



# CYCLISTS' CONSIDERATION OF ENERGY EXPENDITURE AND AIR POLLUTION IN ROUTE PLANNING:

Planning and  
Policy Implications

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Cyclists' Consideration of Energy Expenditure and Air Pollution  
in Route Planning:

Planning and Policy Implications

by

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## Abstract

Despite the many positive benefits of cycling, and negative health risks of air pollution, very little is known about cyclists' consideration of air pollution when route planning. Even less is known about the role of energy expenditure in route planning.

An intercept survey of cyclists was conducted in the city of Vancouver in the summer of 2016. A total of 648 participants took part in the study. After data cleaning, there were 602 respondents remaining in the sample. Two ordinal logistic regression models were developed, one for cyclists' consideration of air pollution and the second for their consideration of energy expenditure in route planning.

The model with consideration of air pollution as the dependent variable had five independent variables. Cyclists who consider energy expenditure, walk frequently, cycle year-round, enjoy physical activity and who are older are more likely to consider air pollution when choosing a route.

The second model had consideration of energy expenditure as the dependent variable and four independent variables. Respondents who see bicycling as exercise, are comfortable on major streets, and enjoy physical activity are more likely to consider energy expenditure when route planning. Those with higher income levels were somewhat less likely to consider energy expenditure. The types of cyclists who are more likely to consider air pollution and energy expenditure when choosing a route can be roughly placed in two categories – 'health conscious' and 'committed' cyclists.

There are a number of potential implications of these findings. Future research should build on these findings and include energy expenditure and air pollution consideration in route planning studies. Public education can improve the public's awareness of air pollution, especially for those less likely to consider pollution in route planning, and provide better information on limiting pollution exposure when route planning. Planners can provide a variety of cycling infrastructure to accommodate a range of cycling types, and design bike routes in ways that limit pollution exposure.

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## Introduction

This is a good time to be a cyclist in North America, as cycling has been increasing, while cycling deaths have been dropping (Pucher, Buehler, and Seinen 2011). Canada is looking much more favourable for cycling than its southern neighbour, with Canada's share of cycling commuters almost double that of America (Pucher, Buehler, and Seinen 2011).

There are numerous health benefits to regular exercise, such as cycling, including increasing fitness levels and reducing risk for disease, and increased lifespan (Sharman, Cockcroft, and Coombes 2004; Oja et al. 2011).

Cyclists prefer different kinds of routes. Some top motivators to cycle are cycling routes away from traffic or separated from traffic. "Interaction with traffic" and "ease of cycling" are some of the most influential factors for likelihood to cycle (Winters et al. 2011). Regular cyclists prefer either off-street or separated cycle facilities (Winters and Teschke 2010). Cyclists place a higher value on designated bike facilities, followed by streets with no parking, and then bike trails located off road (Tilahun, Levinson, and Krizek 2007). Interestingly, one study found cyclists who are very comfortable in mixed traffic have little preference for cycling infrastructure type, with the exception of bike paths mixed with pedestrians, which is less desirable (Hunt and Abraham 2007). Bike lanes are more appreciated by cyclists with less experience and by those who do not cycle (Fraser and Lock 2011).

Cyclists consider a variety of factors when choosing which route to take including the bike facility type, vehicle speed limits, route interruptions (e.g. stop signs), traffic calming and parking (Sener, Eluru, and Bhat 2009; Winters and Teschke 2010; Tilahun, Levinson, and Krizek 2007). Also, the type of trip (commute, recreation, etc) has an impact on route preference (Broach, Dill, and Gliebe 2012). One study finds that the most important factors for route choice are travel time and traffic volume (Sener, Eluru, and Bhat 2009).

Two elements of route choice that receive little focus in the academic literature are energy expenditure and air pollution consideration when choosing a route. The objectives of this study were to investigate whether cyclists consider air pollution and energy expenditure when selecting cycling routes, and to determine which, if any, cyclist attributes are associated with those preferences, such as education levels, cyclist type and age.

## Context: Vancouver/Metro Vancouver

The City of Vancouver is one of Canada's largest cities, with a metropolitan population of 2.3 million people (Metro Vancouver 2016). Situated on Canada's west coast, Vancouver has a temperate climate (Government of Canada 2016). Residents are insulated from the summer heat and winter chill that many other regions in North America face. This may encourage Vancouverites to cycle, as heat, cold and snow are a hindrance to cycling (Motoaki and Daziano 2015).

Although Vancouver has an amenable climate for cycling, the city sees high levels of rain during the winter months, and a drop in cycling rates over those months (Government of Canada 2016; TransLink 2013). Rain is a deterrent to cycling, and inexperienced cyclists are 2.5 times more likely to avoid cycling in the rain compared with more experienced cyclists (Fraser and Lock 2011; Motoaki and Daziano 2015).

Vancouver is a hilly city, especially when travelling in a north-south direction. Cyclists generally avoid hills, either by finding another route, or taking a different mode (Fraser and Lock 2011).

Public policies have an impact on cycling rates especially the provision of cycling facilities (Pucher, Buehler, and Seinen 2011). Vancouver has invested in cycling infrastructure over the last 20 years, and now has a well-developed network of bike paths, neighbourhood bikeways, lanes and separated cycle tracks (Winters et al. 2011). Vancouver cycling strategy has focused on neighbourhood streets as bikeways, traffic calming and integration with transit (Pucher, Buehler, and Seinen 2011).

Vancouver has seen a rise in cycling mode share, from 3% in 2008 to 5% in 2014 (TransLink 2013; CH2MHILL and Mustel Group Market Research 2015). This helped Vancouver reach its 2020 transportation target six years early in 2014: half of all trips are via transit, cycling or walking. The final goal is two-thirds (66%) of all commute trips are made by sustainable transportation such as transit, cycling or walking by 2040 (Vancouver 2012).

In 2016, Vancouver launched a bike sharing service. Preliminary evidence indicates that bike share programs encourage cycling (Pucher, Buehler, and Seinen 2011).

## Background/Literature Review

### *Air Pollution in the Literature*

Cycling increases people's physical activity, and thus breathing rates (McNabola, Broderick, and Gill 2007). Cyclists can inhale more pollution than drivers as their increased breathing rate results in higher exposure, and although the health benefits outweigh the risks, minimizing and mitigating air pollution exposure is an important goal (Int Panis et al. 2010; Rojas-Rueda et al. 2012; Franklin, Brook, and Arden Pope 2015). This increased pollution exposure is in part because cycling often occurs near roadways, where air quality is typically degraded (Badland and Duncan 2009).

A literature review by Franklin et. al. (2015) finds that much of the literature connects air pollution to a host of heart diseases and mortality. These risks are increased with long term exposure to air pollution. This is especially prevalent for pollution that results from burning fossil fuels – largely from motor vehicles (Sharman, Cockcroft, and Coombes 2004). More recent research links air pollution with increased insulin resistance and a higher risk of developing diabetes (Franklin, Brook, and Arden Pope 2015). There are also connections between air pollution and cancer and respiratory illnesses (Sharman, Cockcroft, and Coombes 2004; Riediker et al. 2004). A literature review by the World Health Organization connects air pollution to an increased risk of death, respiratory symptoms, heart attacks, and lung cancer. Deaths connected to air pollution in Europe are as high as deaths from car accidents based on initial evidence (2005).

The evidence from the literature is that higher pollution exposure is connected to higher volumes of vehicles, and bicycle routes with a degree of separation from the roadway limit cyclists' pollution exposure (Schepers et al. 2015). Bike paths have lower levels of some pollutants compared to bike lanes, (MacNaughton et al. 2014; Bigazzi and Figliozzi 2015). Some studies recommend limiting exercise near high traffic volumes or exercising in parks (Franklin, Brook, and Arden Pope 2015; Sharman, Cockcroft, and Coombes 2004).

However, estimating the differences between routes can be difficult because of “poorly quantified traffic-exposure relationships” (Bigazzi and Figliozzi 2015, 14 – 18). As well, studies on exposure or inhalation of particulate matter in urban areas can vary, and often cannot be generalized (Do Vale, Vasconcelos, and Duarte 2015).

Even though there is a degree of uncertainty in measuring pollution levels between route types, the negative health impacts of air pollution are well established (Franklin, Brook, and Arden Pope 2015; Pope III and Dockery 2006). Although there is need for more research into air pollution and health, the evidence is strong enough to warrant reduction in air pollution exposure (World Health Organization 2005). The public has a general sense of these impacts (Day 2006; Bianco et al. 2008).

Earlier studies find that pollution is not a direct consideration when choosing a route. Yet, some of the other considerations such as traffic volume along the route and separation from the roadways are important considerations, and are tied into pollution (Stinson and Bhat 2003). A newer study finds cyclists may potentially weigh pollution exposure when choosing a route, but this may just be a preference for facility type, shorter travel time or traffic avoidance (Bigazzi, Broach, and Dill 2016). This

preference for avoiding traffic is found in other studies (Broach, Dill, and Gliebe 2012; Sener, Eluru, and Bhat 2009).

There is still a gap in the literature regarding cycling, air pollution and physical activity (Schepers et al. 2015) and perceptions of air pollution near roadways and the association with travel patterns (Badland and Duncan 2009). There is also little in the research connecting pollution and route choice (Bigazzi, Broach, and Dill 2016).

### *Energy Expenditure in the literature*

A review of the literature finds little related to energy expenditure and route choice. There are some elements of route choice preference such as time factors that are related to energy expenditure (Stinson and Bhat 2003). Wind is related to the amount of energy used, but there is little known about the impact of wind on cycling (Heinen, van Wee, and Maat 2010; Parkin, Ryley, and Jones 2007). There is also some connection between preference for the type of terrain on a cycle route, such as hills, which would require more physical exertion (Stinson and Bhat 2003).

Several studies have found that cyclists avoid hills (Winters et al. 2010; Heinen, van Wee, and Maat 2010). There is some variability to these results. Sener et al (2009) found both commuting and recreational cyclists have a preference for moderate hills compared to flat terrain. Steep hills are less preferred. In general commuting cyclists prefer moderate hills over steep terrain. Males have more of a preference than females for steep hills, either as commuting or non-commuting cyclists. Another study finds that steep inclines have a negative impact on cycling (Fraser and Lock 2011). These results show that steep slopes result in cyclists choosing another route or forgoing cycling altogether. This is more pronounced for less experienced cyclists, as they are 3 times more likely to be deterred by the presence of a steep slope.

Since there is almost no research in the field examining energy expenditure and route choice directly, this study will add a missing piece to the literature.

### *Cyclist Typology*

In 2006, a transportation planner with the City of Portland developed a cyclist typology. Cyclists were divided into four categories: 'no way, no how,' 'interested but concerned,' 'confident and enthused,' and 'strong and fearless.' The author of the typology, Roger Geller, hypothesized that most of the population would be in the 'no way, no how' and 'interested but concerned' categories, with much smaller numbers in the 'confident and enthused' and 'strong and fearless' categories. The initial research he did more or less confirmed his hypothesis (Geller 2006).

Geller's typology became widely accepted in the following years. Cities adopted Geller's typology, or modified it slightly, as a way to categorize their own cyclists (Dill and McNeil 2013). At the same time, a number of different cyclist typologies were developed in the literature (Damant-Sirois, Grimsrud, and El-Geneidy 2014; Dill and McNeil 2013). Winters et al (2011) identified four kinds of cyclists – potential, occasional, frequent and regular. These were divided by cycling frequency with potential cyclists stating they had a bike and would be willing to cycle.

In 2013 two researchers, Jennifer Dill and Nathan McNeil, conducted a telephone survey in the Portland area to test how well the Geller typology performed. The two authors gave detailed descriptions on how they divided respondents into each of the types. The four types were broken down into sub-categories of 'utilitarian,' 'recreational,' and 'non-cyclists.' Their finding was that Geller's original typology held up quite well. Further research opportunities includes isolating actual cycling behaviour from comfort levels and interest in cycling or developing a new typology (Dill and McNeil 2013).

Geller's typology, as well as Dill and McNeil's re-evaluation has received critiques over the years. One review of Dill and McNeil noted that some of the cycling types cycled *more* than the 'strong and fearless' group during the typical winter months, and a higher percentage of the 'strong and fearless' types were classified as 'non-cyclists' compared to the 'confident and enthused' or 'interested and concerned' (Damant-Sirois, Grimsrud, and El-Geneidy 2014).

### *Related Public Policy*

Policies and programs play an important role in increasing the cycling share in European cities, especially compared to North America (Pucher and Buehler 2008a). Europe provides a number of examples for policies that encourage cycling: intersection modifications, bike parking, integration with transit, training and education, promotional events, as well as complimentary policies – taxation, parking and land use (Pucher and Buehler 2008a; Pucher and Buehler 2008b).

Two prominent policies to increase the cycling mode share are traffic calming measures and separate cycling facilities (Pucher and Buehler 2008a). Time is important for cyclists. Planning direct cycling routes that are as free-flowing as possible makes cycling more attractive (Rietveld and Daniel 2004).

There is no one 'silver bullet' to increase cycling rates. The key is following a multi-faceted approach (Pucher and Buehler 2008a). Model forecasting predicts that a suite of policies including improved cycling facilities, intersection improvement and land use planning will help cycling share rise in the future. However, without these improved policies and planning measures, cycling will likely decline (Wardman, Tight, and Page 2007).

Environmental interventions help encourage cycling across the wider population – although the rate is low, this translates into a broad impact across a large population, possibly more than individual or group interventions that have better success rates, but across a much smaller population. Environmental interventions include new infrastructure, policies, investment in cycling infrastructure (traffic calming, cycle lanes), financial incentives, and bike share. Individual or group interventions include education, giveaways, support, and employee programs (Stewart, Anokye, and Pokhrel 2015).

Much of the variation in cycling rates between cities is due to the geography, topography, and population composition. Public policies with the most impact are cycling convenience along the route, safety, and preference in relation to vehicles (Rietveld and Daniel 2004).

Municipal policies do matter for mode choice decisions over short distances (Rietveld and Daniel 2004). The City of Vancouver's Greenest City targets include using land use planning to support transportation (City of Vancouver 2015).

## *Hypotheses*

As there is not much research around air pollution and energy expenditure in route planning, there is limited material to draw on to create hypotheses. However, there are some elements from the literature, and some general ideas that can be used.

Those with higher education levels will be more likely to consider pollution. Some sources in the literature show a link between higher education levels and recognizing the negative health impacts of pollution or lower risk of pollution deaths (Pope III and Dockery 2006; Badland and Duncan 2009).

