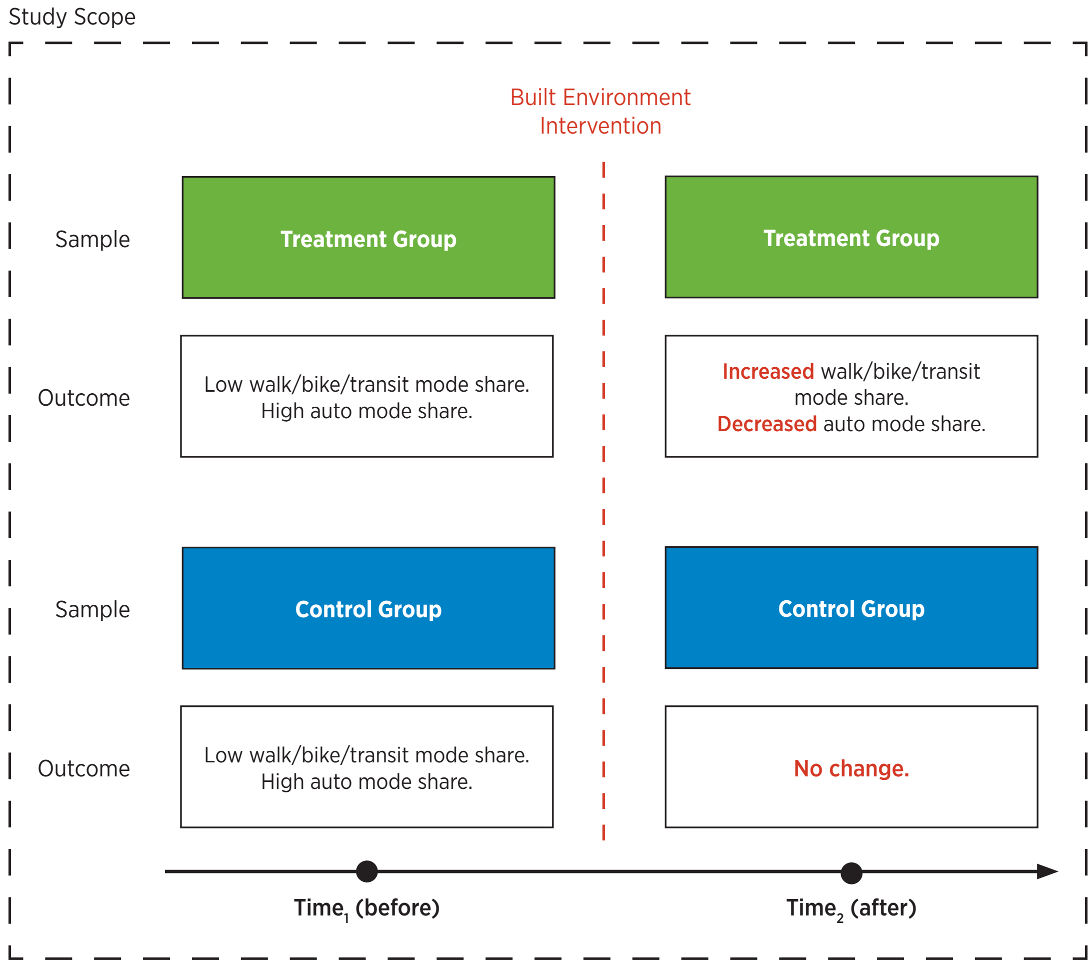


Figure 9. Overview of research design.

[14] West, S.T., & Shores, K.A. (2011). The impacts of building a greenway on proximate residents' physical activity. *Journal of Physical Activity & Health, 8*, 1092–7

[15] Hong, A., Boarnet, M.G., & Houston, D. (2016). Hong, A., Boarnet, M.G., & Houston, D. (2016). New light rail transit and active travel: a longitudinal study. T*ransportation Research Part A: Policy and Practice, 92*: 131–144.

3.1.2 Sampling Plan

Residents that met the following criteria were considered eligible for participation in the study:

- Living in downtown Vancouver;
- Living within a kilometre of the Comox-Helmcken Greenway;
- Had no plans to move to a new address during the time of the study; and
- Was 18 years of age or older by the next birthday.

An address-based sampling method was used, whereby a random sample of household addresses were geographically defined within the kilometer-wide study area of downtown Vancouver. The sampling frame was the Canada Post address-based data file for Vancouver.

3.1.3 Recruitment Plan

Mailings were sent to households requesting their participation in the study. A connection to the Comox-Helmcken Greenway as the rationale for the study was not specified in order to avoid any potential participation bias. The mailing contained a notification letter that described the following information to the residents:

- Description of the study;
- Privacy protections for participation;
- Incentives for participation;
- Instructions for respondent selection within the household; and
- Link to the online electronic survey registration.

3.2 Research Methods

3.2.1 Trip Diary Survey

A two-day personal Trip Diary Survey was administered to participants in order to understand their travel patterns (see "Appendix A: Trip Diary Survey"). Questions included:

- Origin of trip;
- Destination of trip;
- Type of destination;
- Purpose of trip;
- Start and end time of trip;
- Modes of travel used for trip; and
- Number of people in trip party.[16]

Study participants were randomly assigned two days of the week to complete their personal Trip Diary Survey in order to ensure an equal distribution of days, including weekday and weekend travel. Participants could print out a trip recording form to assist them during their diary days. Participants would then log online after their two diary days were completed and input their travel information on a web interface.

In terms of travel modes, participants had an option of indicating 11 different types of modes:

1. Walking;[17]
2. Cycling;
3. Bus (transit);
4. Bus (school);
5. SkyTrain;
6. Ferry (SeaBus);
7. Ferry (False Creek Ferry/Aquabus);
8. Auto (driver);
9. Auto (passenger);
10. Taxi; and
11. Other.

For the purposes of the study, only the emission and energy impacts were examined for walking, cycling, auto, and bus trips—all other modes were excluded from the analysis. Taxi trips were combined with auto trips. All trip types, including recreational and utilitarian trips,

[16] The number of people in the trip party was used as a proxy for vehicle occupancy for auto trips. There were a very small number of trips with six or more people recorded; these trips were collapsed down to five people to account for unrealistic occupancy numbers. Sensitivity testing found no statistically significant differences.

[17] Trips that were explicitly specified by participants as other forms of trips by foot (e.g., running) under "11. Other" were reclassified as "1. Walking" trips.

were included. In order to isolate the effects of the Comox-Helmcken Greenway, the analysis only examined trips that took place entirely within metro Vancouver, and had origins and/ or destinations within downtown Vancouver. For further clarity, if the entire trip took place outside of downtown Vancouver in another neighbourhood or municipality, the trip was not counted. However, if a portion of the trip traversed through downtown Vancouver, it was counted.

Sampling weights or expansion factors were not applied to the dataset. Data collection was conducted during the fall and winter for both before and after periods, from October 2012 to March 2013 (Phase 1), and from October 2014 to March 2015 (Phase 2). The Trip Diary Survey was prepared and analyzed using Excel and the statistical package Stata.

For each recorded trip, the origin and destination was geocoded in ArcGIS based on the street address when provided, or the center of the closest street intersection. In order to estimate the distance travelled for each trip, ArcGIS Network Analyst was used to calculate the shortest distance path (based on Dijkstra's algorithm) using a separate active and motorized GIS street network layer. The two GIS street networks were defined as follows:

1. **Active:** a street network for walking and bicycle trips that contains only road segments where pedestrians are permitted (i.e., limited access highways and freeway ramps are removed); and
2. **Motorized:** a street network that contains all paved road segment features.

The exact travel path participants took was unknown as GPS was not used to obtain objective travel routes. In cases where the participant completed a trip with the same origin and destination, such as a recreational exercise trip that started and ended at their home address, the distance travelled could not be estimated.

3.2.2 Model: Motorized GHG Emissions and Energy Consumption

A custom Vancouver-specific GHG emission modeling method was developed for the purposes of this study in order to accommodate significant data limitations.

GHG emission and energy consumption intensity factors were developed to reflect an average emission and energy profile for an average passenger vehicle and city transit bus in the City of Vancouver. These intensity factors can be used for any future study to model GHG emissions in Vancouver where distance travelled is known (or estimated), but actual vehicle ownership by model and type is unknown. This method was developed in response to two data limitations:

1. The Trip Diary Survey did not ask participants the type of vehicle they drove or were a passenger in; and
2. The Insurance Corporation of British Columbia (ICBC), the provincial body responsible for vehicle insurance, registration, and licensing, was unable to provide actual vehicle ownership by vehicle model and type for the West End neighbourhood.

The intensity factors are based on existing emissions modeling work prepared for the BC Community Energy and Emissions Inventory (CEEI). As part of BC's commitment to the 2008 Local Government "Green Communities" Act (Bill 27), CEEIs have been developed for each local government jurisdiction in the province by the BC Ministry of Environment. According to the BC provincial government:

> "The Community Energy and Emissions Inventory collects data from GHG source sectors from utilities, public agencies and other trusted partners, in order to calculate the size of each sector's carbon footprint in each local government jurisdiction across B.C. Additionally, the CEEI monitors supporting indicators from core sectors and other sources to help track the progress of local government efforts to reduce GHG emissions across their communities. ... The inventory is the first of its kind in North America, and it helps local governments meet the Climate Action Charter commitment to measure and report on community GHG emissions profiles."[18]

[18] Government of BC. (2015). *Community Energy & Emissions Inventory (CEEI)*. Victoria, BC: Government of BC. Retrieved from: http://www2.gov.bc.ca/gov/content/environment/climate-change/reports-data/community-energy-emissions-inventory

The study adopts provincial standards for quantifying community-wide GHG emissions. The BC's CEEI initiative are informed by and reflects guidelines and accounting principles from the following:

- World Resources Institute (WRI)'s GHG Protocol;
- ICLEI - Local Governments for Sustainability's International Local Government GHG Emissions Analysis Protocol; and
- Federation of Canadian Municipalities (FCM)'s Partners for Climate Protection (PCP).

