ENHANCING ENVIRONMENTAL LOAD MITIGATION BENEFITS

FROM CLEAN VEHICLE INCENTIVES:

IN CONTEXT OF METRO VANCOUVER

A Thesis

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ABSTRACT

Automobile dependency, both in developed and developing parts of the world, has resulted in unintended economic, environmental, and social damages the past few decades. While it is essential to fundamentally reduce automobile dependency with strategic land use planning and paradigm shift in the long run, motor and fuel efficiency should play a key role mitigating environmental load in the short run, with electric vehicles (EVs) being one of the alternatives.

Much of the existing literature has conducted benefit cost analyses of clean energy vehicle adoptions (Thomas, 2011; McConnell & Turrentine, 2010; Chupp, Myles, & Stephenson, 2010) and investigated their incentive policies both from consumers' and social perspectives (Franke & Krems, 2013; Ko & Hahn, 2013; Potoglou & Kanaroglou, 2007) but none has investigated how a particular policy's social benefits can be enhanced by taking consumer preferences into consideration in a more aggregate manner. Incentive policies that incorporate consumer preferences have potential to increase social and individual benefits in addition to initially intended environmental benefits.

The objective of this thesis is to investigate methods that could potentially enhance the social benefits resulting from environmental load mitigation such as greenhouse gas emissions and air pollution from the provision of incentives for electric vehicles in British Columbia, particularly its Metro Vancouver region. By monetizing the private benefits of incorporating under-utilized facilities into the policy using existing data and simulations and investigating consumer preferences of different incentives, the study attempts to quantitatively demonstrate that the government is able to reach more potential electric vehicle drivers with smaller subsidies installment by implementing non-monetary incentives, resulting in larger social benefits.

This thesis consists of five chapters. Chapter 1 provides the overview of British Columbia's Climate Action Plan and Clean Energy Vehicle Program. In Chapter 2 environmental load mitigation benefits of electric vehicle adoption in Metro Vancouver is calculated, and then Chapter 3 explains how incorporating non-monetary incentives into the policy would increase the social welfare and estimates their benefits. Chapter 4 presents the results of a questionnaire survey to better understand consumer preferences for different types of incentives, and Chapter 5 concludes the study by giving policy recommendations based on the lessons learned from the questionnaire survey.

Based on the IPCC report's marginal damage cost of greenhouse gas emissions and APEEP model's marginal damage cost of dominant air pollutants emissions, it was estimated each adoption of an electric vehicle from a conventional gasoline vehicle in Metro Vancouver results in $ 679.06 of environmental load mitigation benefits in monetary terms over the course of eight years. Given its relatively clean power sources that do not depend on coal, British Columbia expects much environmental benefits and achievement of its stringent greenhouse gas emissions reduction target from adoption of electric vehicles.

Providing consumers with monetary benefits, however, is not the only method to incentivize them to switch to electric vehicles. In addition to the monetary incentives, HOV lane permits allow electric vehicle drivers to use reserved, fast lanes, significantly reducing travel time during peak hours, and complimentary street parking provides them with access to parking spots operated by governments free of charge. When the government implements those non-monetary incentives in addition to the existing monetary incentives, now they are able to subsidize a greater number of electric vehicles within the same budget constraint and without reducing each consumer's utility.

Based on the available government data about household expenditures and traffic patterns, investigations estimated that free street parking and provision of HOV lane permits result in annual private benefits of $109.52 and $64 respectively. In case of HOV lane permits, however, only 7.1% of electric vehicle drivers would live and commute where direct time savings benefits from HOV lanes are expected, and thus it is not ideal to reduce the same amount of monetary incentives in return for provision of non-monetary incentives.

In order to further understand consumers' preferences for different non-monetary incentives in addition to the currently implemented monetary incentives, a consumer survey was conducted targeting Metro Vancouver residents. Despite only 3.85% of the respondents living and commuting routes with HOV lanes, 34.6% answered they are willing to accept reduction in monetary incentives in return for HOV lane permits for five years. Unexpectedly 53.8% of the respondents answered better availability of public charging infrastructure would positively affect their electric vehicle purchase in addition to monetary incentives; this compares to 42.3% for free street parking and 28.8% for HOV lane permits.

Given the diverse set of preferences for different types of incentives and strong preference for charging infrastructure revealed in the survey, the study presents two policy recommendations to enhance the total social benefits out of the policy.