Cyclist typology will be connected to consideration of air pollution. Different riders prefer different route types, with many riders preferring routes away from traffic, which normally have less pollution exposure (Badland and Duncan 2009; Hunt and Abraham 2007; Bigazzi, Broach, and Dill 2016; Stinson and Bhat 2003). Less confident riders may thus have less exposure to vehicles, exhaust and pollution and so be less likely to consider air pollution in route planning. More confident riders will be more likely to consider pollution.

Consideration of energy expenditure will be linked to interest in physical activity. Physical activity and energy expenditure are connected. The more active you are, the more energy you use. The reverse is also true - the less active you are, the less energy you use. The direction of this connection is uncertain. Cyclists who have more interest in activity may be more likely to consider energy expenditure, or the reverse may be true.

Gender will be related to consideration of energy expenditure. There are some gender differences in route preference with hills, with males having more of a preference for some hill types (Sener, Eluru, and Bhat 2009). This may translate in differences in consideration of energy expenditure, as hilly routes may require more energy. There is some evidence males have a greater preference for physical activity than females (Bhat and Lockwood 2004).

In summary, it is hypothesized that education and cyclist typology will be significant independent variables for consideration of air pollution in route planning. Gender and elements related to physical activity will be significant independent variables for consideration of energy expenditure.

## Methods

### *Survey Design*

This study was done in conjunction with Dr. Alex Bigazzi, a cross-listed Civil Engineering and Planning professor at the University of British Columbia, and Simone Tengattini, a master's student in Civil Engineering at the University of British Columbia. Dr. Bigazzi and Mr. Tengattini designed a study that allows them to estimate an energy expenditure model of urban cyclists. This author designed the accompanying survey instrument (stated preference) that forms the basis for this study.

A review of the literature was conducted to determine which questions might be most appropriate to include. The questions were designed to be as simple to answer as possible.

Several questions were used to determine the cyclist typology that best fit respondents. The original typology developed by Roger Geller (2006) and then re-tested by Dill and McNeil (2013) was the main basis. Initially, elements of the Damant-Sirois, Grimsrud, and El-Geneidy typology were incorporated (2014). However, a number of questions were required to replicate their typology, and could not be included due to space limitations in the survey instrument. Including key questions from the Dill & McNeil typology was simpler, and ultimately, the Geller original typology is still widely regarded and used (Dill and McNeil 2013). Additional elements for the typology were drawn from an earlier Vancouver study that adopted elements of the Geller typology (CH2MHILL and Mustel Group Market Research 2015).

Other typologies were also examined including Gatersleben and Haddad (2010) with other elements including consideration of weather drawn from the typology developed by Damant-Sirois, Grimsrud, and El-Geneidy (2014).

The survey was three pages long and included questions on trip purpose, travel mode, cycling frequency, comfort in various cycling environments, speed, and demographic questions. Several questions on air pollution, energy expenditure, and physical activity were also included. The questions were either fill-in-the-blank ("What is your age"), or check a box for a scale or range such as Likert. Almost all the data collected was quantitative. See Appendix A for a copy of the survey instrument.

Demographic questions were included based on elements included in other cycling studies found in the literature. To enable easier comparison, questions were molded as close as possible to Statistic Canada's Census. However, cycling statistics are not that robust, as only work trip data are available from Statistics Canada. The Census does not break down cycling into demographic details such as age, income or vehicle ownership (Pucher, Buehler, and Seinen 2011). For a local context, the demographic questions from the 2014 Transportation Panel Survey (2015) were consulted, as well as the Pedestrian and Bicycling Survey (Krizek, Forsyth, and Agrawal 2010).

The survey was tested prior to deployment. The survey was sent around to friends and colleagues, both those with a background in statistics and transportation, and others with little to no such background. Based on comments received, some scales were adjusted, wording was changed, and question ordering was revised all to improve readability and simplicity and strengthen the quality of data received. The survey instrument was approved by the University of British Columbia's Research Ethics Board prior to data collection.

### *Data Collection*

Once the survey instrument was complete, two pilot data collection days were completed on the University of British Columbia campus. On the first day of piloting, 12 respondents completed the survey, while 18 completed the second day of piloting. A few minor adjustments were made after the piloting phase. Since there were no significant changes needed after the pilot tests, this initial data was included with the rest of the study.

The study included three parts. One was the paper questionnaire and consent form. A second piece was a series of measurements and observations of the cyclist and their bicycle. The final section was a coast down test performed by the cyclist, which measured friction and rolling resistance.

The coast down test portion was the most restrictive when choosing test locations. The sensors used for this part were placed 10 metres apart, and the whole test area was about 130 metres long. Locations were chosen that were long enough to accommodate this setup, and relatively straight and flat. In order to maximize safety and minimize any interactions, especially with traffic, sites were chosen that were physically separated from the roadway, or on bicycle paths.

Data was collected in July and August of 2016 on sixteen different days across eight sites. All sites were visited twice except for one, and one high volume site was used three times. Time of day of the data collection was varied to capture a variety of cyclists. All of the sites were within the city of Vancouver. Several locations in neighbouring municipalities were planned, but not realized because of weather and logistical issues.

Signs describing the study were placed around the study location. Cyclists were asked if they wanted to take part as they approached. Total time to complete the study was ten to fifteen minutes. Cyclists were given snack bars, juice boxes and bells for taking part. A number of cyclists came up to the team without being asked, especially if there was a small crowd already. Over 600 respondents took part in the study ( $n = 648$ ).

### *Data Preparation*

Respondents filled out paper surveys in the field. Results were coded, and manually entered into Microsoft Excel 2013. The data were examined for skipped or missing questions and any obvious errors were corrected. Respondents who skipped questions related to the dependent variables – either the air pollution or energy expenditure question – were removed. Surveys that were missing key questions needed to construct the cyclist typology were removed. Respondents who left whole sections blank were also taken out. The total number of responses initially was 648. After data cleaning this dropped to 602. These responses were uploaded into SPSS.

### *Typology Classification*

Cyclists were divided into four categories, by closely following the Geller typology expanded on by Dill & McNeil (2013).

Those who were 'very comfortable' on arterial/main roads with no bike facilities were categorized as 'strong and fearless.' Those who had an average of 3.25 on two questions dealing with comfort on main roads with bike infrastructure were categorized as 'enthused and confident.' Some cyclists put their responses in between two answers, such as midway between "comfortable" and "very comfortable." When averaged with other responses, this resulted in answers such as 3.25. Respondents who were uncomfortable on bike paths were listed as 'no way, no how.'

At this point, some cyclists did not fit into a category. They were not 'very comfortable' on major roads, with or without lanes, nor 'very uncomfortable' on bike lanes. Interest in cycling was used to further classify responses. Those who agreed with the statement 'I would like to travel by bicycle more than I do now' were listed as 'interested but concerned.' Cyclists who disagreed with the statement were listed as "no way, no how". However, some of these had cycled for transportation in the past 30 days (including the trip they were on for the study) and were re-classified as 'interested but concerned'. The meaning of "transportation" was adopted from Dill and McNeil to mean cycling for work, school or shopping (Dill and McNeil 2013).

This left some respondents without a type. These cyclists picked the middle option ("neither agree nor disagree") for the question 'I would like to travel by bicycle more than I do now'. Dill and McNeil omitted this centre value, while our survey instrument included it. Those who picked this centre value were placed in the 'interested but concerned' category if they had cycled for transportation (work, school, or shopping) at least once in the past 30 days. This still left four respondents without a category. These were excluded from analysis as part of the initial data cleaning.

There was one interesting anomaly. One respondent put down "very comfortable" for major streets without bike lanes, but "very uncomfortable" on bike paths. This could have been an error on the cyclist's part. It could also be a legitimate answer. Some research finds that more experienced cyclists find time on shared pathways less desirable or more dangerous than on bike lanes on main roads (Hunt and Abraham 2007; Damant-Sirois, Grimsrud, and El-Geneidy 2014).

There are nine users classified as 'no way, no how.' This may seem strange, as all of the participants were on a cycle trip when recruited. Cyclists were put in this category because they either were very uncomfortable on bike paths removed from traffic, or were not interested in cycling more, and had not cycled for transportation (work, school, or shopping) in the past 30 days, including that trip. Within the sub-category described by Dill and McNeil, cyclists in the 'no way, no how' category would be classified as either 'recreational' or 'non-cyclists.' Since all of them were on some kind of cycle trip when intercepted for the study, all of the 'no way, no how' cyclists would be classified as 'recreational, no way no how' cyclists.

## Model Estimation

Data analysis was conducted using SPSS 23/24. Responses to air pollution (“I consider air pollution (air quality) when choosing a bicycle route”) and energy expenditure (“I consider energy expenditure (physical effort) when choosing a bicycle route”) statements were the dependent variables. Responses for the two dependent variables were on a five point Likert scale, from “strongly disagree” to “strongly agree.” Since these two dependent variables were ordinal, ordered logistic regression was used (called ordinal logit regression in SPSS). Separate ordinal logit regression models were estimated for each dependent variable.

Independent variables for the models were initially identified from the literature. Models were built in two ways. One approach was bottom up – adding variables one at a time. A top down approach was also used - putting all potential variables in one model and seeing which were significant. A second step was trying each variable individually to test significance, model fit, and r-squared. Independent variables from the most promising models were re-coded, along with the dependent variables, collapsing categories for better results. The central limit theorem was used as a guide, and variable levels were re-coded to include more than thirty observations if possible. Models were developed iteratively. New models were compared to older models. Variables were added and removed to the models throughout the process, and variables were often recoded several times for best results.

Most independent variables were analysed as ordinal variables. Models were also run analyzing variables as scale variables both individually and in a top down approach using all variables. Most variables gave better results as ordinal variables. Some variables were naturally scale (e.g. age) while others yielded better outcomes when analyzed as scale (e.g. income).

Models employing interaction effects were also examined. These models had greater explanatory power, but there were a number of warnings in the model for zero frequencies and singularities in the Fisher information matrix. Interaction effects were not included in the final models.

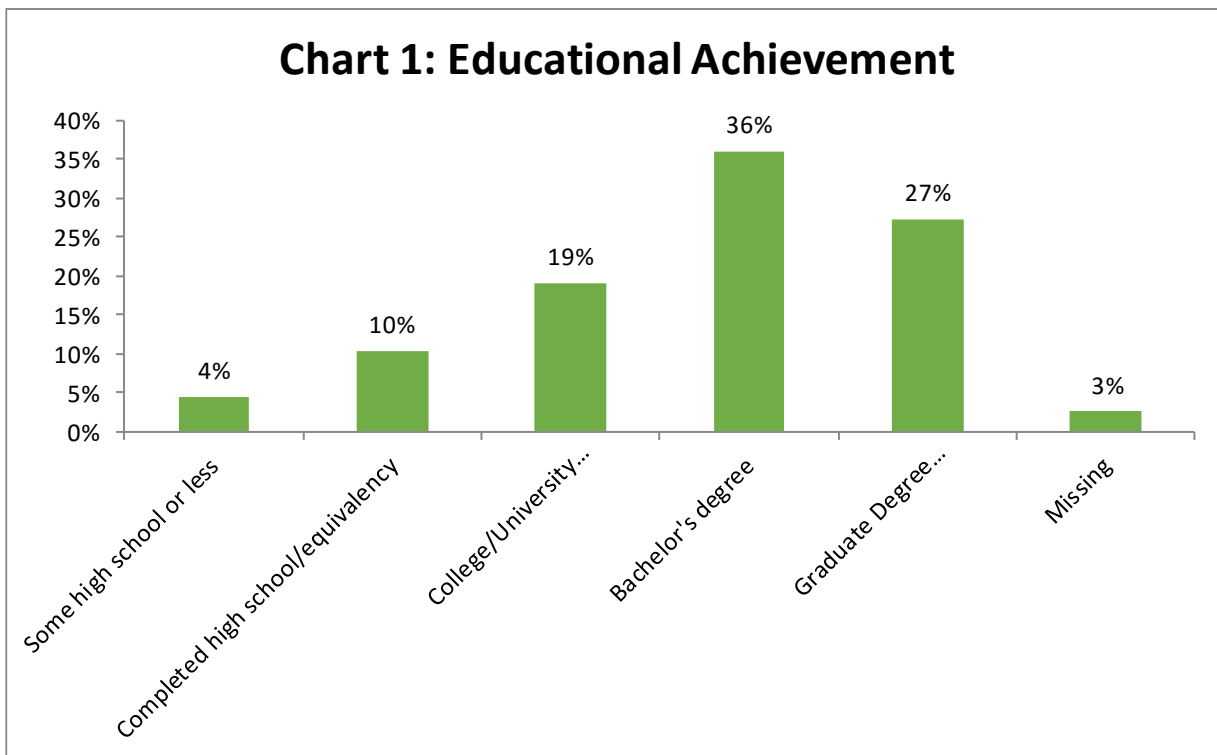
Final model variables were checked against the literature and descriptive statistics to ensure logical consistency.