This method was chosen in order to align the study with provincial protocols for GHG emissions reporting, allowing the study results to be directly comparable to any GHG emissions modelling work done in BC. The Ministry of Environment's complete CEEI methodology is available as a technical document online.[19]

In absence of ICBC data to develop a more accurate approximation of the study sample's vehicle profile, the present study leverages the Ministry of Environment's use of the 2010 ICBC vehicle registration data for the City of Vancouver's 2010 CEEI. Data sources for the CEEI and the present study are listed below:

- **Average fuel efficiency ratings for passenger vehicles** are based on Natural Resources Canada (NRCan)'s *2014 Fuel Consumption Guide* to reflect body style and weight,[20] with US Environmental Protection Agency (EPA) 2014 adjustment factors[21] applied to vehicles older than 2008 model year to reflect fuel efficiency differences between test and real driving conditions.
- **Average fuel efficiency ratings for city buses** are based on data provided by TransLink.[22]
- **GHG emission intensity factors for passenger vehicles** are based on data tables used in Environment Canada's *National Inventory Report (NIR) 1990-2012: Greenhouse Gas Sources and Sinks in Canada* as part of Canada's annual GHG inventory submission to the United Nations Framework Convention on Climate Change.[23]

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[19] BC Ministry of Environment. (2014). C*ommunity Energy and Emissions Inventory (CEEI) Initiative: Technical Methods and Guidance Document 2007-2010 Reports*. Victoria, BC: BC Ministry of Environment. Retrieved from: http://www2.gov.bc.ca/assets/gov/environment/climate-change/reports-and-data/community-energy-and-emissions-inventory-ceei/ceei_techmethods_guidance_final.pdf

[20] Natural Resources Canada. (2014). *Fuel Consumption Guide 2014*. Ottawa, ON: Natural Resources Canada. Retrieved from: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/tools/fuelratings/FCG2014WCAG_e.pdf

[21] US Environmental Protection Agency & US Department of Energy. (2014). *Model Year 2014 Fuel Economy Guide*. Golden, CO: US Environmental Protection Agency & US Department of Energy. Retrieved from: https://www.fueleconomy.gov/feg/pdfs/guides/FEG2014.pdf

[22] TransLink. (2010). *Sustainability Report 2010*. Burnaby, BC: TransLink. Retrieved from: http://www.translink.ca/-/media/Documents/about_translink/corporate_overview/sustainability/translink_2010_sustainability_report.pdf

[23] Environment Canada. (2014). *National Inventory Report 1990-2012: Greenhouse Gas Sources and Sinks in Canada*. Ottawa, ON: Environment Canada. Retrieved from: https://www.ec.gc.ca/ges-ghg/

- **GHG emission intensity factors for city buses** are based on data provided by a consultant for TransLink;[24] and
- **Energy consumption intensity factors** are based on the National Energy Board (NEB)'s *Energy Conversion Tables* for gasoline and diesel.[25]

The CEEI contains information on average fuel efficiency ratings and a corresponding emission intensity factor (Bio CO_2, CO_2, CH_4, N_2O, and CO_2e) by:

- **Vehicle type** (small and large passenger cars; light trucks, vans, SUVs; and city bus); and
- **Fuel type** (gasoline, diesel, and hybrid).

Two types of emission intensity factor are provided in the CEEI:[26]

1. **Emissions per litre of fuel burned (kg/L)** for passenger vehicles; and
2. **Emissions per passenger-kilometre (kg/psg-km)** for city bus.

As the study focuses on GHG emissions, only the carbon dioxide equivalent (kg CO_2e) intensity factor was used. Additional calculations to derive intensity factors for emissions per vehicle-kilometre (kg/veh-km) for passenger vehicles, and emissions per litre of fuel burned (kg/L) for city bus were calculated by the author (see Table 2).[27]

Using the combined information from the CEEI and additional data sources, weighted average emission and energy intensity factors were calculated for the City of Vancouver. For passenger vehicles, the number of registered vehicles in Vancouver as of 2010 was used to develop the weighted average intensity factor.[28] From these intensity factors, there are two relevant methods for estimating GHG emissions relevant to this study:[29]

[24] First Environment. (2011). *Verification Report for BC Transit & TransLink Low Carbon and Electric Vehicle Offset Project Pacific Carbon Trust*. New York, NY: First Environment. Retrieved from: https://mer.markit.com/br-reg/services/processDocument/downloadDocumentById/100000000008410

[25] National Energy Board. (2015). *Energy Conversion Tables*. Ottawa, ON: National Energy Board. Retrieved from: https://www.neb-one.gc.ca/nrg/tl/cnvrsntbl/cnvrsntbl-eng.html

[26] Electric vehicles (EV) and plug-in hybrid vehicles (PHEV) are not included in BC's emissions reporting as there are zero tail-pipe emissions.

[27] Based on the provided data from TransLink, the weighted average emission and energy factors assumes a bus occupancy of 29 passengers, producing a load of 35% to 38% for a typical trolley bus (maximum capacity of 77 to 82 passengers), and a load of 121% for a community shuttle (maximum capacity of 24 passengers); TransLink. (2012). *Fleet Pictorial*. Burnaby, BC: TransLink. Retrieved from: http://www.translink.ca/-/media/Documents/plans_and_projects/expansion_upgrades/Fleet%20Pictorial.pdf

[28] Weighted average energy consumption factors assume 1 L of fuel = 34.66 MJ for gasoline; 38.68 MJ for diesel.

[29] GHG Protocol. (2013). *Scope 3 Calculation Guidance*. Retrieved from: http://ghgprotocol.org/sites/default/files/ghgp/Scope3_Calculation_Guidance.pdf

1. **Fuel-based method:** involves determining the amount of fuel consumed during travel, and applying the appropriate emission factor for that fuel; and
2. **Distance-based method:** involves determining the distance travelled and mode during travel, and applying the appropriate emission factor for the mode used.

Following provincial protocol, passenger vehicle emissions were estimated using the fuel-based method (weighted factor expressed as kilograms per litre; kg/L), while city bus emissions were estimated using the distance-based method (weighted factor expressed as kilograms per passenger-kilometre; kg/psg-km). Intensity factors using the two methods are provided for both passenger vehicle and city bus in Table 3 for completeness.

Table 2. Average fuel efficiency rates and GHG emission intensity factors for BC.

Vehicle Type	Fuel Type	Fuel Efficiency Rate	CO_2e Emission Factor (Fuel-based)	CO_2e Emission Factor (Distance-based)	Registered Vehicles in Vancouver
Small and Large Passenger Car	Gasoline	10.3 L/100 km	2.3200 kg/L	0.2390 kg/veh-km	165,708
	Diesel	7.7 L/100 km	2.6230 kg/L	0.2020 kg/veh-km	2,494
	Hybrid Gasoline	7.0 L/100 km	2.3200 kg/L	0.1624 kg/veh-km	2,296
Light Trucks, Vans, and SUVs	Gasoline	14.7 L/100 km	2.3530 kg/L	0.3459 kg/veh-km	91,749
	Diesel	12.5 L/100 km	2.6240 kg/L	0.3280 kg/veh-km	1,552
	Hybrid Gasoline	10.0 L/100 km	2.3530 kg/L	0.2353 kg/veh-km	1,023
City Bus	Diesel	55.7 L/100 km	2.3686 kg/L	0.0904 kg/psg-km	N/A

Source: BC Community Energy and Emissions Inventory (CEEI) and TransLink; additional calculations by author.

Table 3. Weighted average fuel efficiency rates, GHG emission intensity factors, and energy consumption intensity factors for Vancouver.

Vehicle Type	Fuel Type	Fuel Efficiency Rate	CO_2e Emission Factor		Energy Consumption Factor	
			Fuel-based	Distance-based	Fuel-based	Distance-based
Passenger Vehicle	Gasoline, Diesel, and Hybrid Gasoline	11.8 L/100 km	2.3362 kg/L*	0.2609 kg/veh-km	34.7214 MJ/L*	4.0912 MJ/veh-km
City Bus	Diesel	55.7 L/100 km	2.6109 kg/L	0.0904 kg/psg-km*	38.6800 MJ/L	0.7460 MJ/psg-km*

Note: The appropriate emission and energy intensity factors used for the corresponding vehicle type follow provincial protocol and are indicated by an asterisk; calculations by author.