First, the government shall allow consumers to select combinations of monetary and non-monetary incentives, as opposed to the conventional one-size-fits-all approach of incentive provision. Such scheme is expected to result in the enhancement of consumer utility, with incentives being allocated to those who highly value them, and avoid congestion resulting from overprovision of HOV lane permits and complimentary parking. Assuming 30% of new electric vehicle buyers would choose one or more of the non-monetary incentives for five years and accept $500 reduction of monetary incentives, the total environmental load mitigation benefits from the policy would increase by 6%.

Secondly, the government requires further investigation on consumers' preference strength among monetary incentives, non-monetary incentives, and charging infrastructure development and allocate financial resources accordingly to maximize drivers' utility. Currently 95% of electric vehicle drivers in British Columbia live in single detached houses, while much of the population lives in multi-unit residential buildings where they need to share parking with other tenants. For many, it is necessary the infrastructure is organized before they are able to start considering purchasing electric vehicles in the first place.

Further adoption of electric vehicles is an important first step to attaining environmental objectives without sacrificing convenience of driving in the short run. Governments are expected to utilize various traffic resources and strategically implement policy instruments with a better understanding of consumer preference in order to maximize the benefits for all.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1: INTRODUCTION

1.1 True Cost of Driving and Electric Vehicles

The term “automobile dependency” was coined by researchers Peter Newman and Jeffrey Kenworthy (1999), as the negative effects of anthropogenic greenhouse gas emissions from the transportation sector had become gradually apparent. Suburban development in North America and rapid growth of megacities in emerging economies had made more parts of the world even more automobile dependent since then, and society has paid its price.

Global climate change, however, is merely a small portion of cost of driving incurred by society, as seen in Table 1.1; every life stage of vehicles, from manufacturing to disposal, involves economic, environmental, and social costs borne by not only those who drive but also those who do not. While a paradigm shift to reduce travel demand and miles travelled is essential in the long run, motor and fuel efficiency should play a key role mitigating greenhouse gas emissions and smog in the short run, with electric vehicles being one of the alternatives.

As opposed to hybrid electric vehicles with both conventional combustion engines and small batteries installed, full electric vehicles (referred to as “electric vehicles” or “EVs” hereafter) operated solely on batteries that regularly need to be recharged from the grid have received much attention since introduced to the mass market (Pacific Institute for Climate Solutions, 2009). Depending on the power source, adoption of electric vehicles results in mitigation of various types of environmental issues as seen in Table 1.1.

1.2 Literature Review: Clean Energy Vehicles, Consumer Preferences, and Social Costs

Much has been debated and discussed regarding clean energy vehicles, consumer perceptions and their policy effectiveness since the late 1990s when hybrid electric vehicles were first introduced to the public market.

Table 1.1: Cost of Driving

	Economic	Environmental	Social
Infrastructure Maintenance	◆◆ More driving requires continuous maintenance of infrastructure.		◆ Less government budget left to be allocated for other usage (compensating the poor).
Change in Land Use Patterns	◆◆ Suburban development implies more investment required for basic infrastructure such as highways and water pipes.	◆◆ Such development patterns come with environmental loads such as biodiversity loss.	◆ Loss of accessibility and connection among people, particularly those who are not able to drive.
Traffic Accidents[1]	◆◆ Loss of productivity, individually and socially.		◆◆ Loss of families and friends results in psychological pain.
Fossil Fuel Consumption	◆ Energy insecurity negatively affects a country's economy.	◆◆ The supply of conventional/unconventional oil is finite.	◆ More gasoline consumed today means less left for future generations.
Congestion	◆◆ Loss of labor and productivity.	◆◆ Automobiles stuck in traffic implies more fuel consumption and GHG emissions	◆ Loss of time that could be spent with families and friends or private time.
Poor Health (Non-Environmental Causes)	◆ The cost of poor health is borne by not only individuals but society as a whole (productivity loss and health care).		◆◆ Lack of exercises due to automobile dependence could lead to disorders such as heart diseases and obesity.
Air Pollution	◆ Air pollution could indirectly cost economies through poor health conditions.	◆◆ The emissions of substances such as NOx, SOx, and particulate matter cause various environmental issues.	◆ Depending on geographic location, air pollution could significantly reduce one's quality of living.
Waste Accumulation	◆ The cost of landfill management is socially borne.	◆◆ Most waste materials such as batteries, used tires, and car bodies end up in landfills.[2]	◆ Waste materials are not only aesthetically unpleasant but left for non-drivers to manage as well.
Climate Change	◆ Resulting sea level rise could harm various industries (while benefit some).	◆◆ GHG emissions from transport sector significantly contribute to global climate change.	◆ The cost of climate change must be paid over generations.