## Results

### Descriptive Statistics

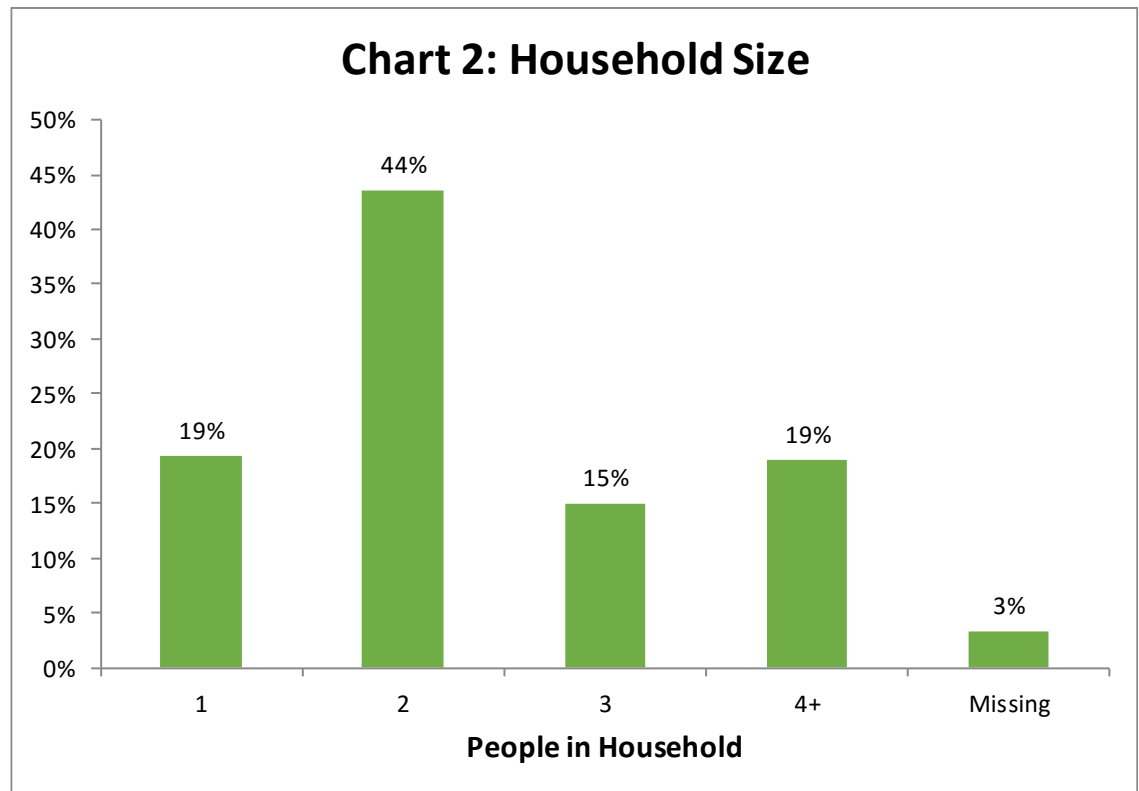
#### Education

Participants have high education levels. At least 82% of respondents have at least some college or university education. Many participants have at least a Bachelor's degree (36%), and almost one-third of the sample have a graduate degree (27%). See chart 1.

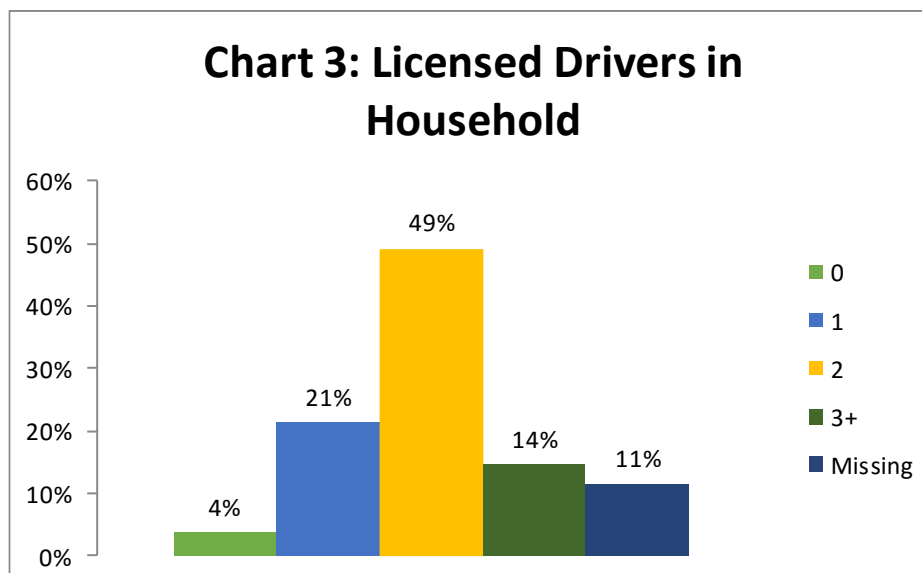


## Household Composition

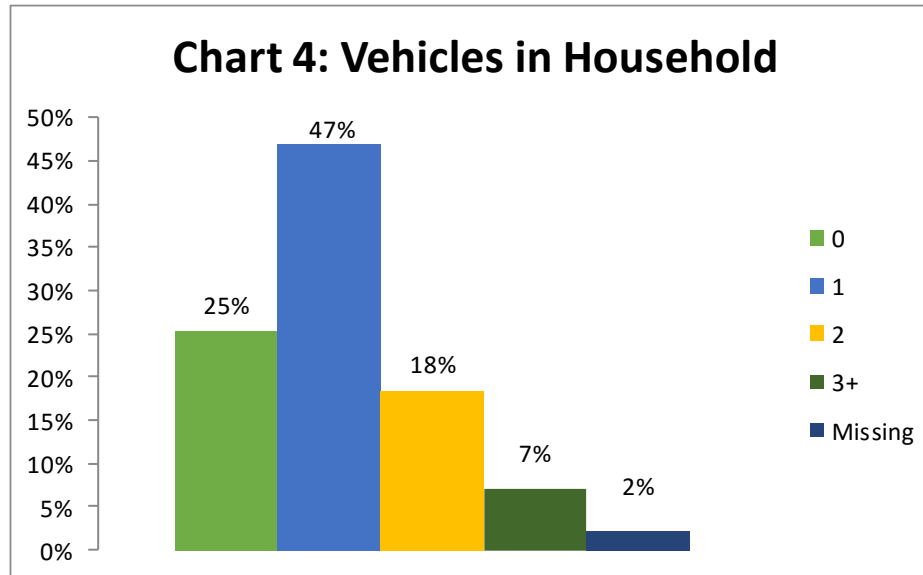
Most of the people surveyed come from a two-person household (44%). Three person households have the lowest representation with 15% of the sample. See chart 2.



Half of cyclists have two drivers in the household (49%). A small number of respondents have no licensed drivers (4%). See chart 3.

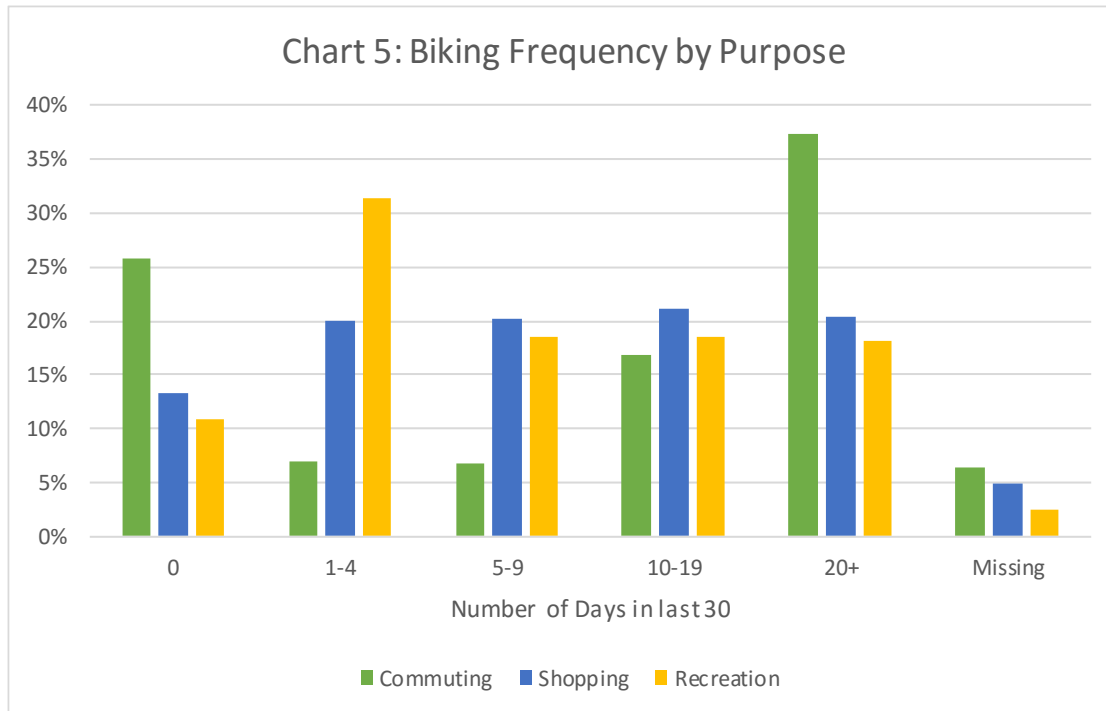


Most of the cyclists come from a household with one vehicle (47%). A quarter of respondents live in households with zero vehicles (25%). See chart 4.



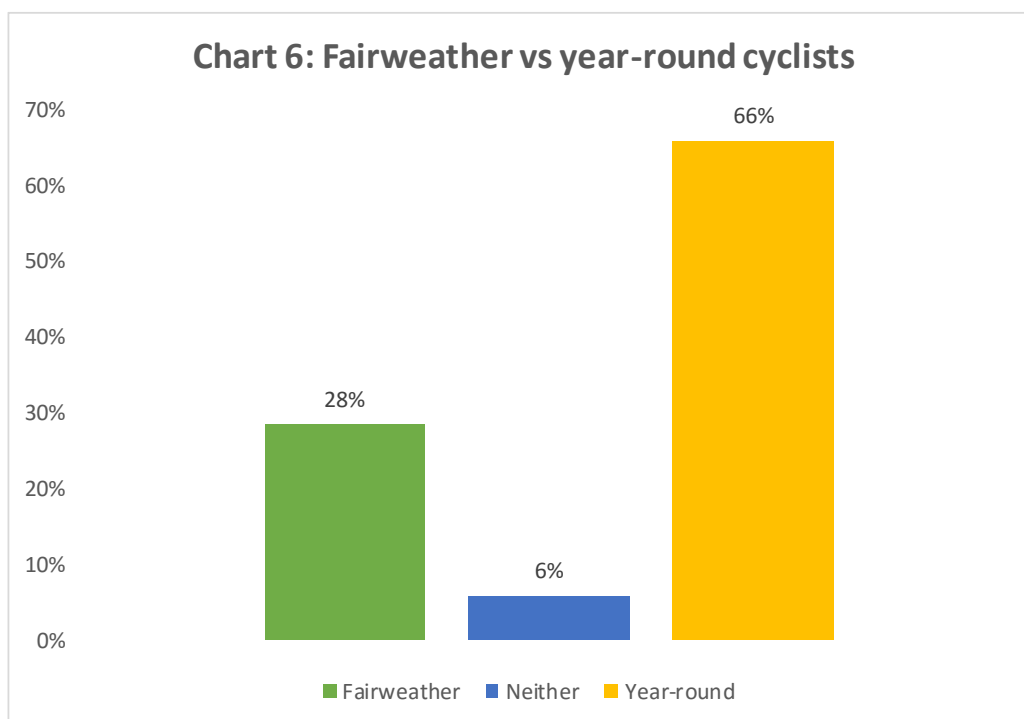
#### Biking Frequency and Type

One quarter of the cyclists have not cycled to commute in the last 30 days (26%). An equal number of cyclists commuted 1-4 and 5-9 days of the past 30 (7% for each). By far the largest contingent of respondents cycle to commute for 20 days or more in the last 30 (37%). Twenty per cent of participants cycle for shopping 1-4 days, 5-9 days, and 20 or more days out of the last 30. Only 13% of people did not cycle at all for shopping purposes. Recreational cycling sees the most number of people (31%) cycle 1-4 days out of the last 30 for recreation.



### Weather Preference

Most of the cyclists (66%) agree with the statement “I bicycle year round regardless of the weather” putting them in the “year round” cycling category. Another twenty-eight per cent of respondents disagree with the statement, and are categorized as “fairweather” cyclists.



## Commute Type by Frequency

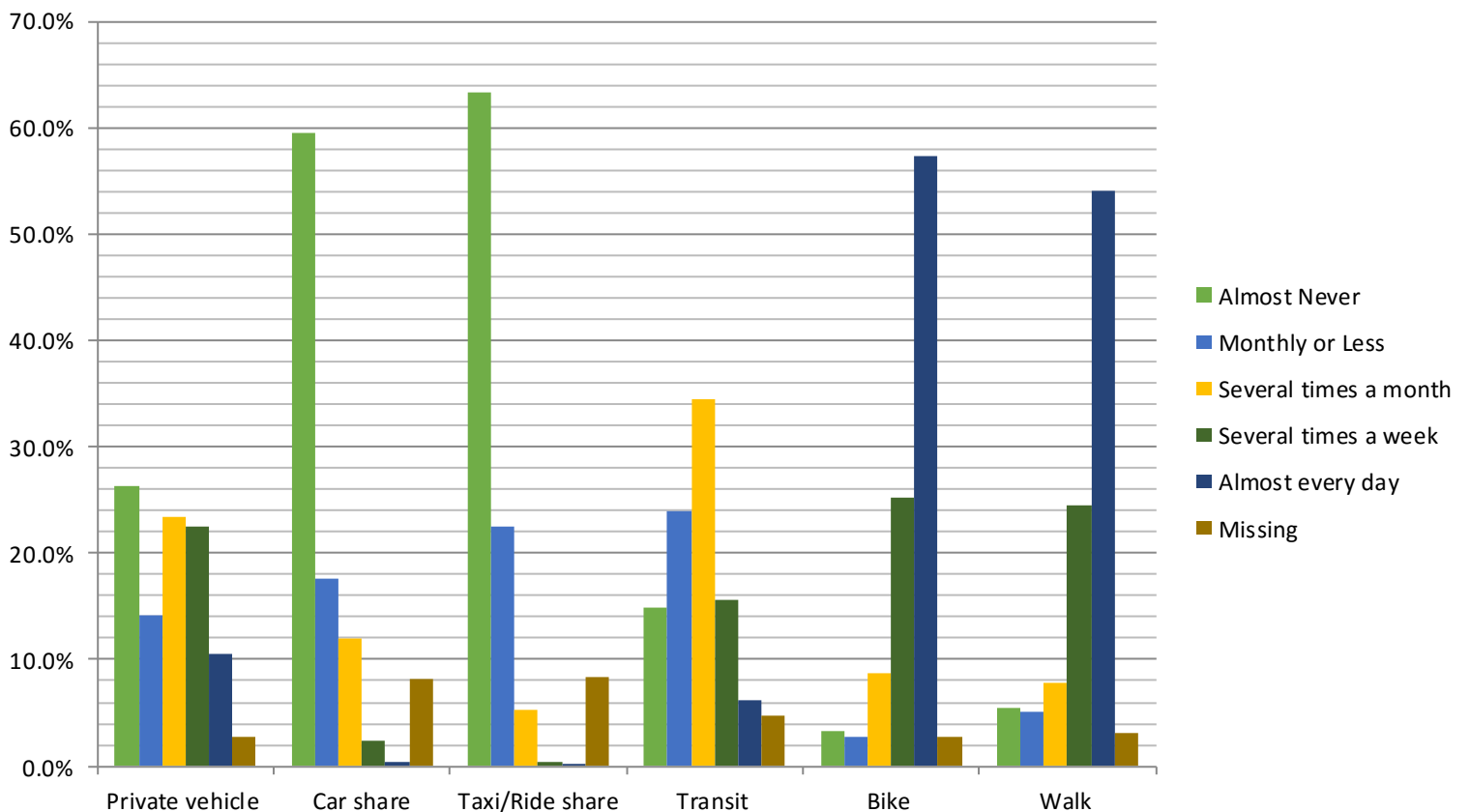
Shared rides are the least frequently used mode, with many users choosing ‘almost never’ for car share and taxi/ride share (60% and 63%, respectively). Similar numbers use shared rides ‘monthly or less’ (car share 18%, taxi/ride share 23%). Very few respondents use any kind of shared ride ‘several times a week’ or more.