The amount of emissions and energy for each motorized trip recorded in the Trip Diary Survey were estimated using the distance travelled with the corresponding weighted average emission factor (Equation 1 and 2) and energy factor (Equation 2 and 3). The amount of emissions (kg CO_2e) and energy (MJ) consumed were then summed to calculate daily averages for each participant based on the two-day survey period. For passenger vehicle trips, the amount of emissions and energy consumed were divided by vehicle occupancy to obtain figures by person. One limitation of the GHG modelling method used in this study is that it cannot directly account for factors that affect emissions such as congested travel time and vehicle cold starts. Walking and bicycle trips were assumed to have a zero emission and energy impact. See “Appendix B: Sample Calculations” for sample calculations.

$$\text{Motorized GHG Emissions}_{\text{Passenger Vehicle}}\ (kg\ CO_2e) = \frac{\text{average fuel efficiency}\ (L)}{100\ km} \cdot \frac{\text{distance travelled}\ (km)}{\text{number of passengers}} \cdot \text{emission factor}\left(\frac{kg}{L}\right) \quad \text{(EQ 1)}$$

$$\text{Motorized GHG Emissions}_{\text{City Bus}}\ (kg\ CO_2e) = \text{distance travelled}\ (km) \cdot \text{emission factor}\left(\frac{kg}{\text{passenger-km}}\right) \quad \text{(EQ 2)}$$

$$\text{Motorized Energy Consumption}_{\text{Passenger Vehicle}}\ (MJ) = \frac{\text{average fuel efficiency}\ (L)}{100\ km} \cdot \frac{\text{distance travelled}\ (km)}{\text{number of passengers}} \cdot \text{energy factor}\left(\frac{MJ}{L}\right) \quad \text{(EQ 3)}$$

$$\text{Motorized Energy Consumption}_{\text{City Bus}}\ (MJ) = \text{distance travelled}\ (km) \cdot \text{energy factor}\left(\frac{MJ}{\text{passenger-km}}\right) \quad \text{(EQ 4)}$$

3.2.3 Model: Physical Energy Expenditure

The method used for modeling physical energy expenditure by calories was adopted from previous research conducted by Dr. Lawrence Frank.[30] Dr. Frank's research sought to create a single metric to define the relative amount of energy consumed from walking versus motorized travel. This would allow researchers and policymakers to conceptualize the integration of the climate change mitigation and health dimensions of transportation.

Dr. Frank's metric measures the relationship between energy expended from walking, energy expended from motorized transportation, and the ratio between the two—the "transport energy index" (kilocalories expended by walking to kilocalories expended by fuel), a novel methodological approach. Thus, the more walking and less driving a person does, the closer the index gets to 1 and beyond. The findings from Dr. Frank's study found that similar urban form strategies can have co-benefits for both climate change mitigation and physical activity, a concept that had been previously untested empirically.

This study extends Dr. Frank's previous work and explicitly accounts for energy expended from both cycling and walking. In doing so, the present study defines an updated transport energy index, expressed as the ratio between kilocalories expended from active travel (walking and cycling combined) to kilocalories expended from motorized travel.

For the purposes of analysis, the numerator (active energy) and denominator (motorized energy) variables were natural log transformed to account for skewed distributions of the data. A value of 1 was added to both variables to retain observations for which kilocalories equaled zero, a mathematical necessity to account for participants that had no energy expenditure by either active or motorized modes (as the natural log of zero is undefined).

The equations (Equations 5 to 7) used to estimate kilocalories expended are based on MET (metabolic equivalent) values, a measure of the intensity of aerobic exercise commonly used in physical activity research (see Table 4).[31] Equation 8 shows the formula for calculating the transport energy index. See "Appendix B: Sample Calculations" for sample calculations.

Table 4. Metabolic Equivalent (MET) values for walking and cycling.

Category	Code	Description	MET Value
Walking	17160	Walking for pleasure	3.5
Cycling	01015	Bicycling, general	7.5

Source: 2011 Compendium of Physical Activities

[30] Frank, L. D., Greenwald, M. J., Winkelman, S., Chapman, J., & Kavage, S. (2010). Carbonless footprints: promoting health and climate stabilization through active transportation. *Preventive Medicine, 50*, S99–105.

[31] Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R., Tudor-Locke, C., Greer, J.L., Vezina, J., Whitt-Glover, M.C., & Leon, A. S. (2011). 2011 Compendium of Physical Activities: a second update of codes and MET values. *Medicine and Science in Sports and Exercise, 43*(8), 1575–1581.

One limitation of the Trip Diary Survey is the inability to account for differences in energy expenditure intensity for a given active travel mode. For example, for trips by foot, participants may have taken a casual walk or have chosen to jog, both of which would have different energy expenditure implications. As there was no option in the Trip Diary Survey to indicate how the trip by foot was completed, changes in actual energy expenditure from before and after the Greenway may be underestimated and/or undetected.

This is an important and significant limitation to consider as the Greenway may have had a differential effect on the intensity of active travel trips. As the formula uses a single MET value to represent all walk and bicycle trips respectively, the model used in the study cannot account for those differences in energy expenditures intensity. The use of accelerometers, common in physical activity research, would greatly improve the accuracy of modelling the physical energy expenditure impacts of the Greenway.[32] For this reason, results from from the present study need to be interpreted with caution.

$$Physical\ Energy\ Expenditure_{Motorized}\ (kcal) = average\ CO_2e\ per\ day\ (g) \cdot \frac{1\ lb}{453.539237\ g} \cdot \frac{1\ gal}{19.564\ lb} \cdot \frac{31{,}250\ kcal}{1\ gal} \cdot \frac{3.5219}{1} \quad \text{(EQ 5)}$$

$$Physical\ Energy\ Expenditure_{Walking}\ (kcal) = 0.35\ kcal\ \frac{lb}{mi} \cdot weight\ (lb) \cdot distance\ travelled\ (mi) \quad \text{(EQ 6)}$$

$$Physical\ Energy\ Expenditure_{Cycling}\ (kcal) = 0.75\ kcal\ \frac{lb}{mi} \cdot weight\ (lb) \cdot distance\ travelled\ (mi) \quad \text{(EQ 7)}$$

$$Transport\ Energy\ Index = \ln\left(\frac{average\ daily\ kcal\ from\ active\ transport + 1}{average\ daily\ kcal\ from\ motorized\ transport + 1}\right) \quad \text{(EQ 8)}$$

[32] Ward, D.S., Evenson, K.R., Vaughn, A., Rodgers, A.B., & Troiano, R.P. (2005). Accelerometer use in physical activity: best practices and research recommendations. *Medicine & Science in Sports & Exercise, 37*(11): S582–588.

3.3 Statistical Methods

A Repeated Measure Mixed Analysis of Variance (ANOVA) was used to analyze the changes before (Phase 1) and after (Phase 2) the Greenway, and to determine if the measured changes in outcomes could be attributed to the Greenway.[33] Repeated Measure Mixed ANOVA is a statistical technique that can determine if the changes produced by an intervention (construction of the Greenway) were different for one group of individuals (treatment—residents living near the Greenway) relative to another group (control—residents not living near the Greenway).

The interpretation of the ANOVA test for the purposes of this study is to measure the *difference in change over time* between the treatment and control group, and not the difference between the treatment and control group. An (exaggerated) example is provided below illustrating the interpretation of the ANOVA test:

- In Phase 1, participants in the treatment group had an average of 3.0 daily bicycle trips, and participants in the control group had an average of 2.0 daily bicycle trips.
- In Phase 2, participants in treatment group increased their average daily bicycle trips by 5.0 trips to 8.0 trips in total, and participants in the control group increased their average daily bicycle trips by 1.0 trip to 3.0 trips in total.

In both the treatment and control group, daily bicycle trips increased. However, the effect was greater in the treatment (increase of 5.0 trips from 3.0 trips in Phase 1 to 8.0 trips in Phase 2) than compared to the control (increase of 1.0 trip from 2.0 trips in Phase 1 to 3.0 trips in Phase 2). The ANOVA test would be able to detect the larger magnitude of change over time in the treatment relative to the control. If the measured change were statistically significant, we would conclude the effect of increased bicycle trips was a result of the Greenway.

For further clarity, the ANOVA test would not be measuring if the 8.0 daily bicycle trips in the treatment group differed with the 3.0 trips in the control group during Phase 2 at the end of the study. Instead, it would be analyzing the *difference in change over time* (+5.0 trips in the treatment compared to +2.0 trips in the control) from Phase 1 to 2 between the treatment and control.

The use of the control group allows the research design to partially control for background trends. For example, the increase in bicycle trips in both the treatment and control group may have been indicative of a city-wide increase in bicycle trips due to city-wide cycling infrastructure improvements. The ANOVA test is able to detect the additional positive benefit conferred by the Greenway. Without the presence of the control group, we would

[33] Advanced statistical techniques such as linear mixed effects regression models were not used for the present study given the intended audience of this report. However, future scholarly publications of this research will make use of these advanced techniques.

have erroneously overstated the benefits of the Greenway, as we would have been unable to statistically distinguish between the city-wide increase in bicycle trips and the increase in bicycle trips directly as a result of the Greenway.

More broadly speaking and for further clarity, Figure 10 provides a conceptual diagram of the analysis of longitudinal data. The "observed outcome trend" refers to the *change over time* on a given transportation outcome for the treatment group exposed to the built environment intervention, such as the construction of a greenway. The "unobserved counterfactual" refers to what would have happened without the construction of the greenway; in this case, nothing. The "intervention effect" refers to the effect of the greenway on the transportation outcome.

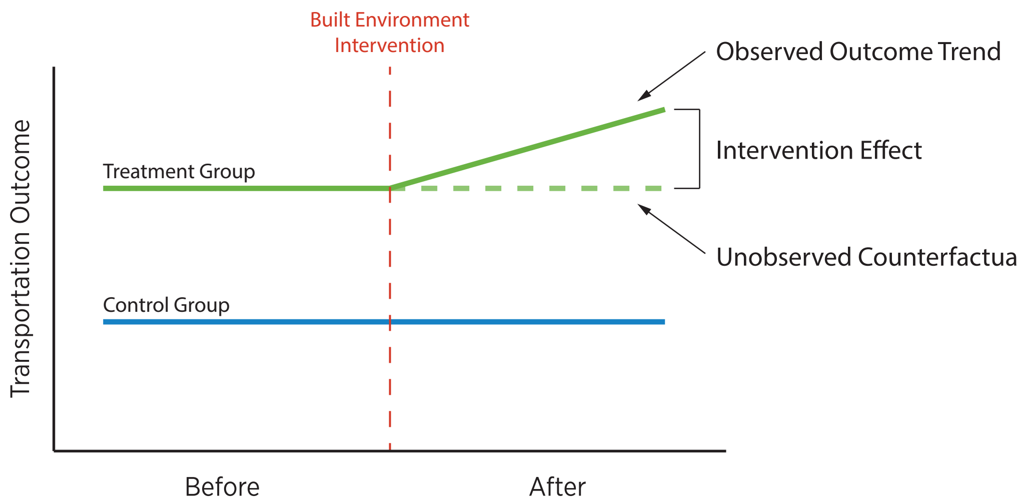

Figure 10. Conceptual diagram of analyzing longitudinal data.