◆◆ indicates direct, explicit effects, while ◆ indicates indirect, secondary effects.
Green cells indicate the effects wider EV adaptation is expected to ameliorate.
Orange cells indicate possible negative effects wider EV adaptation could cause, given constant distance traveled.

Types of capital/cost discussed on the table above can be defined as follows:

- Economic cost refers to monetary, material cost that is quantifiable from a conventional business accounting perspective.
- Environmental cost is any harm done to natural environment, resulting in the depreciation of the quantity and/or quality of the services and products it provides.
- Social cost refers to factors that negatively affect one's quality of life, as opposed to standard of living measured with economic cost, which cannot be quantifiably measured in conventional accounting such as social connection and equity.

[1] Brand, Petri, Haas, Krettek, & Haasper (2012) hypothesize the reduction of the engine sound from electric and hybrid cars significantly increases the risk of accidents under 30km/h before the tire-road friction takes place.
[2] Unless properly recycled or disposed.

Ozaki & Sevastyanova (2011), in their surveys targeting the early adopters of Toyota Prius, one of the leading hybrid electric vehicle models, in the London Metropolitan region, concluded environmental concerns are the largest determinant of the Prius purchase, and argued the following are necessary in order to trigger further adoption of hybrid electric vehicles: (i) the implementation of more hybrid-friendly transportation policy instruments such as congestion charge exemptions, (ii) the establishment of social norms through media that emphasizes the positive effects of hybrid cars, and (iii) the diffusion of information regarding "aesthetic, experimental, and practical" values associated with hybrid cars. Ozaki (2012) claimed environmental benefits are not produced solely from technological advancement but rather "coproduced" through the interactions of manufacturers, technology, and the end-users.

One of the technical obstacles associated with the adoption of electric vehicles is the so-called "range anxiety," or limited driving range per charge; Franke & Krems (2013), in the study targeting EV drivers in Berlin, found recharging was done most with 15-20% or 30-35% of batteries left. In a consumer preferences survey conducted in Korea by Ko & Hahn (2013), among different product attributes such as battery price, holding tax, subsidies type, subsidies level, battery swappability, and the availability of charging facilities, consumers were willing to pay a significantly higher amount for electric vehicles with swappable batteries. In Potoglou & Kanaroglou's study (2007) targeting the residents of the metropolitan area of Hamilton, Canada, households were willing to pay \$500-\$1200 to save \$100 in maintenance costs annually, and \$2200-\$5300 to save \$1000 in fuel costs annually. The effects of HOV lanes permits and free parking on clean energy vehicle purchase, however, were not significant due to the low parking fees and low awareness of HOV lanes in the region. In a similar conjoint analysis in Korea, Choi & Oh (2009) argued the decrease in fuel costs of at least 45% a year and reduction of maintenance cost every six months by approximately $150 are necessary to make hybrid electric vehicles competitive with conventional gasoline vehicles.

Faqua (2012) investigated if the current tax credit of $7,500 being provided for plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) by the US federal government is environmentally viable by computing the changes in public benefits resulting from amelioration of air pollution, climate change effects, and oil dependence on the county level. The study, based on the nested logit model, found that cost savings from reduced oil dependency occupies two thirds of the total cost savings, and 18% (553 counties) and 49% (1514 counties) expect higher CO_2 emissions and lower air quality due to EV adoption, as the power source plays a significant role determining the amount of environmental load mitigation.

In Japan, where the automobile industry constitutes a significant part of its economy, both federal and local governments have provided tax exemption and subsidy policies for hybrid vehicles since as early as 2000. From a sole economic perspective, the policy contributed to an increase of new vehicle purchases by 900,000 units and the country's gross domestic product by 0.56% in 2009 (Saruyama, 2010). From an environmental point of view, however, the policy is estimated to have improved the average mileage of newly purchased vehicles by 0.449km/l, which implies it cost the government $362million of investment to improve the mileage by 0.1km/l (Kitano, 2013). The policy sure has worked as a powerful economic stimulus after the 2008 economic downturn yet whether it was a cost-effective tool to reduce Japan's GHG emissions is ambiguous.