Active modes of transportation, bike and walk, have the highest use frequency, 57% and 54%, respectively for ‘almost every day.’ Bike and walk also have the highest number of users take this mode ‘several times a week’ at 25% and 24% respectively. Very few users say “almost never” for these two modes (bike 3%, walk 6%).

Transit is lightly used by respondents. Most (34%) say they used transit ‘several times a month.’ Some (24%) used transit ‘monthly or less.’ Only a few respondents take transit ‘almost every day’ (6%).

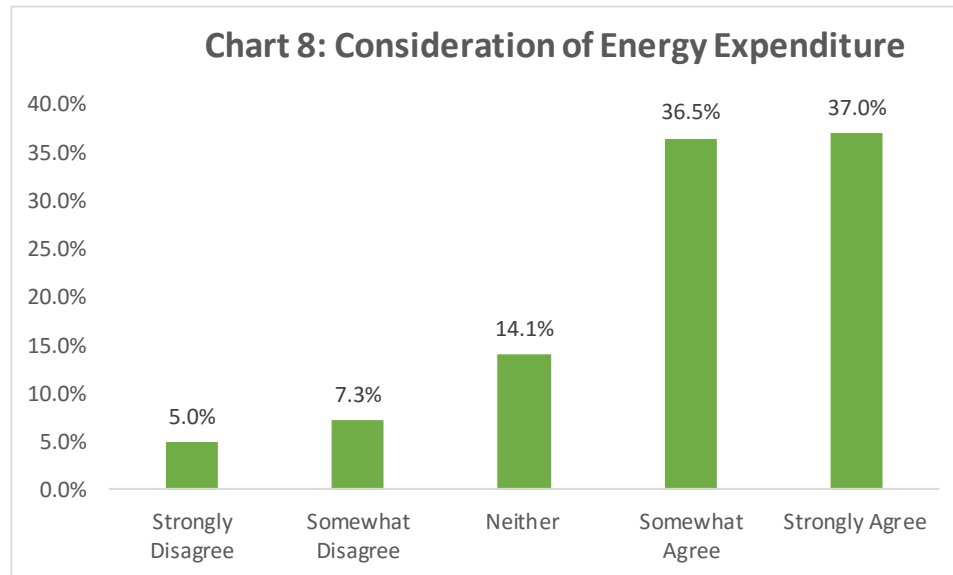
The frequency usage for private vehicles is much more balanced in comparison. The largest majority of cyclists use a private vehicle ‘almost never’ (26.2%), followed by ‘several times a month’ (23.4%). The lowest number of respondents use a private vehicle ‘almost every day’ (10.5%).

### Chart 7: Commute type by Frequency



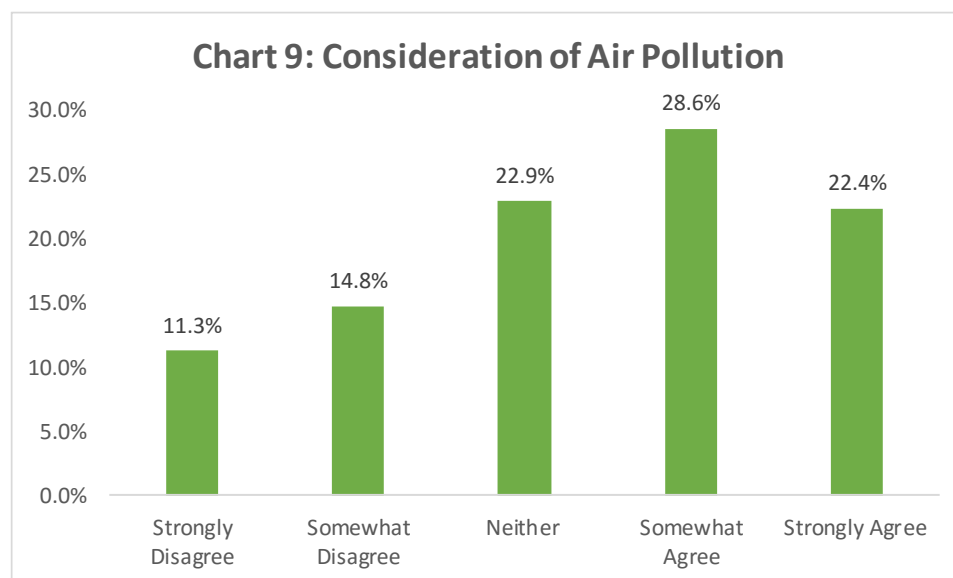
## Energy Expenditure Consideration

Few cyclists say they did not consider energy expenditure. Only 12.3% of cyclists disagree. Almost three-quarters of respondents say they considered energy expenditure when choosing a route (73.6%).



## Air Pollution Consideration

Only one-quarter of cyclists say they did not consider pollution (26.1%) when choosing a route, with slightly less than a quarter picking the neutral option (22.9%), and half of cyclists choose agree (51.0%).

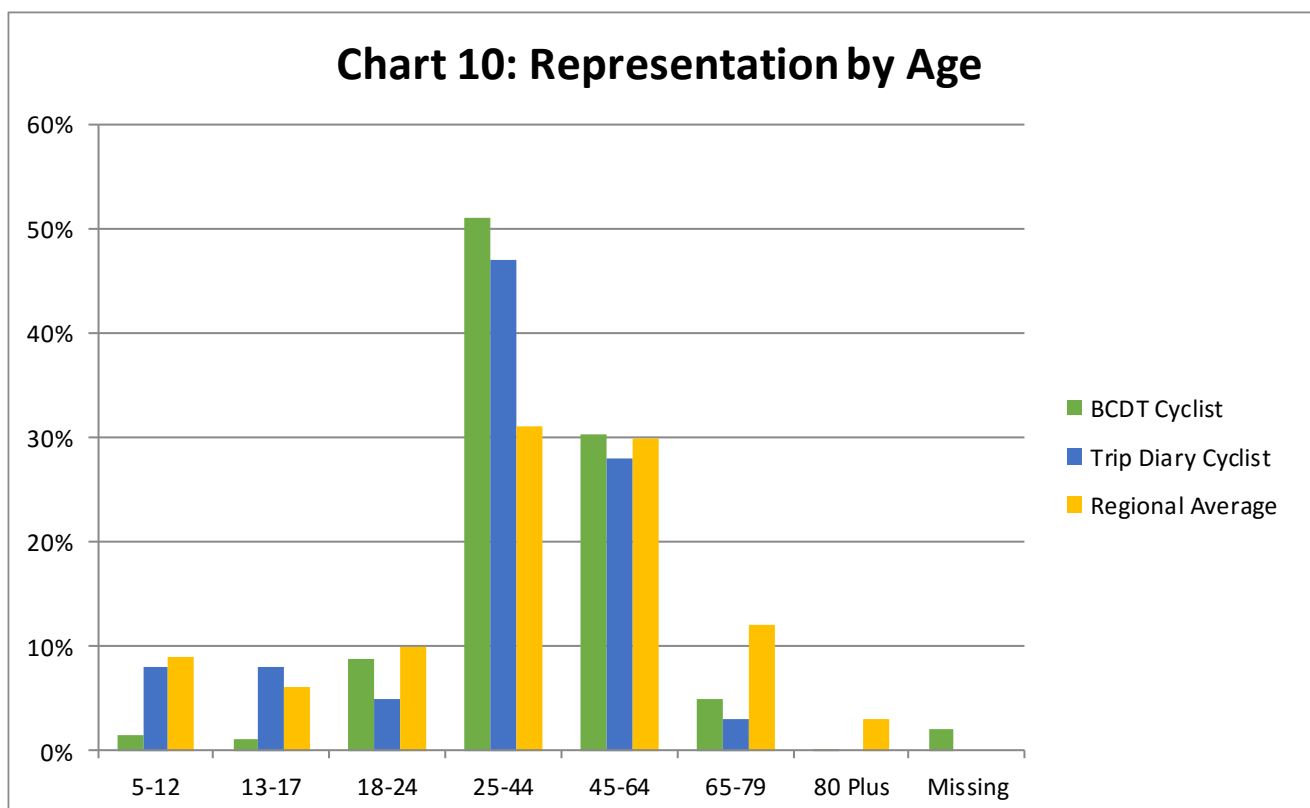


## Air Pollution versus Energy Expenditure Consideration

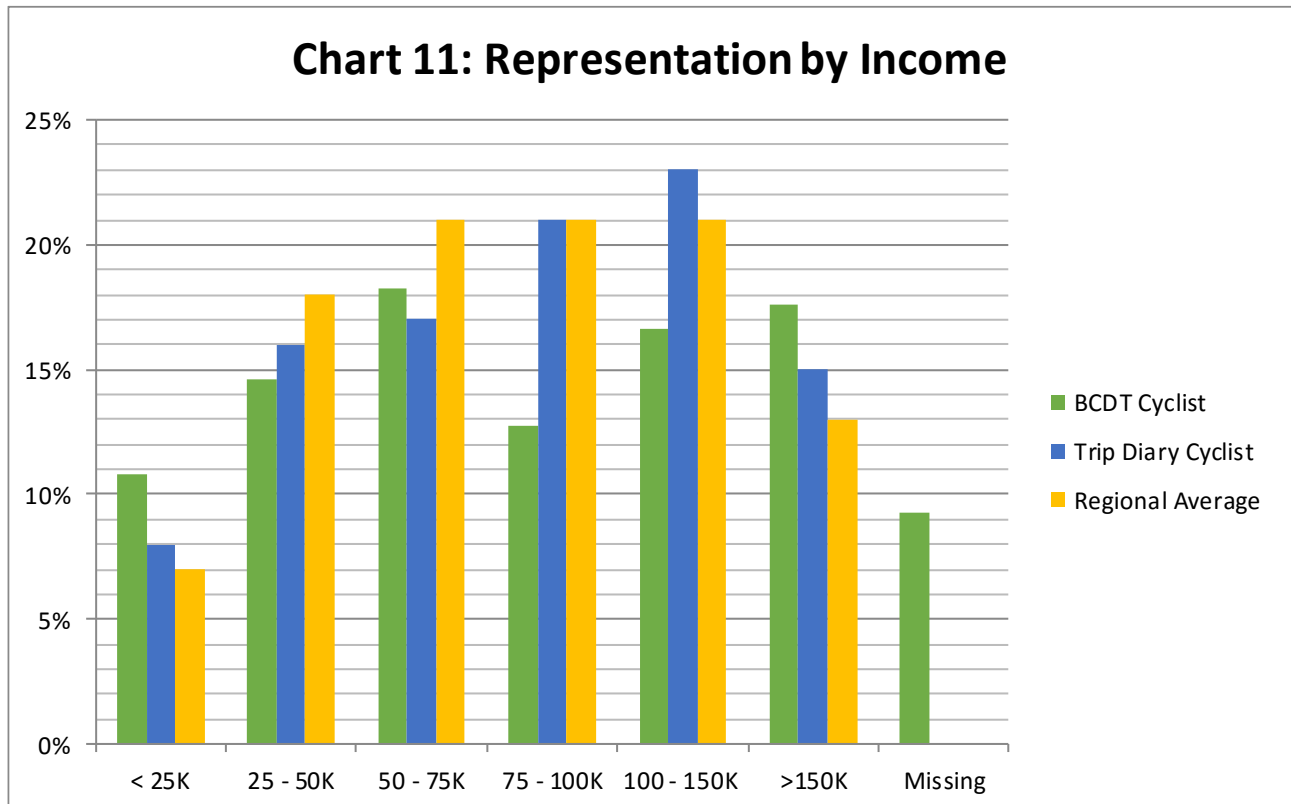
More cyclists say they consider energy expenditure (73.6%) than air pollution (51.0%). A higher percentage of cyclists disagree with the statement that they considered air pollution (26.1%) than those who disagree regarding energy expenditure (12.3%). More cyclists pick the neutral option for pollution (22.9%) than energy expenditure (14.1%).

## Representation Compared to Region

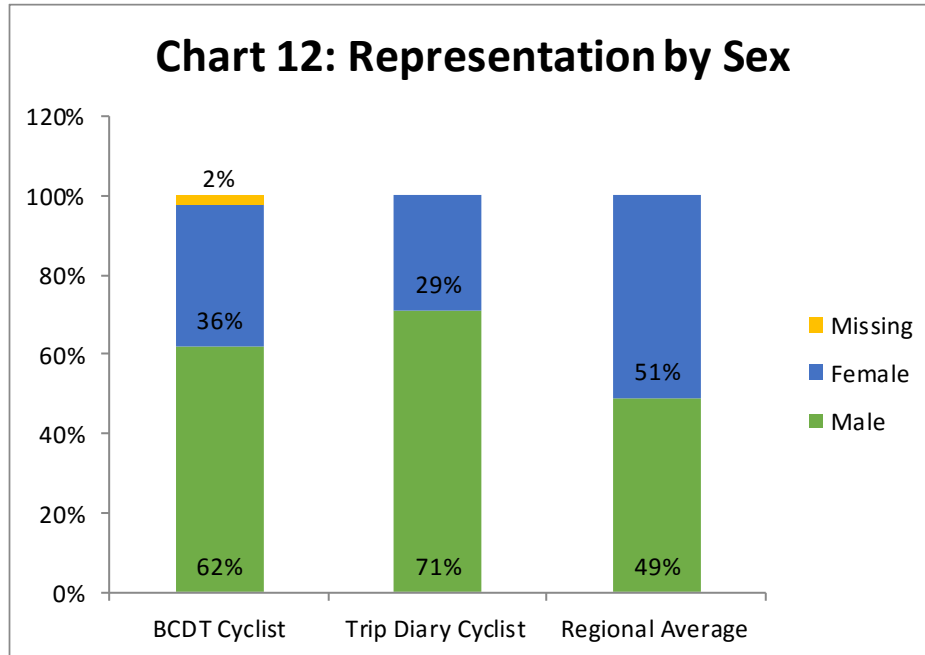
This study sample compares favourable well to cyclists from the 2011 regional trip diary and the regional average for Metropolitan Vancouver across age, income and sex. The regional average is drawn from custom made sub-regional population estimates from the regional trip diary, which are expanded from Census information (TransLink 2013). Comparing age, most of the age categories are close to the cyclists from the trip diary and the regional average. Children are under-represented. Only 1% of the sample is in either the 5 -12 or 13 -17 age group. The Trip Diary has 8% of the sample in each age range, while the regional average has 9% in the 5-12 group, and 6% in the 13 – 17 range. See chart 10.