The study uses a 95% confidence level (alpha of 0.05) to reject the null hypothesis that there is no effect of the Greenway. In other words, when a statistically significant difference between the treatment and control group is detected using the ANOVA test, we are 95% certain that the result was not due to random chance.

3.4 Study Limitations

The study carries several limitations in its methodology that should be considered when interpreting the findings.

- **Study context:** The effects attributed to the Greenway were found in a neighbourhood context characterized by a dense, highly walkable area with generally good pedestrian and bicycle infrastructure, low automobile ownership and usage, and good transit options. As a result, the study's findings may not be generalizable to other contexts.
- **Network context:** The study isolates the Greenway with respect to the total bicycle network. In other words, the presence of the existing bicycle network is not taken into account. For example, a standalone greenway in an area with no other bicycle facilities may have a different impact than a new greenway in a developed network.
- **Treatment and control group:** The research design defines the treatment and control group by geographic proximity to the Greenway. The use of proximity to define the control group is based on the research design of similar studies. More advanced statistical techniques could be employed in future research to model outcomes based on participants' distance away from the Greenway. This would treat participant's proximity to the Greenway as a continuous variable, rather than a binary variable.
- **Trip sample:** The study only investigated the impact of the Greenway for a subset of trips (walk, bicycle, bus, and auto trips with origins and/or destinations in downtown Vancouver) from the Trip Diary Survey.
- **Emission and energy intensity factors:** Emission and energy intensity factors used in the study are weighted averages based on existing and convenient data sources. This is a necessity as actual vehicle ownership by model and type is unknown for the sample.
- **Estimation of distance travelled:** Distance travelled per mode is estimated using the shortest path algorithm (Dijkstra's) calculated in GIS. While this is a standard method used in transportation modeling, this may not necessarily reflect the actual route travelled by participants, particularly for active modes and non-utilitarian trips.[34] The use of GPS for data collection in future research would improve understanding of the exact route travelled by participants.
- **Estimation of physical energy expenditure:** Energy expenditure were estimated using MET values, which are average population values based on physical activity studies. The study generalizes across different intensities of walking (e.g., walking at a slow pace versus running for exercise) and cycling (e.g., cycling for leisure versus moderate to vigorous effort), a limitation due to the non-specificity of intensity of the active transport mode recorded in the Trip Diary Survey.

[34] Ortúzar, J. & Willumsen, L.G. (2011). *Modelling Transport (4th ed.)*. Chicheser, UK: John Wiley & Sons.

Section 4
Results

4.1 Study Sample

The study sample consisted of 207 participants living in downtown Vancouver, divided into two groups: 135 participants living within one-block of the Greenway (treatment group; 65.2% of the sample), and 72 participants living at least half a kilometre away from the Greenway (control group; 34.8% of the sample).

Figure 11 shows the geographic distribution of the participant's primary place of residence by treatment and control group.

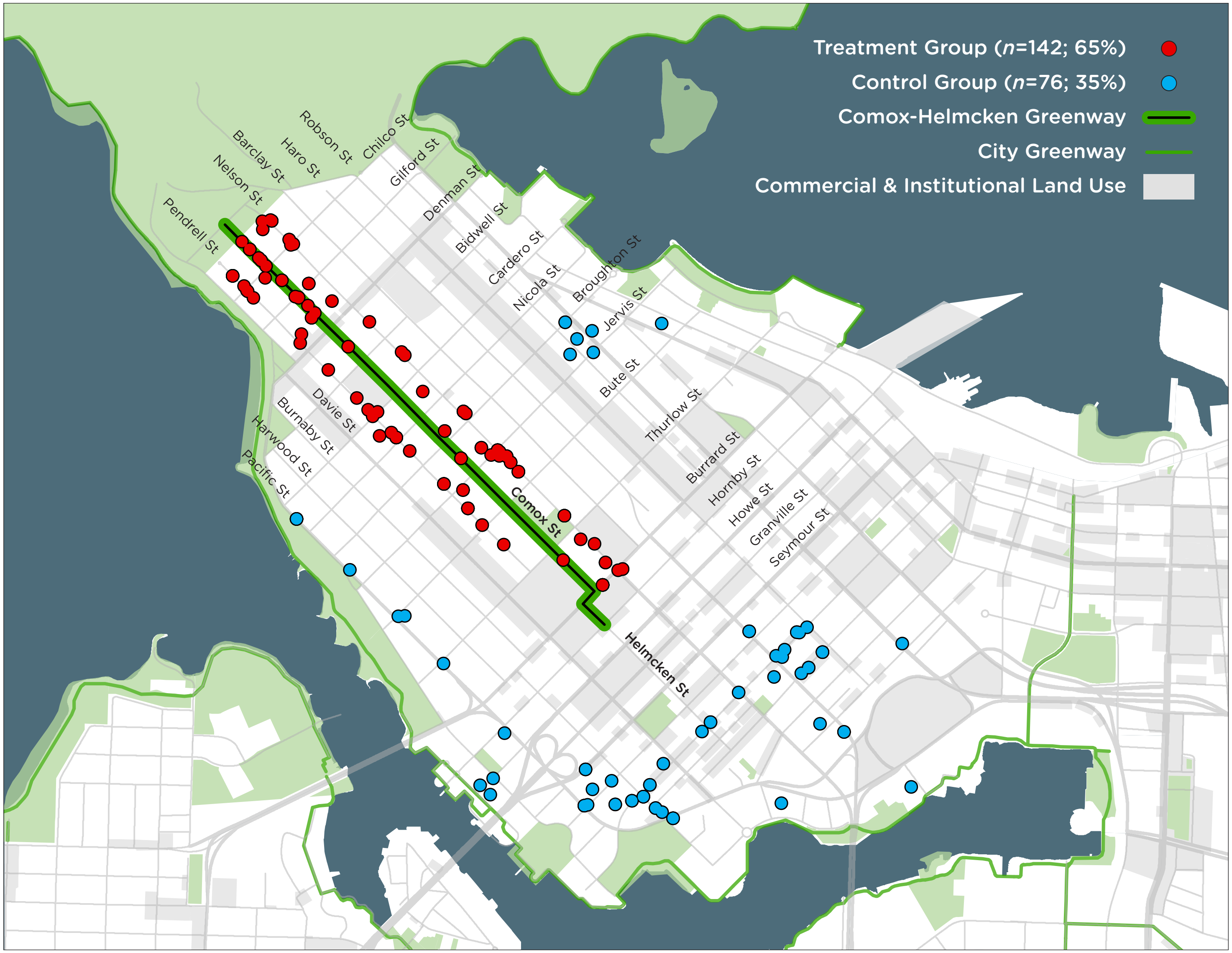

Figure 11. Geographic distribution of participants' primary place of residence.

4.2 Demographics

This section provides an overview of the demographic characteristics for the study sample. Figures for the West End are sourced from the City of Vancouver's custom tabulation of Census data. Cross-sectional comparisons with the control group were conducted using t-tests at the 95% confidence level for Phase 2 data. Table 5 shows descriptive statistics for demographic variables.

Table 5. Participant characteristics.

Characteristic	Time	Treatment Group (*N* = 135)			Control Group (*N* = 72)		
		Mean or %	SD		Mean or %	SD	
Age	1	47.4	14.1		41.8	13.8	
	2	49.4	14.1	***	43.8	13.8	***
Gender (% Male)	1	47.4%	50.1%		31.9%	47.0%	
	2	47.4%	50.1%		31.9%	47.0%	
Ethnicity (% White)	1	92.6%	26.3%		79.2%	40.9%	
	2	92.6%	26.3%		79.2%	40.9%	
Employment Status (%)							
Employed	1	73.3%	44.4%		73.6%	44.4%	
	2	73.3%	44.4%		77.8%	41.9%	
Unemployed	1	26.7%	55.6%		26.4%	55.6%	
	2	26.7%	55.6%		22.2%	58.1%	

Note: Statistical significance for paired t-test comparison: $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.001$ (***).

Table 5 (cont'd). Participant characteristics.