While governments have been implementing incentive policies to encourage EV adoption, some are skeptical of their true social costs. Thomas (2011), with a well-to-wheel integrative approach to evaluate energy consumption and gas emissions of vehicles, concluded replacement of all small vehicles in the US by battery electric vehicles only results in the total GHG emissions reduction of 7.5%, while that of all US vehicles by fuel cell electric vehicles (FCEVs) leads to the reduction of 40%. McConnell & Turrentine (2010) claim the cost effectiveness of CO_2 abatement from subsidies policies for clean energy vehicles are high in the US, as the improvement of vehicle fuel economies is essentially determined by the federal government's fuel economy standards. Chupp, Myles, & Stephenson (2010), focusing on the tax deduction incentives for hybrid electric vehicles and their price fluctuations in the United States, analyzed approximately half of the subsidies is capitalized into the increase in vehicle prices. Those studies suggest the government needs to strategically plan their incentive provision schemes, including what kind of incentives they implement, in order to generate the most benefits out of them.

Much of the literature has studied the effects of clean energy vehicle adoption and their incentive policies both from individual consumers' and more macro, social perspectives, yet none has investigated how a particular policy's social benefits can be enhanced by taking consumer preferences into consideration in a more aggregate manner. Consumers' preferences towards incentives vary significantly region by region, and thus incentive policies shall incorporate them in order to maximize both social and individual benefits while attaining the environmental objectives.

1.3 Benefits and Costs of Incentive Policies

Any type of policy instruments, programs, or investment decisions, whether economic or environmental, involves a tradeoff between benefits and costs; that is, there are parties who receive welfare while others must pay for its costs. As a rule of thumb, cost-benefit analyses quantify both costs and benefits associated with a certain decision in monetary terms, compare them, and the project proceeds when the net social benefits are positive, or when the benefits exceed the costs (Boardman, Greenberg, Vining, & Weimer, 2011).

Different types of investment projects have their own cost-benefit measurement criteria, and cost-benefit analyses for transportation investments are no exception. For instance, the World Bank (2005) presents an approach to evaluate the total overall economic impact of transportation projects as follows:

$$\Delta \text{ economic impact} = \Delta \text{ consumers' welfare} + \Delta \text{ producers' welfare, government revenue} + \Delta \text{ externalities} - \Delta \text{ investment costs} \quad (1.1)$$

Consumers' welfare, or sometimes referred to as consumer surplus, is the difference between each consumer's willingness to pay for a certain product and its actual price. Similarly, producers' welfare, or also called producer surplus, is the difference between cost of production for each unit and the price it sells in the market. Government revenue is the difference between the income it generates and its expenditures; such as taxes and subsidies. Externalities are any benefits or costs that are incurred by parties that are not directly involved in transactions.

Those benefits and costs can be categorized into two types by focusing on who receives or incurs them, as shown in Table 1.2. Private benefits and costs, or also known as generalized benefits and costs, are those received on a private level. In case of purchasing an electric vehicle, the price of vehicles and their fuel and maintenance costs are incurred by purchasers through monetary payments. Because electric vehicles have significantly lower fuel and maintenance costs compared to conventional gasoline vehicles, individual drivers privately benefit from lower maintenance expenditures once they purchase the vehicles. Similarly, when one switches to an electric vehicle from another vehicle by liquidating the previous vehicle, its partial monetary value comes back to the owner as a residential value.

As opposed to the aforementioned benefits and costs that are tangibly enjoyed or incurred, some are not very clear to see. Cost-benefit analyses for transportation projects frequently include the intangible cost of time it takes to travel from one point to another, and the benefits resulting from time savings could make up a significant part of the overall benefits of transportation projects (Waters, 1992), as shown in the proceeding chapter of the present study.

Table 1.2: Private and Social Benefits and Costs: In Case of Purchasing an Electric Vehicle

Private (Generalized) Benefits and Costs	**Social Benefits and Costs**
• vehicle price (after incentives and rebates) • fuel and maintenance costs • travel time costs • residential value (of previous vehicles)	Externalized Costs • air pollution costs • greenhouse gas emission costs • accident costs
Transfer Costs • carbon taxes	

Social benefits and costs are those society as a whole receives and incurs, and they are also called externalized benefits and costs. Adoption of electric vehicles, assuming they retrieve power generated from relatively clean sources such as solar, wind, and hydro, results in reduction of air pollution and greenhouse gas emissions, contributing to the elimination of otherwise required social expenditures. Recent encouragement of various fuel-efficient technologies by government is an attempt to maximize such social benefits with minimum expenditures possible.