The current study has comparable income numbers to the trip diary survey and regional average. The lowest income bracket (less than 25K) and the highest income bracket (more than 150K) are slightly overrepresented in our study. For this study, 11% of respondents are in the 'less than 25K' bracket, compared to 8% (Trip Diary) and 7% (regional average). In the highest income range ('more than 150K'), 18% of cyclists in this study are in that bracket, compared to the Trip Diary (15%) and the regional average (13%). The income question is the most frequently skipped by participants, with 9% of cyclists choosing not to answer. See chart 11.

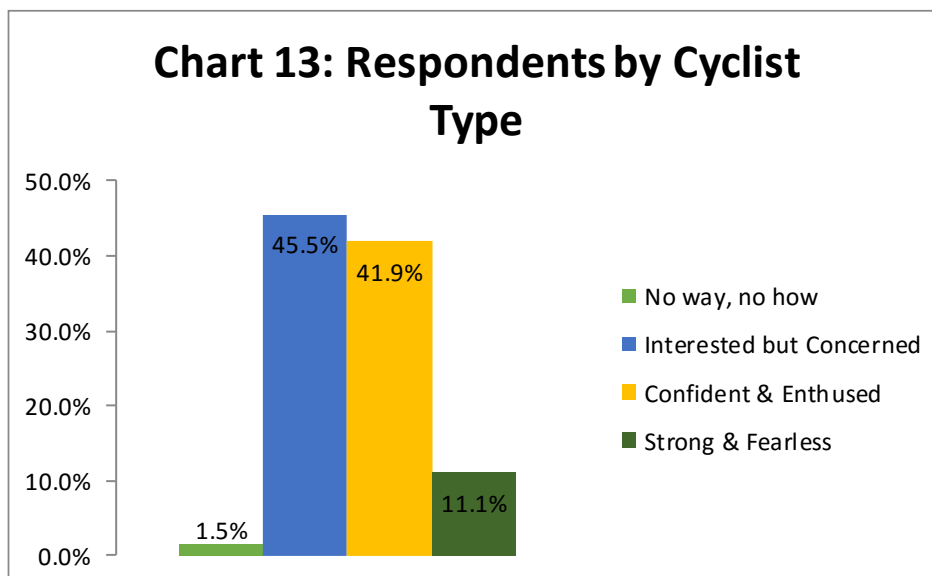


There is less representation by males in our survey (62% vs 71%) and better representation for females (36% vs 29%). Our survey results are closer to the 51% female and 49% male regional average, compared to the Trip Diary.

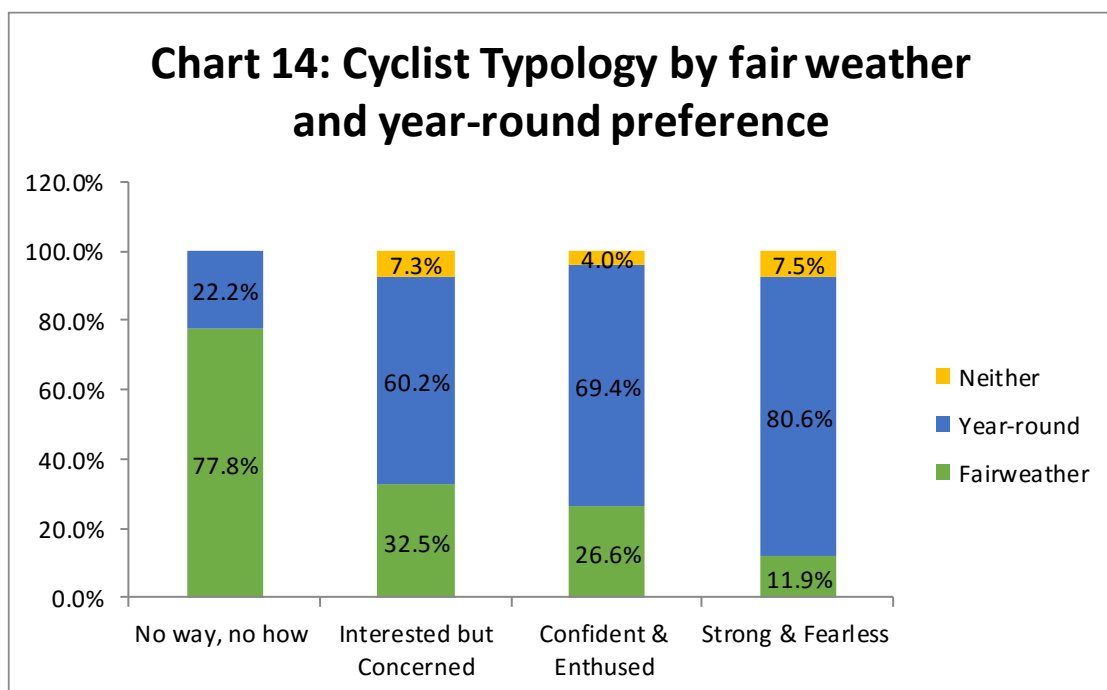


### Typology Results

Most cyclists are in the 'interested but concerned' category (46%), with 'confident & enthused' a close second (42%). "Strong & fearless" cyclists made a strong showing with 11% of respondents. Only 1% of cyclists are in the 'no way, no how' category.

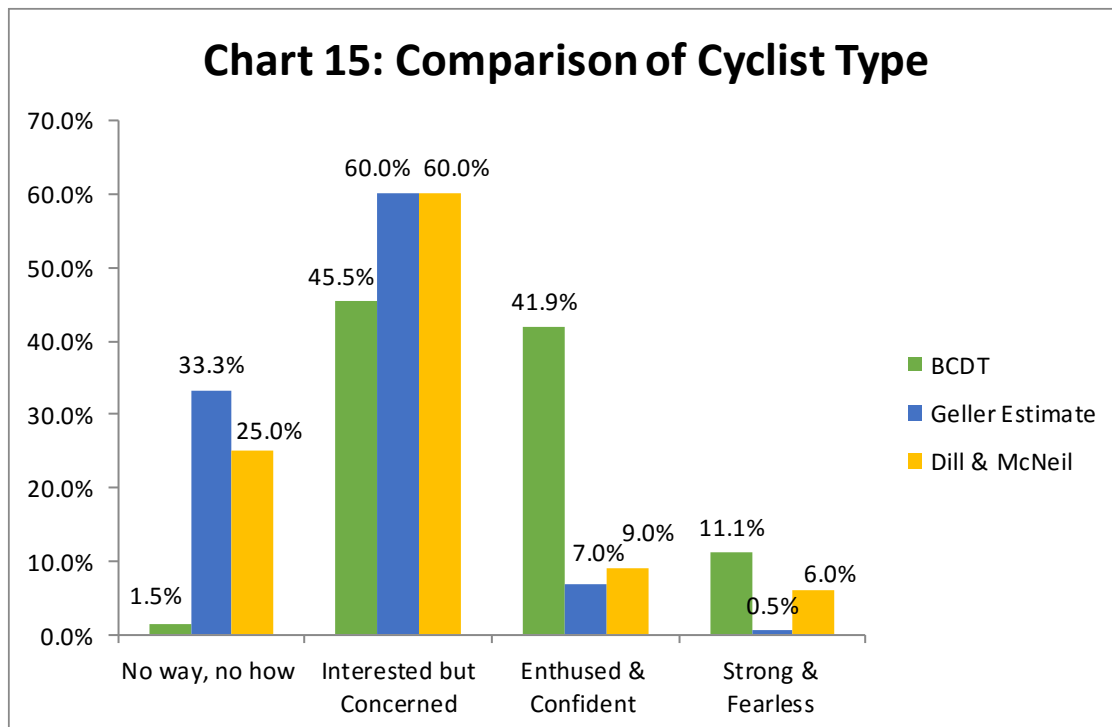


The distinction between fairweather and year-round cyclists follows a predictable pattern. 'Fairweather' cyclists decrease moving from the 'no way, no how' cyclists across to 'strong and fearless.' Most of the 'no way, no how' cyclists are fairweather (77.8%), with that number dropping across 'interested and concerned', 'enthused and confident' and 'strong and fearless' (32.5%, 26.6%, 11.9%, respectively). The inverse happens with the 'year-round' category. Only 22.2% of 'no way, no how' cyclists are year-round, while this increased for 'interested but concerned' (60.2%), 'enthused and confident' (69.4%) and 'strong and fearless' (80.6%).



### Comparison to other studies

These results vary from Geller and McNeil. The 'interested but concerned' category is fairly close (45.5% vs 60.0% for both Geller and Dill & McNeil). The 'no way, no how' category has much lower representation, while the 'enthused and confident' and 'strong and fearless' are generally over-represented in comparison. See chart 15.



This disparity is not surprising, as this study is looking at a different population than both Geller and Dill and McNeil. This study only includes people who were intercepted while on a current cycle trip. The breakdown is what percentage of these cyclists fall into each of the categories. Geller's original typology is based on a breakdown of the entire population of Portland, and is based on Geller's personal estimate. Dill and McNeil's classification numbers are from a phone survey of adults in the Portland area.

### Model Estimation Results

Two models were developed, one for pollution and one for energy expenditure. Although neither model had high predictive power, several clear relationships were found between the independent and dependent variables in each model.

The pollution model was more predictive of the two, with a pseudo  $r^2$  of .100 (Nagelkerke: also, Cox & Snell: .087). The energy expenditure model had a lower pseudo  $r^2$  of .069 (Nagelkerke: also, Cox & Snell: .062).

#### Pollution Model

Five independent variables were included in the final pollution model – energy expenditure, enjoy physical activity, cycling year-round, walking frequency, and age. The scale for several of the independent variables - enjoy physical activity, cycling year-round and energy expenditure was a five-point Likert scale. Respondents chose one response from strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, or strongly agree.

All the variables were put in the model as ordinal variables, except for age, which was a scale variable. All the independent variables were statistically significant with a confidence level of 95%. Three variables (energy expenditure, physical activity, age) were also significant at the 99% confidence level. See table 1, 2 and 3.

Table 1: Pollution Model

Statistical Significance of Model	0.001
Pseudo $R^2$	
Nagelkerke	0.100
Cox & Snell	0.087

Table.2: Pollution Model Ordinal Variable Summary

Variable	Responses	N	Marginal Percent
Air Pollution (dependent variable)	Disagree	150	26.3%
	Neutral	125	21.9%
	Agree	295	51.8%
Energy Expenditure	Neutral/Agree	499	87.5%
	Disagree (Reference)	71	12.5%
Walking Frequency	Several times week or more	466	81.8%
	Several times month or less (Reference)	104	18.2%
Cycle year-round	Agree	381	66.8%
	Disagree/Neutral (Reference)	189	33.2%
Enjoy Physical Activity	Agree	540	94.7%
	Disagree/Neutral (Reference)	30	5.3%
Valid		570	100.0%
Missing		32	
Total		602	

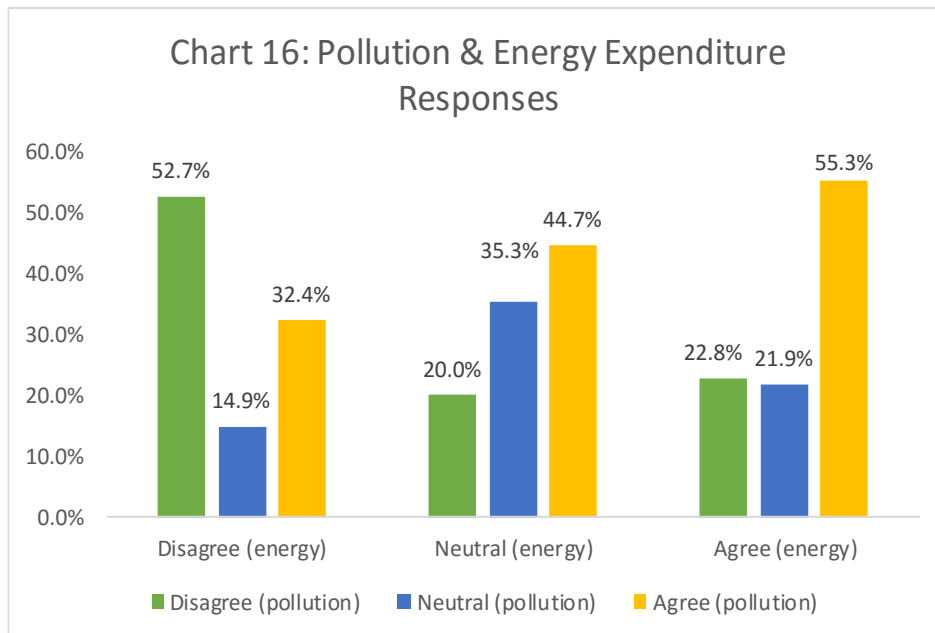
Table.3: Pollution Model Output

	Co-efficient	Odds Ratio	Standard Error	P-value
Energy Expenditure	0.785	2.190	0.250	0.002
Walking Frequency	0.511	1.660	0.207	0.014
Cycling year-round	0.389	1.475	0.173	0.024
Enjoy Physical Activity	1.361	3.900	0.389	0.001
Age (scale)	0.016	1.016	0.006	0.005

### Energy Expenditure

The reference level for this variable is set to those who picked disagree – either strongly or somewhat. Those who agreed or chose the neutral option with the statement “I consider energy expenditure (physical effort) when choosing a bicycle route” are 2.2 times more likely to consider air pollution, than those who disagreed.