Characteristic	Time	Treatment Group (*N* = 135)			Control Group (*N* = 72)		
		Mean or %	SD		Mean or %	SD	
Annual Household Income (%)							
< $10,000	1	1.7%	13.0%		1.7%	13.0%	
	2	0.8%	9.2%		3.3%	18.1%	
$10,000 - $19,999	1	6.8%	25.2%		5.1%	22.2%	
	2	5.9%	23.7%		5.0%	22.0%	
$20,000 - $29,999	1	5.9%	23.7%		0.0%	0.0%	
	2	6.8%	25.2%		0.0%	0.0%	
$30,000 - $39,999	1	9.3%	29.2%		8.5%	28.1%	
	2	9.3%	29.2%		6.7%	25.2%	
$40,000 - $59,999	1	22.9%	42.2%		15.3%	36.3%	
	2	21.2%	41.0%		8.3%	27.9%	
$60,000 - $79,999	1	15.3%	36.1%		23.7%	42.9%	
	2	14.4%	35.3%		25.0%	43.7%	
$80,000 - $99,999	1	16.1%	36.9%		15.3%	36.3%	
	2	15.3%	36.1%		11.7%	32.4%	
> $100,000	1	22.0%	41.6%		30.5%	46.4%	
	2	26.3%	44.2%		40.0%	49.4%	*
Number of Household Residents	1	1.6	0.6		1.7	0.9	
	2	1.6	0.7		1.8	0.9	
Transportation (%)							
Vehicle Ownership	1	44.4%	49.9%		70.8%	45.8%	
	2	46.7%	50.1%		69.4%	46.4%	
Bicycle Ownership	1	59.3%	49.3%		59.7%	49.4%	
	2	68.1%	46.8%	**	62.5%	48.8%	
Carsharing Membership	1	27.4%	44.8%		15.3%	36.2%	
	2	34.1%	47.6%	*	23.6%	42.8%	*

Note: Statistical significance for paired t-test comparison: $p \leq 0.05$ (*), $p \leq 0.01$ (**), $p \leq 0.001$ (***). Household Income: Participants were only asked to report their household income for the Phase 2 survey. To address the missing Phase 1 data, participants were also asked to recall what their income was during that period.

4.2.1 Age

Overall, the study's treatment sample ranged in age from 22 to 88 years old in Phase 1, and 24 to 90 years old in Phase 2. The mean age was 47 years old in Phase 1, and 49 years old in Phase 2. Study participants are generally older than the typical West End resident (mean age of 37 years).

When compared to the control group (mean age of 43 years), the treatment had statistically significant older participants (mean age of 49 years old).

4.2.2 Gender

Overall, the treatment sample skewed slightly towards individuals identifying as female when compared to the West End as a whole. 52.6% of participants identified as females, and 47.4% of participants identified as male. This breakdown remained the same from Phase 1 to Phase 2. In the West End, males are the dominant gender group, forming 52.4% of all residents, with 47.6% of residents identifying as female.

When compared to the control group (68.1% of participants identifying as females), the treatment had statistically significant fewer female participants.

4.2.3 Household Income

Overall, the treatment sample reported a relatively high median household income bracket of $60,000 to $79,000 in both Phase 1 and 2. In Phase 2, when broken down by income brackets, the largest share of participants reported an annual household income of $100,000+ (26.3%), followed by $40,000 to $59,999 (21.2%). This means that the study participants have a substantially higher household income than the typical West End resident (median income bracket of $30,000 to $39,999).[35]

When compared to the control group, there was no statistically significant difference in annual household income.

[35] City of Vancouver. (2013). *West End Community Plan*. Vancouver, BC: City of Vancouver. Retrieved from: http://vancouver.ca/files/cov/west-end-community-plan.pdf

4.2.4 Transportation

The sample reported varying levels of transportation access. The majority of participants reported owning a bicycle, with slightly less than half reported owning a motor vehicle, and about a quarter of the sample reported having membership with a carsharing network.

Overall, ownership and membership increased across the board from Phase 1 to 2. The largest increase observed was for membership with a carsharing network, from 27.4% in Phase 1 to 34.1% in Phase 2, a statistically significant increase when compared to the control. An increase was observed in both the treatment and control; there was no statistically significant difference when comparing the treatment and control cross-sectionally.

Bicycle ownership saw the second largest increase, from 59.3% in Phase 1 for the treatment to 68.1% in Phase 2, a statistically significant increase when compared to the control. An increase was observed in both the treatment and control; there was no statistically significant difference when comparing the treatment and control cross-sectionally.

Motor vehicle ownership increased slightly from 44.4% in Phase 1 for the treatment to 46.7% in Phase 2. However, this increase was not statistically significant when compared to the control. In addition, there was no statistically significant difference when comparing the treatment and control cross-sectionally.

4.3 Transportation Characteristics

This section provides an overview of the changes in transportation characteristics for the study sample.

4.3.1 Mode Share

Mode share is defined as the proportion of total person trips by travel mode.

For participants in the treatment, a total of 897 trips were recorded in Phase 1 within the study scope, and a total of 795 trips were recorded in Phase 2. In general, the majority of trips are dominated by walking, followed by auto, bus, and lastly bicycle travel (see Table 6). This generally corresponds with the Census data for journey to work in the West End.[36]

- **Walk trips** saw a decline in both the treatment (from 66.3% to 65.2%; a percentage change of −1.8%) and the control (from 65.1% to 63.9%; change of −1.7%).
- **Auto trips** saw a decline in the treatment (from 21.2% to 19.9%; change of −6.2%). In contrast, the control saw an increase (from 25.6% to 29.3%; change of +14.7%).
- **Bus trips** saw an increase in the treatment (from 9.4% to 9.8%; change of +4.8%). In contrast, the control saw a decline (from 5.5% to 3.8%; change of −29.8%).
- **Bicycle trips** saw an increase in the treatment (from 3.1% to 5.2%; change of +65.2%)—the greatest change out of all the modes. In contrast, the control saw a decline (from 3.9% to 2.9%; change of −25.7%).

In summary, the Comox-Helmcken Greenway had an overall positive benefit with reductions in auto trips, and an increase in bicycle and bus trips. However, walk trips unexpectedly declined, although it should be noted this trend was observed in both the treatment and control group.

[36] City of Vancouver. (2013). *West End Community Plan*. Vancouver, BC: City of Vancouver. Retrieved from: http://vancouver.ca/files/cov/west-end-community-plan.pdf

Table 6. Change in mode share.

Mode	Time	Treatment Group (*N* = 135)				Control Group (*N* = 72)			
		No. of Trips	Share	Absolute Δ	Percentage Δ	No. of Trips	Share	Absolute Δ	Percentage Δ
Walk	1	595	66.3%			285	65.1%		
	2	518	65.2%	−1.2%	−1.8%	266	63.9%	−1.1%	−1.7%
Auto	1	190	21.2%			112	25.6%		
	2	158	19.9%	−1.3%	−6.2%	122	29.3%	+3.8%	+14.7%
Bus	1	84	9.4%			24	5.5%		
	2	78	9.8%	+0.4%	+4.8%	16	3.8%	−1.6%	−29.8%
Bicycle	1	28	3.1%			17	3.9%		
	2	41	5.2%	+2.0%	+65.2%	12	2.9%	−1.0%	−25.7%

Note: Walk = all trips made by foot; Auto = auto driver, auto passenger, and taxi; Bus = transit bus and shuttle, and school bus. Trips made by other modes (e.g., SkyTrain) were excluded from the present study as they fell outside the study scope in terms of emissions and energy.

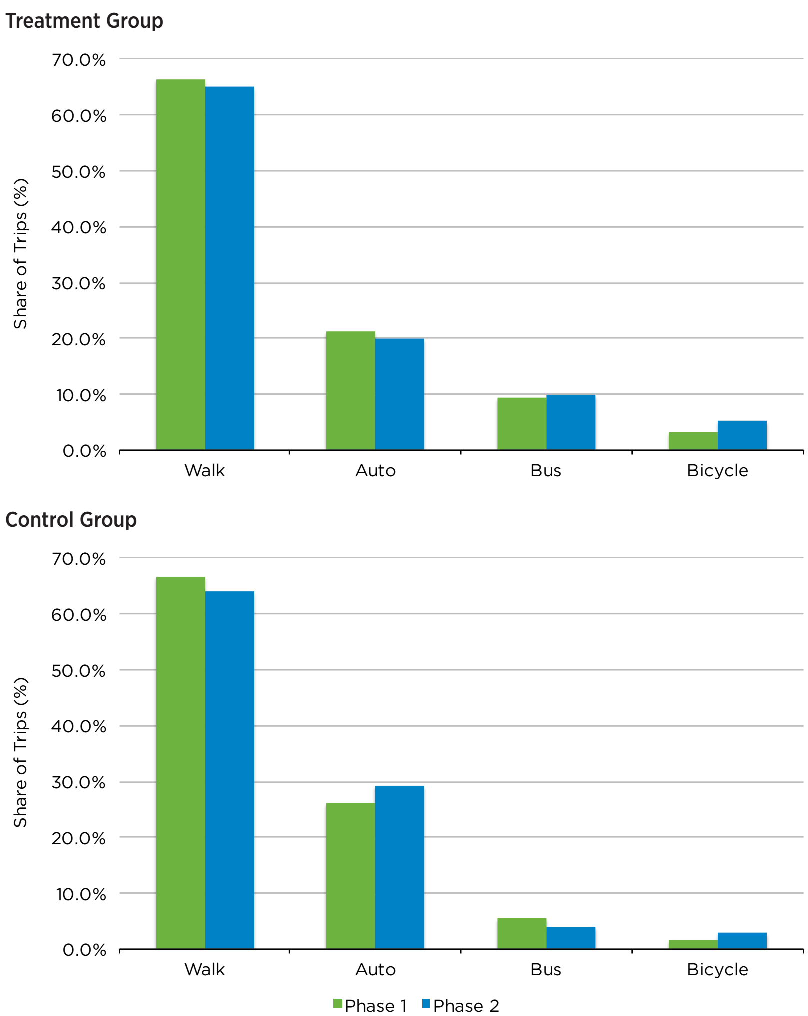

Figure 12. Change in mode share.

4.3.2 Distance Travelled

Average daily distance travelled is defined as the average daily amount of total travel (as measured in kilometres) by travel mode.