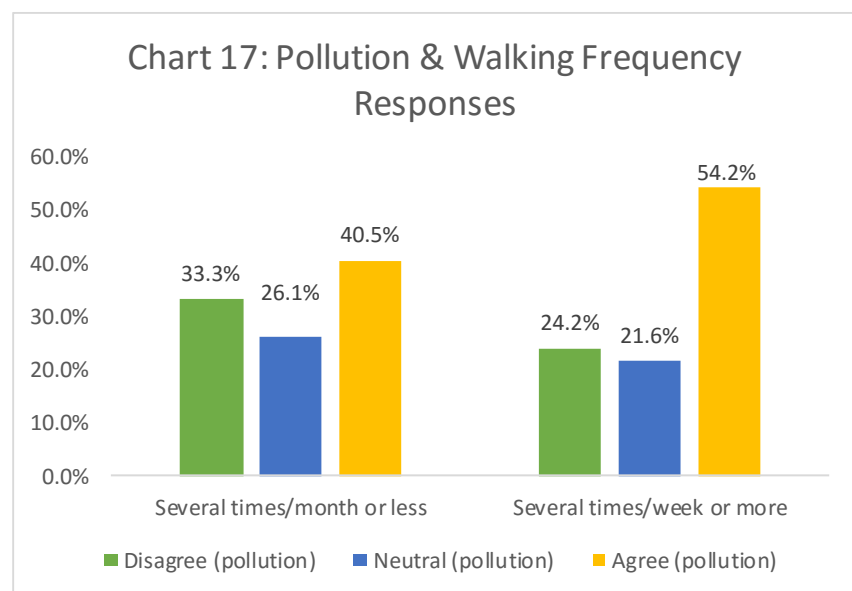
This can be seen in the descriptive statistics as well. Respondents who consider energy expenditure are more likely to also consider pollution (55.3%), compared to those who are neutral (21.9%) or disagree (22.8%) with the pollution question. The neutral energy expenditure category shows a clear preference to consider pollution (44.7%), compared to neutral (35.3%) and disagree (20.0%) options. Similarly, those who disagree with the energy expenditure question are more likely to also disagree with the pollution question (52.7%), compared to choosing neutral (14.9%) or agree (32.4%) for pollution. See chart 16.



### Walking Frequency

Cyclists were asked “how often do you use the following modes for personal travel around Vancouver.” This included commuting, but excluded work-related travel. Cyclists who walk several times a week or more are 1.7 times more likely to consider air pollution, compared with those who walked several times a month or less.

A look at the descriptive statistics (chart 17) on this also follows this trend. Those who walk at least several times a week agree with the pollution statement (54.2%) more than they chose the neutral (21.6%) or disagree (24.2%) options. Those who walk several

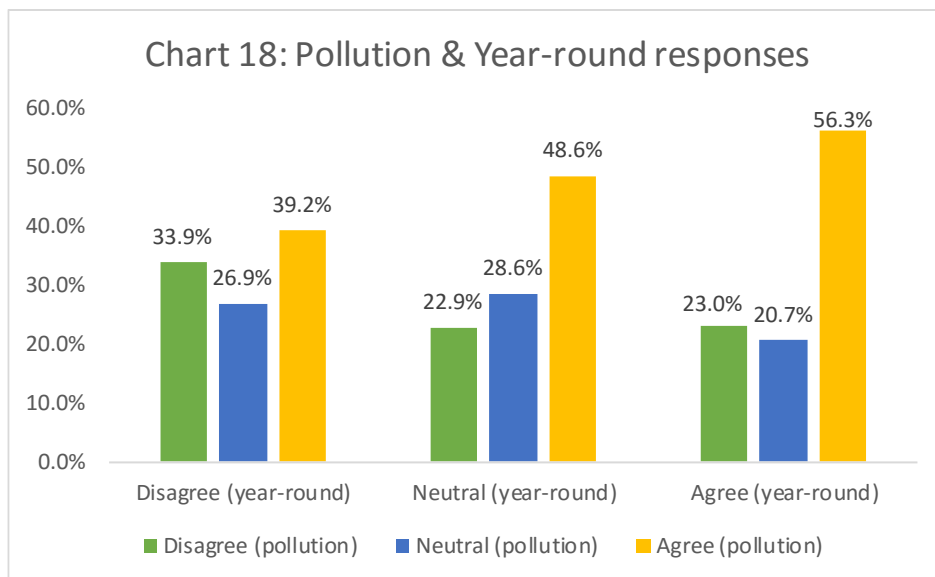


times a week or more are 1.7 times more likely to consider air pollution, compared with those who walked several times a month or less.

times a month or less were less likely to agree with the pollution statement than those who walk more (40.5% versus 54.4%, respectively). Respondents who walk less were also more likely to disagree with the pollution statement (33.3%) compared to those who walk more (24.2%).

### Cycle Year-Round

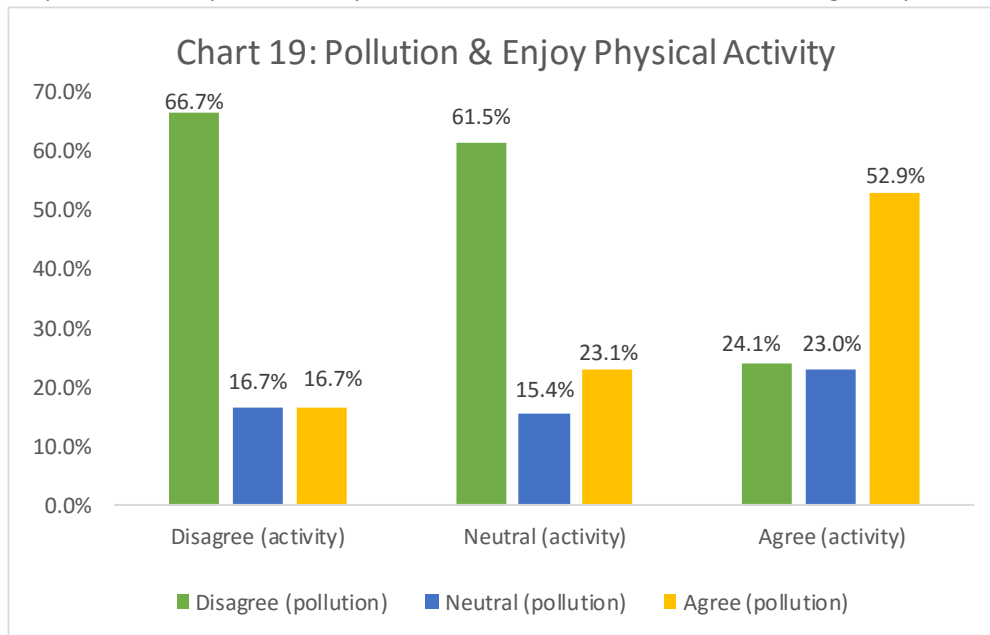
Participants who agree with the statement “I bicycle year-round, regardless of the weather (rain or cold)” were more likely to agree with the air pollution statement by a factor of 1.5 compared to those who choose disagree or neutral.



These results are also seen when looking at the descriptive statistics for the variable, although not as clearly as some of the other variables (see chart 18). Cyclists who agree with the year-round statement were more likely to also agree with the pollution statement (56.3%) compared to choosing neutral (20.7%) or disagree (23.0%) for the pollution statement. Interestingly, respondents who pick the neutral or disagree option for cycling year-round also agree with the pollution statement more often than they pick the neutral or disagree option. However, respondents are more likely to agree with the pollution statement if they also agree with the year-round one (56.3%) than those who pick neutral (48.6%) or disagree (39.2%) for the year-round question.

## Enjoy Physical Activity

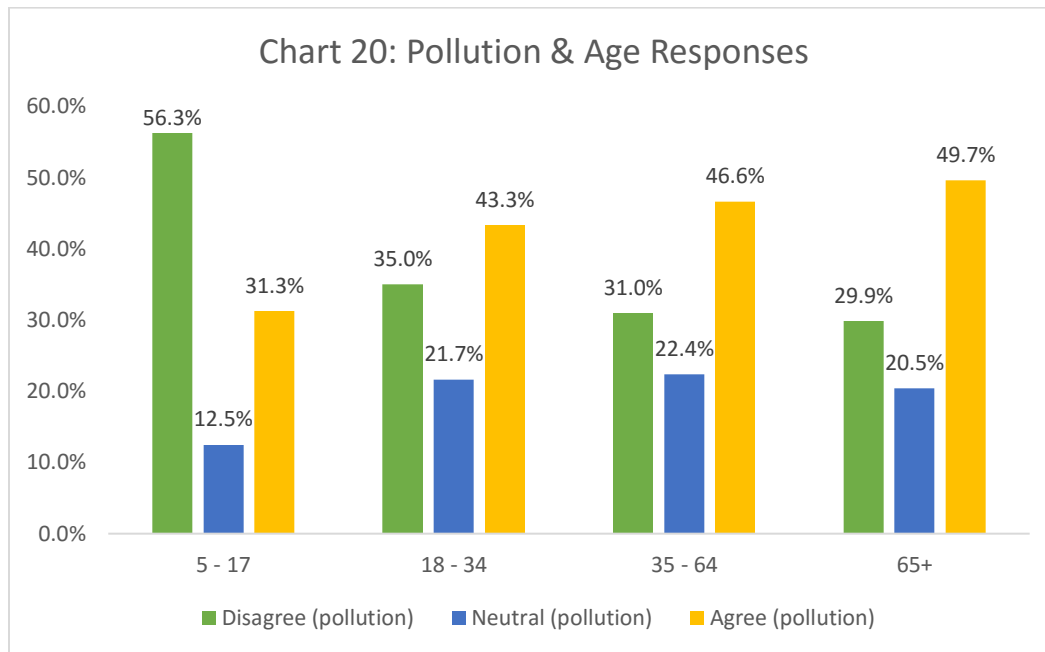
Those who agree with the statement “I enjoy physical activity,” were 3.9 times more likely to consider air pollution compared to respondents who chose the neutral or disagree option.



This is borne out in the descriptive statistics as well. Respondents who disagree with the physical activity question are more likely to also disagree with the pollution question (66.7%), versus those who pick the neutral category (16.7%) or the agree category (16.7%). Those who pick the neutral option for physical activity are more likely to disagree with the pollution question (61.5%) rather than pick the neutral option (15.4%) or agree (23.1%). Cyclists who agree with the physical activity statement are more likely to also agree with the pollution statement (52.9%) compared to those who were neutral (23%) or disagree (24.1%) with the physical activity statement. See chart 19.

## Age

Age is the final independent variable for this model. For each one year increase in age, participants are more likely to agree with the pollution statement by a factor of 1.0.



This trend is easy to see in the descriptive statistics, especially once the age categories are collapsed (chart 20). Respondents in the youngest age group (5 – 17) are more likely than any other age to disagree with the pollution question (56.3%) compared to the next closest age category (35.0%). The percentage of cyclists who disagree drops steadily through each age cohort from 56.3% (5 – 17) to 35.0% (18 – 34), 31.0% (35 – 64) and 29.9% (65 and over). This trend is mirrored for those who agree with the pollution questions. The lowest percentage agree in the 5 – 17 group (31.3%), and then increase steadily from there for the 18 – 34 group (35.0%), 35 – 64 cohort (46.6%) and over 65 group (49.7%).

## Energy Expenditure Model

The energy expenditure model includes four independent variables: bicycling as exercise, comfort level on major streets, enjoy physical activity, and income. Respondents were asked to rate the statement “I consider energy expenditure (physical effort) when choosing a bicycle route.” Cyclists chose from a five-point Likert scale for this and the bicycling as exercise and enjoy physical activity statements. The choices were strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree and strongly agree.

Three of the four independent variables are ordinal, with income as a scale variable.. All the independent variables are statistically significant at the 95% confidence level. The variables bicycling as exercise and comfort level on major streets are also statistically significant at the 99% confidence level. See table 4, 5, and 6.

Table 4: Energy Expenditure Model

Statistical Significance of Model	0.001
Pseudo R <sup>2</sup>	
Nagelkerke	0.069
Cox & Snell	0.062

Table 5: Energy Model Ordinal Variable Summary

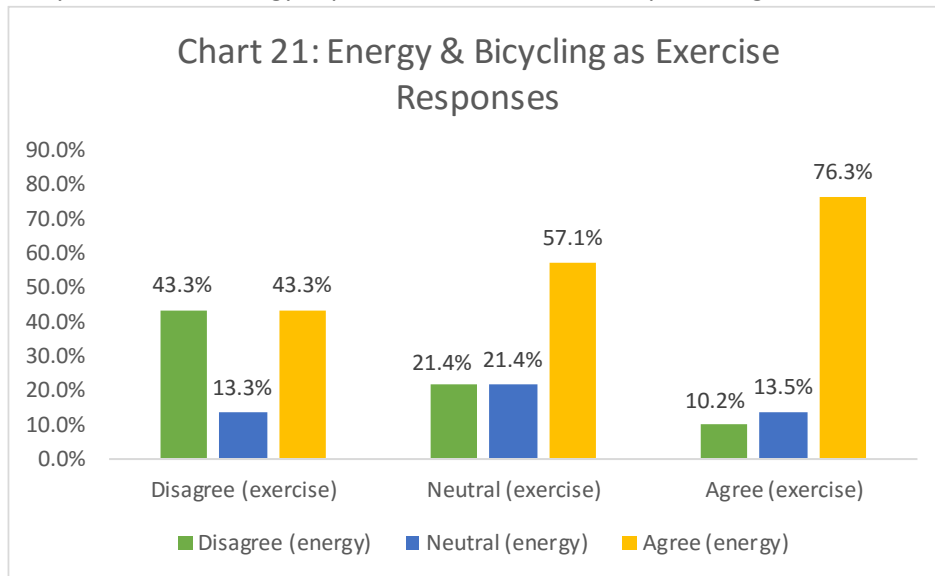
Variable	Responses	N	Marginal Percent
Energy Expenditure (dependent variable)	Disagree/Neutral	142	26.3%
	Somewhat Agree	193	35.7%
	Strongly Agree	205	38.0%
Bicycling as exercise	Agree	487	90.2%
	Disagree/Neutral (Reference)	53	9.8%
Comfort Level on Major Streets	Comfortable	188	34.8%
	Uncomfortable (Reference)	352	65.2%
Enjoy Physical Activity	Agree	513	95.0%
	Disagree/Neutral (Reference)	27	5.0%
Valid		540	100.0%
Missing		62	
Total		602	

Table 6: Energy Expenditure Model Output

	Co-efficient	Odds Ratio	Standard Error	P-value
Bicycling as Exercise	0.887	2.427	0.297	0.003
Comfort Level on Major Streets	0.497	1.640	0.170	0.004
Enjoy Physical Activity	0.949	2.580	0.414	0.022
Income (scale)	-0.116	0.089	0.049	0.018

## Bicycling as Exercise

Participants who agree with the statement “bicycling is a form of exercise for me” were 2.4 times more likely to consider energy expenditure than those who pick disagree or neutral.