For participants in the treatment, the distance travelled by motorized transport was greater than active transport (see Table 7). These results are expected as active travel (walk and bicycle) is generally limited to shorter distance trips relative to motorized travel (auto and bus). Table 8 shows the results of the ANOVA model.

- Overall, the **total** average daily amount of travel declined by −14.9% for participants in the treatment (from 8.8 km to 7.5 km). In contrast, the control saw an increase in travel by +4.6% (from 7.6 km to 9.1 km). When compared to the control group, there was no statistically significant reduction detected, $F(1,205) = 2.3$, $p = 0.130$.
- For **active travel**, the average daily distance declined by −3.4% for participants in the treatment (from 2.2 km to 2.1 km). Conversely, the control saw an increase in active travel by +51.9% (from 1.6 km to 2.0 km). When compared to the control group, there was no statistically significant reduction detected, $F(1,205) = 1.4$, $p = 0.238$.
- For **motorized travel**, the average daily distance declined by −20.5% for participants in the treatment (from 6.5 km to 5.1 km). Conversely, the control saw an increase in motorized travel by +5.4% (from 5.3 km to 6.8 km). When compared to the control group, there was no statistically significant reduction detected, $F(1,205) = 3.1$, $p = 0.079$.

In summary, the Comox-Helmcken Greenway had a positive benefit with reductions in the total amount of travel, particularly motorized travel. However, active travel on a whole declined. As residents in the West End predominately choose to walk, one explanation may be that the Greenway increased residents' accessibility to local services and amenities, reducing the overall distance travelled by active modes. Also, there may have been differential changes to utilitarian vs. recreational travel from the Greenway, something which is not explored in the present study.

Table 7. Change in average daily distance travelled.

Outcome	Time	Mean	SD	95% CI
Treatment Group (*N* = 135)				
Active (km)	1	2.2	2.0	[1.8 – 2.5]
	2	2.1	3.2	[1.6 – 2.6]
Motorized (km)	1	6.4	9.8	[4.8 – 8.1]
	2	5.1	7.3	[3.9 – 6.3]
Total (m)	1	8.9	9.3	[7.2 – 10.5]
	2	7.5	7.6	[6.2 – 8.9]
Control Group (*N* = 72)				
Active (km)	1	1.6	1.6	[1.2 – 1.9]
	2	2.0	2.5	[1.4 – 2.6]
Motorized (km)	1	5.3	9.2	[3.2 – 7.5]
	2	6.8	9.7	[4.5 – 9.1]
Total (km)	1	7.6	9.2	[5.4 – 9.9]
	2	9.1	9.6	[6.8 – 11.4]

Table 8. Model result: change in average daily distance travelled.

Outcome	*df*	*SS*	*MS*	*F*	*p*-value	Significance
Average Daily Distance Travelled: Active (m)	208	1,607.7	7.7	1.7	0.000	$p \leq 0.001$
time	1	3.2	3.2	0.7	0.401	ns
group*time	1	6.3	6.3	1.4	0.238	ns
residual	205	930.7	4.5	-	-	-
Average Daily Distance Travelled: Motorized (m)	208	20,911.4	100.5	1.7	0.000	$p \leq 0.001$
time	1	0.6	0.6	0.0	0.923	ns
group*time	1	182.8	182.8	3.1	0.079	ns
residual	205	12,055.4	58.8	-	-	-
Average Daily Distance Travelled: Total (m)	208	19,765.8	96.9	1.7	0.000	$p \leq 0.001$
time	1	0.2	0.2	0.0	0.956	ns
group*time	1	133.1	133.1	2.3	0.130	ns
residual	205	10,937.7	57.6	-	-	-

Note: ns = not statistically significant.

4.4 Transportation Emission and Energy Outcomes

This section provides an overview of the changes in transportation emission and energy characteristics for the study sample (see Table 9). Table 10 shows the results of ANOVA model.

Table 9. Change in transportation emission and energy outcomes.

Outcome	Time	Mean	SD	95% CI
Treatment Group (*N* = 135)				
Motorized GHG Emissions (kg CO2e)	1	1.1	2.0	[0.8 – 1.5]
	2	0.9	1.5	[0.6 – 1.1]
Motorized Energy Consumption (MJ)	1	16.0	29.9	[10.9 – 21.1]
	2	12.2	22.4	[8.4 – 16.0]
Physical Energy Expenditure Equivalent: Motorized (kcal)	1	14,129.6	24,931.1	[9,885.7 – 18,373.5]
	2	10,891.1	18,779.4	[7,694.4 – 14,087.8]
Physical Energy Expenditure: Active (kcal)	1	88.9	107.0	[70.7 – 107.1]
	2	87.1	165.3	[59.0 – 115.3]
Transport Energy Index (active kcal/motorized kcal)	1	-1.7	5.5	[−2.7 – −0.8]
	2	-1.9	5.4	[−2.9 – −1.0]
Control Group (*N* = 72)				
Motorized GHG Emissions (kg CO2e)	1	1.0	1.7	[0.6 – 1.4]
	2	1.4	2.3	[0.8 – 1.9]
Motorized Energy Consumption (MJ)	1	13.9	24.9	[8.0 – 19.7]
	2	19.9	33.9	[12.0 – 27.9]
Physical Energy Expenditure Equivalent: Motorized (kcal)	1	12,005.1	20,926.5	[7,087.6 – 16,922.5]
	2	16,983.9	28,256.0	[10,344.1 – 23,623.7]
Physical Energy Expenditure: Active (kcal)	1	59.3	86.4	[39.0 – 79.6]
	2	77.8	145.0	[43.7 – 111.9]
Transport Energy Index (active kcal/motorized kcal)	1	−2.3	5.4	[−3.6 – −1.1]
	2	−2.4	5.6	[−3.7 – −1.1]

Table 10. Model result: change in transportation emission and energy outcomes.

Outcome	*df*	*SS*	*MS*	*F*	*p*-value	Significance
Motorized GHG Emissions (kg CO2e)	208	931.6	4.5	1.8	0.000	$p \leq 0.001$
time	1	0.5	0.5	0.2	0.663	ns
group*time	1	10.3	10.3	4.2	0.041	$p \leq 0.05$
residual	205	500.1	2.4	-	-	-
Motorized Energy Consumption (MJ)	208	205,588.5	988.4	1.8	0.000	$p \leq 0.001$
time	1	121.7	121.7	0.2	0.634	ns
group*time	1	2,287.0	2,287.0	4.3	0.040	$p \leq 0.05$
residual	205	110,002.7	536.6	-	-	-
Physical Energy Expenditure Equivalent: Motorized (kcal)	208	1.4333×10^{11}	6.89107879×10^{8}	1.8	0.000	$p \leq 0.001$
time	1	71,113,521.8	71,113,521.8	0.2	0.664	ns
group*time	1	1.5853×10^{9}	1.5853×10^{9}	4.2	0.041	$p \leq 0.05$
residual	205	7.696×10^{10}	3.75416997×10^{8}	-	-	-
Physical Energy Expenditure: Active (kcal)	208	4.715247 x 106	22,669.5	1.8	0.000	$p \leq 0.001$
time	1	6,565.5	6,565.5	0.5	0.468	ns
group*time	1	9,624.0	9,624.0	0.8	0.380	ns
residual	205	2,550,261.1	12,440.3	-	-	-
Transport Energy Index (active kcal/motorized kcal)	208	8,687.3	41.8	2.4	0.000	$p \leq 0.001$
time	1	2.2	2.2	0.1	0.726	ns
group*time	1	0.6	0.6	0.0	0.858	ns
residual	205	3,630.2	17.7	-	-	-

Note: ns = not statistically significant.

4.4.1 Motorized GHG Emissions

Average daily motorized GHG emissions is defined as the average daily amount of GHG emissions emitted (as measured in kg CO_2e) per participant as a passenger/occupant during motorized travel. For context, the average Vancouver residents emits 4.2 kg CO_2e daily from transportation.[37]

- For participants in the **treatment**, average daily GHG emissions declined by −22.9% (from 1.1 kg CO_2e to 0.9 kg CO_2e).
- In contrast, participants in the **control** saw their average daily emissions increase by +41.5% (from 1.0 kg CO_2e to 1.4 kg CO_2e).
- When compared to the control group, there was a statistically significant reduction of average daily GHG emissions, $F(1,205) = 4.2$, $p = 0.041$.

When annualizing the total average GHG emissions for the treatment sample, this translates into 56 tonnes of transportation CO2e being released annually prior to the Greenway. After the Greenway, with the observed reduction of −22.9%, this figure dropped to 43 tonnes of CO_2e.

In summary, the Comox-Helmcken Greenway had a positive environmental benefit with a statistically significant effect of reductions in motorized GHG emissions for residents living within one-block of the Greenway.

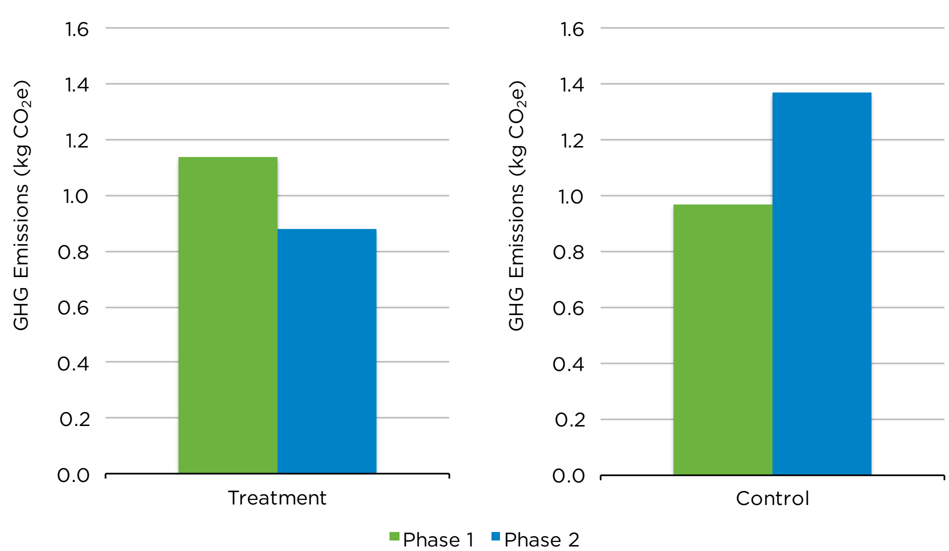

Figure 13. Change in average daily motorized GHG emissions.