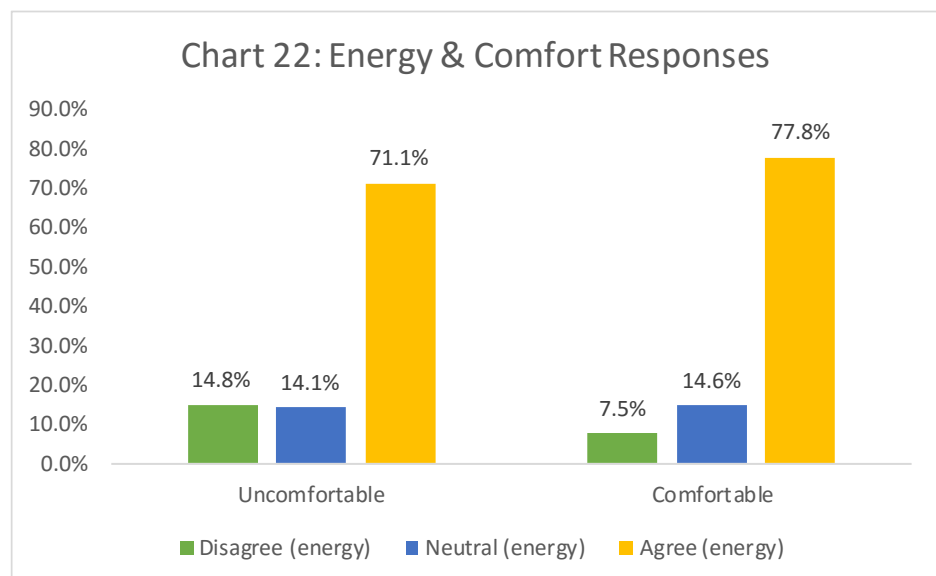
In the descriptive statistics, people who disagree with the bicycling as exercise statement are more likely to also disagree with the energy expenditure statement (43.3%) compared to those who choose neutral (21.4%) and agree (10.2%) regarding bicycling as exercise. The same trend occurs with those who agree with the energy expenditure statement. Those who disagree with the bicycling as exercise statement are less likely to also agree with the energy expenditure statement (43.3%) compared to those who picked neutral (57.1%) or agree (76.3%) for bicycling as exercise.

## Comfort Level

Cyclists who are very comfortable or comfortable on “major streets without bicycle lanes” are more likely to consider energy expenditure by a factor of 1.6 versus those who are very uncomfortable or uncomfortable.

Looking at the descriptive statistics, cyclists who are very

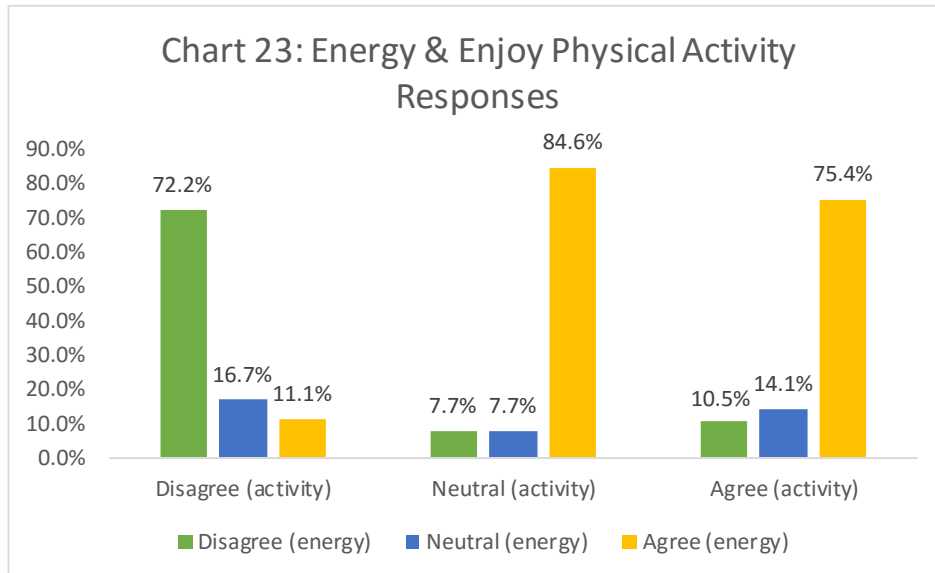
uncomfortable or uncomfortable are more likely to disagree with the energy expenditure statement (14.8%), than those who are comfortable or very comfortable without bicycle lanes (7.5%).



People who are comfortable without bicycle lanes are also more likely to consider energy expenditure (77.8%) than those who are uncomfortable (71.1%).

### Enjoy Physical Activity

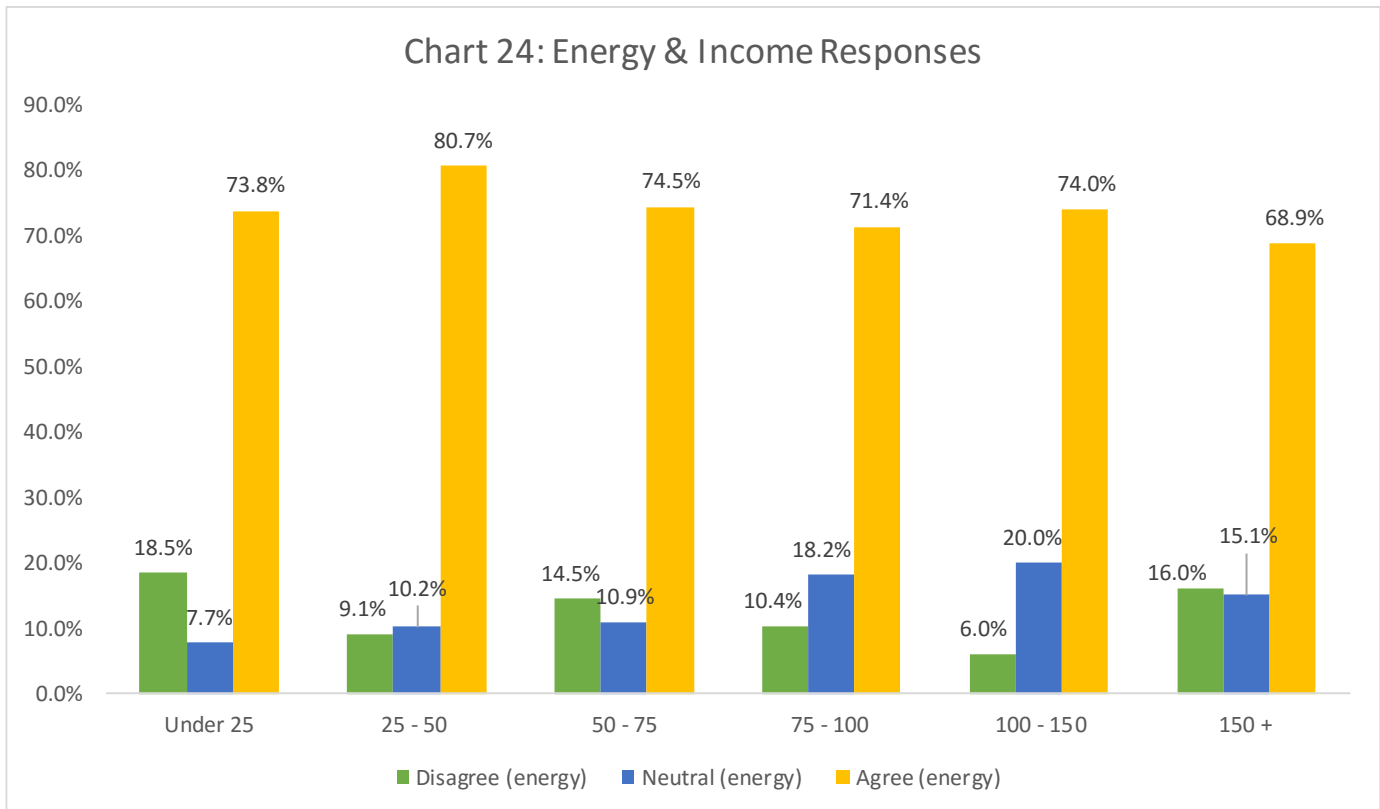
Those who agree with the statement “I enjoy physical activity” are 2.6 times more likely to consider energy expenditure than those who pick disagree or the neutral option.



Many cyclists who disagree with the physical activity statement also disagree with the energy expenditure statement (72.2%), compared to those who chose neutral (7.7%) or agree (10.5%) for physical activity. Similarly, respondents who disagree with the physical activity statement rarely agree with the energy expenditure statement (11.1%), compared to cyclists who pick the neutral (84.6%) and agree (75.4%) statement for physical activity.

## Income

As income increases, cyclists are less likely to consider energy expenditure (odds-ratio .09). Income is divided into 6 ranges: under 24,999, 25,000 – 49,999, 50,000 – 74,999, 75,000 – 99,999, 100,000 – 149,999, and over 150,000. Graphically, cyclists in the top income range (150K and over) are least likely to agree that they considered energy expenditure (68.9%) compared to the other income categories. See chart 24.



## Discussion

### Pollution

The final pollution model fails to support any of the hypothesized independent variables. Education is not significant, nor is typology. Cycle year-round, an element of some typologies though not the one the survey questions are modeled after, is included. Three new variables show up – consideration of energy expenditure, walking frequency and enjoy physical activity.

Although there is a connection between pollution consideration and education in the literature, education is not included in the final model. In one of the preliminary pollution models, education was a statistically significant variable that improved the predictive power of the model. In that model, respondents with the lowest education levels were least likely to consider pollution, echoing the Badland and Duncan study that those with higher education levels were more likely to perceive air pollution as having a negative impact. However, upon closer examination, many of those with lower education levels are 17 or younger. Substituting age for education resulted in a variable with a better p-

value, and a model with more predictive power. The Badland and Duncan study asks specifically about perceived health effects related to pollution, while this study asks if air pollution was considered when choosing a route. While these two topics are likely related – those who consider air pollution may also recognize its negative health impacts – there is no clear connection between the two. Also, the Badland and Duncan study only includes adults 18 years of age and older, while this study has participants as young as five.

Age is a significant variable, with older cyclists more likely to consider air pollution. As cyclists get older, they may become more sensitive to health concerns, and therefore more concerned with pollution. Some studies find older subjects with higher education levels are more knowledgeable about health risks from various sources including air pollution (Riediker et al. 2004; Bianco et al. 2008). It may be that older cyclists are more knowledgeable about air pollution, and thus consider it when planning a route.

Cyclists who cycle year-round are more likely to consider air pollution. Although weather preference is not included in the Geller typology or the Dill and McNeill revision, some typologies do consider weather (Damant-Sirois, Grimsrud, and El-Geneidy 2014). There may also be an activity component to this. Cyclists who cycle all year are likely in fairly good shape. Year-round cyclists could also be classified as more ‘committed’ cyclists. Perhaps these kinds of cyclists are more conscientious of many elements of their trip, including air pollution.

Enjoy physical activity has the highest odds ratio of the variables in the model. This variable also has one of the clearest distinctions when comparing respondent’s answers to the physical activity and pollution statements. There is a clear trend that the more one enjoys physical activity, the more one considers pollution (when adjusting for low sample size). In all, those who enjoy physical activity, and engage in it for transportation, are more likely to consider air pollution.

Consideration of energy expenditure in route selection has the second highest odds ratio among the variables. This may be because people who consider energy also consider the quality of the air when they are engaging in activity and expending energy.

Cyclists who walk at least several times a week or more are more likely to consider air pollution. Walking outdoors exposes people to pollution (Franklin, Brook, and Arden Pope 2015). People who walk more may be aware of their surroundings including vehicle exhaust, and thus more likely to consider pollution in their route consideration.

These last three kinds of cyclists could be classified as “health conscious” cyclists. It makes sense that cyclists who stay active and consider their health would also consider how much pollution they take into their lungs.

### **Energy Expenditure**

Two elements of the hypothesized physical activity effects are supported in the final model – bicycling as exercise and enjoy physical activity. Gender is not a significant variable, and does not support the hypothesis. Comfort level on major streets is a significant variable not included in the hypothesis. This is another element of cyclist typology – though typology was not a hypothesized variable for energy

expenditure, and this still fails to support that hypothesis. Income is also a new variable not included in the hypothesis.

Like the air pollution model, physical activity is a main component of the energy expenditure model. Those who enjoy activity or consider cycling to be a form of exercise are more likely to consider energy expenditure. Some studies in the literature find that some cyclists prefer moderate hills over flat terrain on their route for several reasons including exercise (Stinson and Bhat 2003). The results of this current study may indicate that some cyclists are trying to get more physical activity, or more exercise, and choose routes that require more energy, such as routes with more hills, etc.

Interestingly, comfort level on major streets with no bicycle infrastructure is significant, while cyclist typology was not. In the typology, cyclists who are very comfortable on major streets with no cycling infrastructure are 'strong and fearless,' while those who are just comfortable usually are classified 'confident and enthused.' For the comfort level variable, cyclists who pick either of the comfortable options are analyzed together. Clearly, this distinction in comfort level results in better outcomes in analyzing the energy expenditure variable. These 'committed' cyclists are more likely to consider energy expenditure, possibly for the same reason as those who like physical activity and consider cycling exercise – cycling is a workout and they want more of a challenge. Of course, this is assuming that these cyclists are more likely to consider energy expenditure because they like higher energy routes. The opposite may also be true.

Three of the variables could be bundled together – cycling as exercise, enjoy physical activity and comfort level - as a type of experienced, comfortable cyclists who views cycling as not only a means of transportation or recreation, but a way to increase their physical activity level.

Income is the only variable in the model that has a negative impact. That is, consideration of energy expenditure declines as income rose. Pucher, Buehler and Seinen (2011) find that cycling rates in general do not change much related to income, but postulate that those with higher income levels will cycle more for exercise and recreation, while those with lower income will cycle more for utilitarian purposes. This is not directly explored in this study, but there are some elements in the model. "Health conscious" cyclists who consider cycling exercise, and who enjoy physical activity may cycle more for exercise and recreation than utilitarian purposes, and this may be why they consider energy expenditure more. But cyclists consider energy expenditure less as income levels rise. This may be because they are less health conscious, or there may be other reasons they are less concerned with energy expenditure.

### **Energy Expenditure and Pollution**

While the models fail to support several hypotheses, elements in the model are related to the hypothesized variables. A variation of typology show up in the pollution model (bicycle year-round) and the energy expenditure model (comfort level). Elements of physical activity are present in the pollution model (energy expenditure, walking frequency, enjoy physical activity) and the energy expenditure model (bicycling as exercise, enjoy physical activity). This may indicate that refined hypotheses in the same general vein as the original hypotheses would yield better results. Also, since similar elements show up in each model it may be possible that consideration of air pollution and energy expenditure are closely related.

The models suggest that two main groups are more likely to consider pollution and energy expenditure in route selection – health conscious people (enjoy physical activity, consider cycling exercise, walk frequently) and ‘committed’ cyclists (bike year-round, comfortable on major streets). Both models have elements of each. One of the cyclist typologies identifies four types of cyclists: dedicated cyclists, path using cyclists, fairweather utilitarians, and leisure cyclists (Damant-Sirois, Grimsrud, and El-Geneidy 2014). The authors identify different motivators for the different types including speed and convenience (dedicated), and health (leisure). Both the dedicated and leisure cyclists identified in that study correspond well to health conscious and experienced cyclists in this study. Each model included one demographic variable – age for pollution, and income for energy expenditure.

Interestingly, energy expenditure is also a statistically significant independent variable within the pollution model. It’s almost as if the energy expenditure model is nested within the pollution model, especially since physical activity exists in both models. However, this is the only variable that crosses over. This does illustrate though that consideration for energy expenditure and pollution are closely linked. This gives further weight to the notion that health conscious and hard core cyclists are more likely to consider energy expenditure and air pollution.

There may be another factor at work in these models. This type of cyclist – ‘health conscious’ and ‘committed’ – is more likely to consider air pollution and energy expenditure. But this may be because this type of cyclist is more aware of all elements of the journey, and is just more likely to consider many aspects of the trip, not just pollution and energy expenditure. An element of this is present in the literature. People who are aware of one connection between environmental risk and health, are much more likely to be aware of a number of such connections (Bianco et al. 2008). A similar phenomenon may be happening here. Cyclists who consider one aspect of the trip – air pollution and energy expenditure – may also be more aware of all aspects of the trip in general. More research is needed to explore this further.

Further research opportunities could include exploration into why cyclists consider energy expenditure. Is it to conserve energy and take the most efficient route, get more exercise, or other variations depending on other factors? There may also be an opportunity to further explore cyclist typologies, merging some elements of the ‘strong and fearless’ and ‘confident and enthused’ types from Geller’s original typology. There could be an element of a health-conscious cyclist, who is comfortable on major roads without cycling infrastructure, and comfortable cycling in a variety of weather.

### **Limitations**

This study has a robust number of participants for an intercept survey. However, there were limited numbers when doing analysis on small subsets of the sample. Also, some cells had no results in the models. For example, no one with income over 100K picked strongly agree for energy expenditure consideration, and somewhat disagree for bicycling as exercise. A larger study would be helpful to determine if some of these smaller numbers resulted in any anomalies.

Since this is a stated preference survey, respondents’ stated choice may not be the same as their actual choice.

Most cyclists who participated in the study reside in Vancouver, not the wider metropolitan region. Yet, the demographics compare well to the metropolitan population. As well, Vancouver is similar to many

North American and European cities in climate and population density (Winters et al. 2011). However, care should be taken extrapolating these results to different population areas.

This study looks at which variables predict cyclists' consideration of air pollution and energy expenditure, but it is beyond the scope of this study to determine why they considered energy expenditure and air pollution, although some theories can still be applied to the results.

Cyclists were intercepted in the late morning through to the evening rush hour and early evening. However, no cyclists were intercepted during the morning commute due to logistical constraints. This may have excluded a segment of cyclists from the study. However, many of the cyclists intercepted in the evening may well be the same cyclists from the morning.

The study was completed during the summer months only, which does not account for seasonal variation in cycling patterns. However, completing the study in the summer likely resulted in a wider variety of participants than would have been captured otherwise.

## Policy and Planning Implications

### Route Choice

This research fills a gap in the literature related to energy expenditure and pollution consideration when choosing a route. A large number of people consider air pollution when choosing a route, with a sizable number considering energy expenditure as well. These two areas are clearly something Vancouver cyclists think about. Gathering more information about the topic is important, especially considering the health implications of air pollution.

Future route planning models should aim to include pollution as a variable. There is virtually no research on energy use and route planning. As this study illustrates, energy and air pollution is a component of route planning that people consider. More research can add greater knowledge to this, increasing understanding in the public domain.

### Public Education

Improved route choice research relating to pollution will improve the body of knowledge, elevating the quality of information available for education.

Younger people are less likely to consider air pollution when cycling. This may indicate that younger people are at a greater risk of exposure to air pollution, as they are less likely to adjust their routes around air pollution. There should be better education in secondary school to increase awareness of children and youth about air pollution.

Broader public education initiatives could also improve the wider population's understanding of the impacts of air pollution. Possible areas of education include promoting cycling away from mixed traffic as a better health alternative. The public can be informed of strategies for the best strategies for cycling in traffic. For example, ideal cycling speeds to limit pollution intake have been identified (Bigazzi 2017).

Education can target those groups less likely to consider pollution and energy – those who are less active, younger, with modest income, and less comfortable in certain cycling environments.

### **Planning & Policies**

A better understanding of pollution and energy expenditure relating to route choice will equip transportation planners to design better routes.

People are generally aware of the health impacts of pollution, but few cyclists see this as a barrier to cycling. Many in an Australian study used off-street routes, with lower pollution exposure (Badland and Duncan 2009). This may mean that cyclists choose lower pollution route when they are aware of the health impacts of pollution. Planners can facilitate this by providing routes away from traffic with lower pollution risk, allowing cyclists to self-select the best route for them.

Cyclists who are less comfortable in certain cycling settings are less likely to consider energy expenditure. In that vein, bicycle planners should endeavor to provide a range of cycling infrastructure. Some routes with moderate hills for the ‘health conscious’ riders, and other easier routes for other cyclists. There is backing in the literature for this, with many cyclists avoiding hills, while some studies have found a preference for moderate and even steep hills (Winters et al. 2011; Sener, Eluru, and Bhat 2009). Vancouver’s hilly nature gives planners options to put in various routes, giving cyclists a range of options, with more ‘health conscious’ or commuter cyclists able to choose hillier options if desired. Steep hills should be mostly avoided if possible, as a smaller segment of cyclists prefers these over moderate hills or flat routes.

In Vancouver, continuing to expand the All Ages and Abilities cycling network in areas of less air pollution exposure would hit several issues at once. Having safe, comfortable cycle paths would encourage younger people to cycle. Locating these protected cycling routes in areas with less vehicle traffic as Vancouver has generally done, would also limit the negative health impacts on younger people who are less concerned with air pollution than their older peers. Winters recommends building cycle routes away from traffic, as this is one of the major deterrents for cyclists (2011, 165). This relates closely to the pollution research, which shows there are lower rates of pollution exposure for cyclists if routes are removed from major roadways (Schepers et al. 2015; Bigazzi and Figliozzi 2015; MacNaughton et al. 2014).

Some literature sources recommend that bicycle routes are placed in low-traffic areas where feasible, and that having a degree of ‘lateral separation’ between bike routes and traffic can reduce cyclists’ exposure to air pollution (Bigazzi, Broach, and Dill 2016). Bicycle planners can plant more trees and shrubs near roadways, as vegetation reduces pollutant levels (MacNaughton et al. 2014).

## Conclusion

There is a noticeable gap in the literature concerning cyclist's consideration of air pollution and energy expenditure. This study explores that topic, and finds that most cyclists (73.6%) consider energy expenditure, and many (51.0%) consider air pollution.

Air pollution exposure is a major health concern, especially for cyclists. This study found that 'committed' and 'health conscious' cyclists are most likely to take pollution into consideration when choosing a route. Casual cyclists, younger people, and those who are less health conscious are less likely to consider pollution.

Bicycle planners can take this into account by building routes separated from major roadways, planting vegetation near roadways, and focusing more on bicycle paths rather than bicycle lanes.

Similar to the pollution findings, cyclists who consider energy expenditure are more likely to be 'committed' and 'health conscious' cyclists. These cyclists may enjoy the challenge and effort needed on more energy intense routes, such as hills. The reverse may also be true, with these cyclists considering energy expenditure because they prefer less high energy routes. Regardless, there is support in the literature that some cyclists prefer routes with moderate and even some steep hills. Planners can provide a variety of routes for cyclists, some more high energy, and others less so.

As Vancouver moves toward its goal of becoming the greenest city, effort should be made to plan bicycle infrastructure that appeals to a variety of people, and limits negative effects such as air pollution.

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## Appendix A: Survey Instrument



a place of mind  
THE UNIVERSITY OF BRITISH COLUMBIA  
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## Bicycle coast-down test: Questionnaire [Test #: \_\_\_\_\_]

### Part I: Trip Information

<b>Where did you start your trip?</b>	Address, intersection, or landmark:
	City:
<b>Where are you going?</b>	Address, intersection, or landmark:
	City:
<b>How long is this trip?</b>	Distance: _____ km    AND    Time: _____ minutes
<b>What is the purpose of this trip?</b> (check one)	<input type="checkbox"/> Commuting to/from work or school <input type="checkbox"/> Shopping, errands, restaurant/dining, etc. <input type="checkbox"/> Recreation or exercise: no destination, just riding <input type="checkbox"/> Other - please, specify: _____

### Part II: Travel Characteristics

<b>How often do you use the following modes for personal travel around Metro Vancouver?</b>					
<u>Include</u> commuting to/from work, but <u>exclude</u> work-related travel.					
<b>Check one box per row:</b>	Almost never	Monthly or less often	Several times a month	Several times a week	Almost every day
Private vehicle, driver or passenger					
Carshare, driver or passenger (Car2Go, Evo, Modo, etc.)					
Taxi, rideshare companies					
Public transit (bus, Skytrain, HandyDART, etc)					
Bicycle					
Walk					

<b>In the past 30 days, how many days did you ride a bicycle for each of the following purposes?</b>					
<b>Check one box per row:</b>	0 days	1-4 days	5-9 days	10-19 days	20+ days
Commuting to/from work or school					
Shopping, errands, restaurant/dining, etc.					
Recreation or exercise: no destination, just riding					

<b>How much do you agree or disagree with the following statements?</b>					
<b>Check one box per row:</b>	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I bicycle year-round, regardless of the weather (rain or cold)					
I would like to travel by bicycle more than I do now.					
Bicycling is a form of exercise for me.					
I enjoy physical activity.					
I consider energy expenditure (physical effort) when choosing a bicycle route					
I consider air pollution (air quality) when choosing a bicycle route					

<b>How comfortable would you feel cycling on your own in each of the following situations?</b>				
<b>Check one box per row:</b>	Very Uncomfortable	Uncomfortable	Comfortable	Very Comfortable
On bicycle paths far away from motor vehicles				
On local neighbourhood streets with little traffic and low speeds				
On major streets, provided they have bicycle lanes separated from traffic with a physical barrier				
On major streets, provided they have painted bicycle lanes				
On major streets without bicycle lanes				

<b>How would you describe the maintenance condition of the bicycle you are riding today?</b>	<input type="checkbox"/> Excellent condition <input type="checkbox"/> Good condition <input type="checkbox"/> Fair condition <input type="checkbox"/> Poor condition
<b>Do you consider the bicycle you are riding today to be heavy or light?</b>	<input type="checkbox"/> My bicycle seems heavy <input type="checkbox"/> My bicycle seems about average <input type="checkbox"/> My bicycle seems light
<b>How would you compare your typical riding speed, compared to other cyclists?</b>	<input type="checkbox"/> Slower than most cyclists <input type="checkbox"/> About average speed <input type="checkbox"/> Faster than most cyclists

### Part III: Personal Information

<b>What is your home postal code?</b> (for example V5M 1P1, or neighborhood if unknown)											
<b>How many people live in your household, including yourself?</b>	_____ person(s) total, including _____ licensed driver(s)										
<b>How many motor vehicles does your household own or lease?</b> (include cars, vans and light trucks, but exclude motorcycles, scooters, bicycles and car-share vehicles)	<input type="checkbox"/> None <input type="checkbox"/> One <input type="checkbox"/> Two <input type="checkbox"/> Three or more										
<b>What is the highest level of education you have completed?</b> (check one)	<input type="checkbox"/> Some high school or less <input type="checkbox"/> Completed high school/equivalency <input type="checkbox"/> College/University certificate or diploma <input type="checkbox"/> Bachelor's degree <input type="checkbox"/> Graduate degree (master's degree or doctorate)										
<b>What is your sex?</b>											
<b>What is your age?</b>											
<b>What is your height?</b>											
<b>How much time in a typical week do you spend in moderate and vigorous-intensity physical activities?</b> (include bicycling and work activities)	<p><u>moderate</u> activity, such as brisk walking, with <u>small</u> increases in breathing and heart rate <b>(circle one)</b></p> <table border="1"> <tr> <td>Less than ½ hour</td> <td>½ - 1 ¼ hours</td> <td>1 ¼ - 2 ½ hours</td> <td>2 ½ - 5 hours</td> <td>over 5 hours</td> </tr> </table> <hr/> <p><u>vigorous</u> activity, such as running, with <u>large</u> increases in breathing and heart rate <b>(circle one)</b></p> <table border="1"> <tr> <td>Less than ½ hour</td> <td>½ - 1 ¼ hours</td> <td>1 ¼ - 2 ½ hours</td> <td>2 ½ - 5 hours</td> <td>over 5 hours</td> </tr> </table>	Less than ½ hour	½ - 1 ¼ hours	1 ¼ - 2 ½ hours	2 ½ - 5 hours	over 5 hours	Less than ½ hour	½ - 1 ¼ hours	1 ¼ - 2 ½ hours	2 ½ - 5 hours	over 5 hours
Less than ½ hour	½ - 1 ¼ hours	1 ¼ - 2 ½ hours	2 ½ - 5 hours	over 5 hours							
Less than ½ hour	½ - 1 ¼ hours	1 ¼ - 2 ½ hours	2 ½ - 5 hours	over 5 hours							
<b>What is your gross annual household income?</b> (in CAD, check one)	<input type="checkbox"/> under \$24,999 <input type="checkbox"/> \$75,000 to \$99,999 <input type="checkbox"/> \$25,000 to \$49,999 <input type="checkbox"/> \$100,000 to \$149,999 <input type="checkbox"/> \$50,000 to \$74,999 <input type="checkbox"/> \$150,000 or more										