[37] Per capita figures for motorized GHG emissions and energy consumption are based on calculations by the author using the 2010 CEEI data for the City of Vancouver. Per capita figures include the following categories: "Small Passenger Cars," "Larger Passenger Cars," "Light Trucks, Vans, SUVs," "Motorcycles, Mopeds," and "Bus."

4.4.2 Motorized Energy Consumption

Average daily motorized energy consumption is defined as the average daily amount of energy consumed (as measured in MJ) per participant as a passenger/occupant during motorized travel. For context, the average Vancouver residents consumes 65.1 MJ daily from transportation.

- For participants in the **treatment**, average daily energy consumption declined by −23.7% (from 16.0 MJ to 12.2 MJ).
- In contrast, participants in the **control** saw their average daily energy consumption increase by +43.8% (from 13.9 MJ to 19.9 MJ).
- When compared to the control group, there was a statistically significant reduction of average daily energy consumption, $F(1,205) = 4.3$, $p = 0.040$.

In summary, the Comox-Helmcken Greenway had a positive environmental benefit with a statistically significant effect of reductions in motorized energy consumption for residents living within one-block of the Greenway.

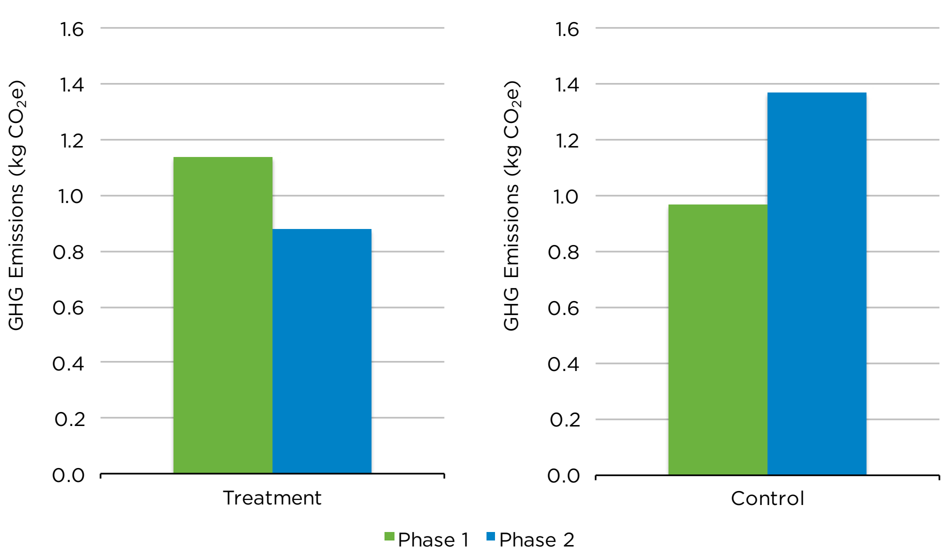

Figure 14. Change in average daily motorized energy consumption.

4.4.3 Physical Energy Expenditure

Average daily physical energy expenditure is defined as the amount of energy expended from human physical activity (as measured in kilocalories). In this study, energy expenditure is expressed in two forms: **average daily physical energy expenditure equivalent by motorized travel** (the equivalent human energy used in motorized travel expressed as a unit conversion from fossil fuel combustion), and **average daily physical energy expenditure by active travel**.

Physical Energy Expenditure Equivalent by Motorized Travel

- For participants in the **treatment**, average daily physical energy expenditure equivalent declined by −22.9% (from 14,129.6 kcal to 10,891.1 kcal).
- In contrast, participants in the **control** saw their energy expenditure equivalent increase by +41.5% (from 12,005.1 kcal to 16,983.9 kcal).
- When compared to the control group, there was a statistically significant reduction of average daily physical energy expenditure equivalent, $F(1,205) = 4.2$, $p = 0.041$.

Physical Energy Expenditure by Active Travel

- For participants in the **treatment**, average daily physical energy expenditure declined by −2.0% (from 88.9 kcal to 87.1 kcal).
- In contrast, participants in the **control** saw their energy expenditure increase by +31.2% (from 59.3 kcal to 77.8 kcal).
- When compared to the control group, there was no statistically significant reduction detected for average daily physical energy expenditure, $F(1,205) = 0.8$, $p = 0.380$.

In summary, the Comox-Helmcken Greenway had a positive environmental benefit with a statistically significant effect of reductions in physical energy expenditure equivalent by motorized travel for participants living within one-block of the Greenway. However, the Greenway did not have an impact on physical energy expenditure by active travel.

4.4.4 Transport Energy Index

The transport energy index is defined as the ratio of kilocalories burned by active travel to kilocalories burned by motorized travel; it is a unitless metric. The more active travel and less motorized travel a person does, the closer the index gets to 1 and beyond.

- For participants in the **treatment**, the index increased by +13.4% (from −1.7 to −1.9).
- For participants in the **control**, the index increased by +3.2% (from −2.3 to −2.4).
- When compared to the control group, there was no statistically significant reduction detected for the transport energy index, $F(1,205) = 0.03$, $p = 0.858$.

In summary, the Comox-Helmcken Greenway did not have an impact on energy as measured by the transport energy index.

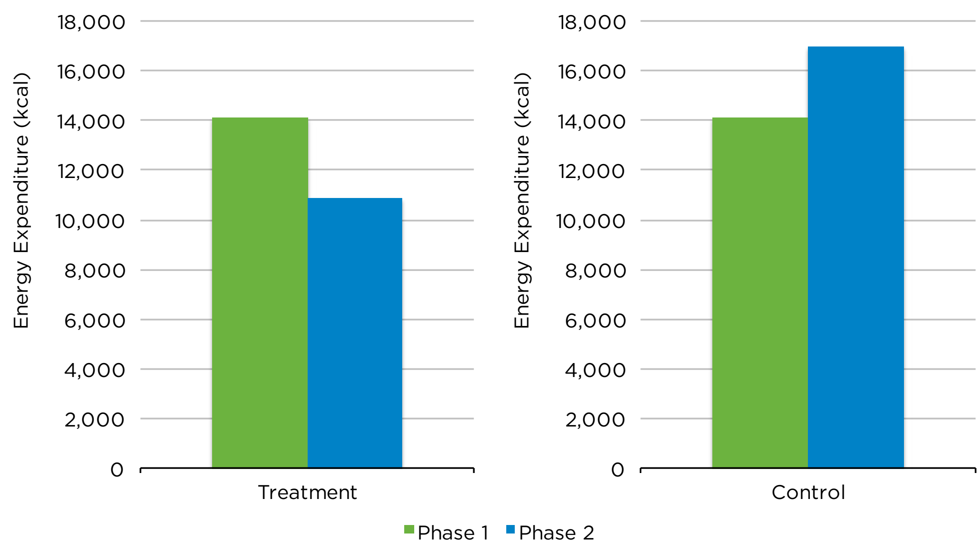

Figure 15. Change in average daily physical energy expenditure equivalent—motorized.

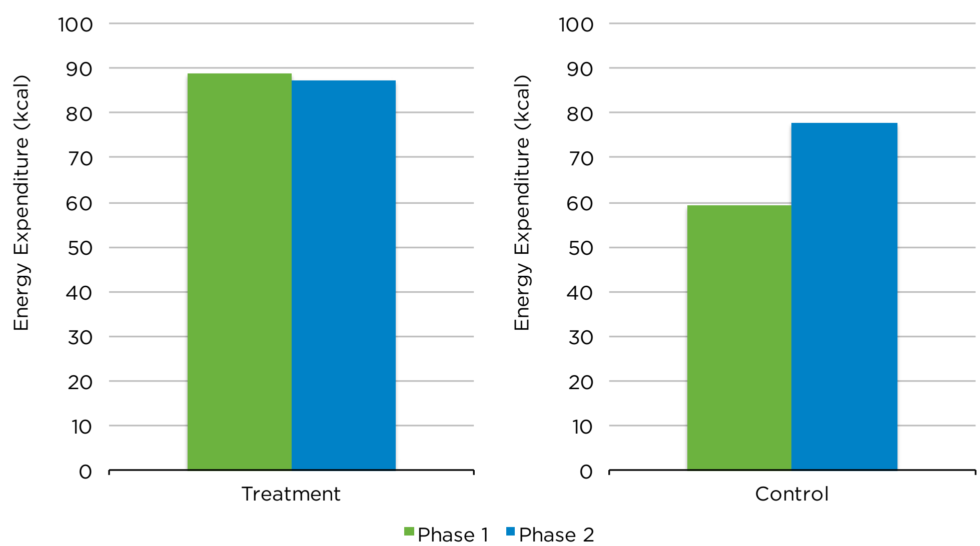

Figure 16. Change in average daily physical energy expenditure—active.

Section 5
Conclusion

The study's findings lend evidence to support the claim that active transportation improvement projects may have a beneficial causal impact on improved environmental outcomes. The City of Vancouver's Comox-Helmcken Greenway yielded significant reductions in transportation GHG emissions and energy consumption for residents living within one-block of the Greenway. However, there were mixed results for changes in health energy outcomes; more research with improved methods is needed to better understand the impact of greenways on physical energy expenditure.

For researchers, the study contributes to a burgeoning subfield of research that aims to establish causality between transportation infrastructure and environmental and health outcomes. Promoting walking and cycling, combined with other land use and urban form strategies, can help reduce emissions and energy. More longitudinal research is needed to identify how robust this relationship is in other neighbourhood contexts.

For practitioners and decision-makers, the findings suggest that the promotion of active transportation should play an important role when developing comprehensive climate change policy. Investments in active transportation infrastructure can help meet our climate change goals by reducing automobile dependency and travel, and encouraging sustainable mode share shift.

For the City of Vancouver, the study's findings contribute to an evidence base that can help support the City's planning and public engagement efforts when engaging in road space reallocation. Previous protected bicycle lane projects such as the Burrard Bridge, Hornby and Dunsmuir Street, and the Point Grey Road/York Avenue generated divisive opposition among the city's residents and businesses. As one study notes:

> "Cycling is increasingly recognized as important for improving the environmental sustainability of urban development patterns and providing for a diversity of benefits. … Yet implementing new cycle lanes has been controversial, with new polarizing discourses about wars on cars and cyclists increasingly used to frame political debates. … On-street bicycle lane projects that involve the reallocation of existing road or sidewalk space to cyclists have the potential to be particularly polarizing."

Evaluating Vancouver's active transportation improvement projects will be an important step for the City in demonstrating to the public and stakeholders the societal benefits gained from investing in active transportation.

Section 6
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Appendices

Appendix A: Trip Diary Survey

Diary TAKE-ALONG SHEET **Day 1** **Start at Midnight on:** Assigned #1 Day of week: _____________ (Month/Date) _____________ PIN #: __________

INSTRUCTIONS: Think of **a trip** as **a recreational trip** with no destination (out for a walk, exercise, dog walk, etc.)
OR one-way travel to a destination for a trip purpose. See Examples at bottom of page.

Note: **Transferring between modes** is part of same trip.

Where did you start on DAY 1? CHECK ONE: ☐ HOME ☐ WORK ☐ OTHER Metro Vancouver location ☐ OUT OF TOWN or STAYED HOME ALL DAY → Leave DAY 1 blank, Turn over for DAY 2
RECORD START: (2 nearby cross streets) ___________________ and ____________________ & Municipality ________________

Where did you go first/next? END location: Write in HOME or WORK or 2 nearby cross streets & Municipality — DAY 1	**TRIP 1** I went to:	**TRIP 2** I went to:	**TRIP 3** I went to:	**TRIP 4** I went to:	**TRIP 5** I went to:
Location type code **1.** House/apt. **4.** School/daycare **8.** Indoor rec/gym **2.** Office building **5.** Hospital **9.** Airport/BC ferries **3.** Outdoor rec (park, beach, golf, etc.) **6.** Store/mall **10.** Other (describe) **7.** Restaurant/theatre	Location code:	Location code:	Location code:	Location code:	Location code:
Main trip purpose *(choose one)* **7.** Shopping **8.** Dining **1.** To walk/exercise **4.** School **9.** Pick up/drop off someone **2.** Work **5.** Recreational/social/entertainment **3.** Going HOME **6.** Personal business (bank, dentist, etc.)	Purpose:	Purpose:	Purpose:	Purpose:	Purpose:
Modes of travel *(List all in order taken)* **1.** Walked **5.** SkyTrain **8.** False Creek Ferry/Aqua Bus **2.** Auto-driver **6.** SeaBus **9.** Bicycle **3.** Auto-passenger **7.** School bus **10.** Taxi **4.** Transit bus/Community shuttle **11.** Other (describe)	Travelled by:	Travelled by:	Travelled by:	Travelled by:	Travelled by:
Start time (RECORD TIME within 5 min.)	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM
Arrival time (RECORD TIME within 5 min.)	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM	_____ AM _____ PM
No. of People: **# In your trip party** *including yourself*: **# Others you spoke to on the street** *(not in trip party)*: **Who you spoke with:** *(List all that apply)* **1.** No one **2.** My party **3.** Co-worker **4.** Neighbour **5.** Vendor **6.** Friend/acquaintance **7.** Driver personnel **8.** Stranger **9.** Other	# in party: ____ # others spoke to: ____ Who you spoke with:	# in party: ____ # others spoke to: ____ Who you spoke with:	# in party: ____ # others spoke to: ___ Who you spoke with:	# in party: ____ # others spoke to: ____ Who you spoke with:	# in party: ____ # others spoke to: ____ Who you spoke with:
IF ORIGIN or DESTINATION is in Downtown Peninsula (west of Main Street), please record: **Downtown route you travelled along** *List Downtown streets, alleys, parks on your route in order taken.*	Route in order:	Route in order:	Route in order:	Route in order:	Route in order:
Did you make another trip today?	☐ NO Last trip of day ☐ YES Go to next column	☐ NO Last trip of day ☐ YES Go to next column	☐ NO Last trip of day ☐ YES Go to next column	☐ NO Last trip of day ☐ YES Go to next column	☐ NO Last trip of day ☐ YES Trip 6+ Print extra

Mustel Research Group: Email: DTRstudy@mustelgroup.com Tel: 604-677-1084 WHEN ALL TRIPS COMPLETED, **PLEASE ENTER ONLINE** www.downtownresidentstudy.com

Examples:		
TRIP #1: Home to school (dropping off child is one trip.)	TRIP #1: Home to coffee shop (stop on way to work is one trip)	TRIP #1: Home to home (walking for exercise only with no destination)
TRIP #2: School to shopping (shopping is another trip.)	TRIP #2: Coffee shop to work (continue to work is a separate trip)	**Transferring** between modes example: walk, bus, walk
	TRIP #3: Work to home (returning home is one trip.)	

Appendix B: Sample Calculations

Table 11. Sample calculations: distance travelled.

Trip Diary Day	Total Distance by Walk (km)	Total Distance by Bicycle (km)	Total Distance by Auto (km)	Total Distance by Bus (km)
1	2	0	5	0
2	0	4	0	5

Table 12. Sample calculations: average daily transportation emission and energy outcomes.

Motorized GHG Emissions (kg CO_2e)	Motorized Energy Consumption (MJ)	Physical Energy Expenditure Equivalent—Motorized (kcal)	Physical Energy Expenditure—Active (kcal)	Transport Energy Index (active kcal/ motorized kcal)
0.9	12.1	11,339.4	184.0	–1.79

Motorized GHG Emissions (kg CO_2e):

$$Day\ 1(Auto): 11.8\ \frac{L}{100\ km} \cdot \frac{5\ km}{1\ passenger} \cdot 2.3362\ \frac{kg\ CO_2e}{L} = 1.4\ kg\ CO_2e$$

$$Day\ 2(Bus): 5\ km \cdot 0.0904\ \frac{kg}{psg\text{-}km} = 0.5\ kg\ CO_2e$$

$$\frac{(1.4\ kg\ CO_2e + 0.4\ kg\ CO_2e)}{2} = 0.9\ kg\ CO_2e\ daily$$

Motorized Energy Consumption (MJ):

$$Day\ 1(Auto): 11.8\ \frac{L}{100\ km} \cdot \frac{5\ km}{1\ passenger} \cdot 37.7214\ \frac{MJ}{L} = 20.5\ MJ$$

$$Day\ 2(Bus): 5\ km \cdot 0.7460\ \frac{MJ}{psg\text{-}km} = 3.7\ MJ$$

$$\left(\frac{20.5\ MJ + 3.7\ MJ}{2}\right) = 12.1\ MJ\ daily$$

Physical Energy Expenditure Equivalent—Motorized (kcal):

$$Day\ 1(Auto)\text{: } 1.4\ kg\ CO_2e \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ lb}{453.539237\ g} \cdot \frac{1\ gal}{19.564\ lb} \cdot \frac{31{,}250\ kcal}{1\ gal} \cdot \frac{3.5219}{1} = 17{,}072.3\ kcal$$

$$Day\ 2(Bus)\text{: } 0.5\ kg\ CO_2e \cdot \frac{1000\ g}{1\ kg} \cdot \frac{1\ lb}{453.539237\ g} \cdot \frac{1\ gal}{19.564\ lb} \cdot \frac{31{,}250\ kcal}{1\ gal} \cdot \frac{3.5219}{1} = 5{,}606.51\ kcal$$

$$\left(\frac{17{,}072.3\ kcal + 5{,}606.5\ kcal}{2}\right) = 11{,}339.4\ kcal\ daily$$

Physical Energy Expenditure—Active (kcal):

$$Day\ 1(Walk)\text{: } 0.35\ kcal\ \frac{lb}{mi} \cdot 160\ lb \cdot 2\ km \cdot \frac{0.6214\ mi}{1\ km} = 69.6\ kcal$$

$$Day\ 2(\text{Bi}cycle)\text{: } 0.75\ kcal\ \frac{lb}{mi} \cdot 160\ lb \cdot 4\ km \cdot \frac{0.6214\ mi}{1\ km} = 298.3\ kcal$$

Transport Energy Index (active kcal/motorized kcal):

$$\ln\left(\frac{184.0\ kcal + 1}{11{,}339.4\ kcal + 1}\right) = \text{-}1.79$$

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