Private benefits and costs are also referred to as the “tangibles” due to the fact they are mostly easy-to-monetize values that correspond to market supply and demand relationships (Litman, 2012). Social benefits and costs, on the other hand, are the “intangibles,” which are much more difficult to quantify, and their evaluation is subject to one’s value judgment

(Litman, 2012). This leads to policy decision making that oversees the intangibles and potential biases in the process. As Litman (2012) claims, conventional policymaking "tends to favor economic objectives over social and environmental objectives, industries over communities, wealthier people over poorer people, and the current generation over future generations."

Wider adoption of electric vehicles and other types of clean energy vehicles are expected to ameliorate negative effects associated with driving in the short and medium run, resulting in overall positive social benefits. It is essential to consider social and environmental benefits and costs, particularly those associated with mitigation of environmental load that consist a significant portion of EV benefits, into policy planning in order to fully assess their social effects and implications.

1.4 British Columbia, Climate Action Plan, and Clean Energy Vehicle Program

The Province of British Columbia, Canada's westernmost province with abundant natural resources and relatively mild climate, has long played its role as a pioneer of environmental stewardship. With the negative effects of anthropogenic greenhouse gas emissions being apparent in the past few decades, the province has been proactively attempting to mitigate them, based on its Climate Action Plan since 2007. Climate Action Plan is an initiative that consists of a set of objectives and strategies to encourage activities that are economically viable and reduce carbon footprint at the same time; the plan attempts to reduce the province's greenhouse gas emissions by 33% of the 2007 levels by 2020 and further to 80% by 2050 (The Government of British Columbia, 2008).

According to the Ministry of Environment's Greenhouse Gas Inventory Report (2012), the total greenhouse gas emissions from the province in 2012 was 61,500 kilotons of carbon dioxide equivalent, with the transportation sector being responsible for 23,334 kilotons, or

37.9% of the emissions. Based on TransLink (2013), more than 70% of travels on a regular working day in Metro Vancouver are dependent on private vehicles, despite the region's relatively well-organized public transit systems. Careful planning and implementation of different types of policy instruments to encourage and discourage certain transportation modes as seen in Live Smart BC programs is expected to determine not only the regional automobile dependency but also the overall long-term success of Climate Action Plan.

British Columbia is one of the cleanest power consumers in North America; its power demand is met by hydro (86.3%), biomass (9.3%), natural gas (6.3%), heat recovery (0.2%), biogas (0.1%), and diesel (0.1%), thanks to its abundant water and natural resources (The Ministry of Energy and Mines, n.d.). Due to its power source, the government expects electric vehicles to play a key role helping them achieve greenhouse gas emissions reduction targets from the transportation sector.

As with any emerging technologies, the prices are one of the most challenging obstacles associated with adoption of electric vehicles in their market introductory stages. According to the author's estimation with certain assumptions[3] comparing an all-electric Nissan Leaf 2014 model and a conventional gasoline-powered Nissan Versa Note (specifications seen in Table 1.3), the total ownership cost of an electric vehicle compared to a conventional vehicle with similar features is still a few thousand dollars higher (detailed calculations found in Appendix I).

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[3] Assumptions made for the investigation are as follows:

- The annual mileage travelled by light vehicles in British Columbia of 13,100km is used (National Resources Canada, 2008).
- It is also assumed all the driving occurs in an urban or suburban condition where frequent stops must be made; thus the fuel economy of 7.1L/100km is used for the cost computation of Versa Note (Nissan Canada, 2014).
- BC Hydro charges 6.9 cents/kWh up to 1350kWh and 10.54 cents/kWh beyond the threshold during a two-month billing cycle. The average BC household consumes around 11,000kWh annually, or 1833kWh every two months, and thus the rate is assumed to be 7.86 cents/kWh, taking the weighted average (BC Hydro, 2014).
- The Leaf's range after full charging is assumed to be 84 miles, or 135km.
- The gas prices in British Columbia have fluctuated significantly in the past years; the estimation used 98cents/L, 123 cents/L, and 148 cents/L scenarios.

Table 1.3: Nissan Leaf and Versa Note: Specifications

	Nissan Leaf 2014 (S) 	Nissan Versa Note 2014 (SV) 
MSRP	$26,698 After $5,000 BC Rebate	$15,678 Including SV Convenience Package
Body Configuration	Hatchback	Hatchback
Dimensions (LWH in mm)	4445 x 1770 x 1550	4157 x 1695 x 1537
Weight (kg)	1470	1125
Capacity	5	5
Doors	5	5
Horse Power	107	109
Color Display (w/o GPS)	AM/FM/CD and MP3	Available with SV Convenience Package (MSRP $680)
Fuel Economy	1.9L/100km (city) 2.3L/100km (hwy) Based on Resource Canada's computation of 8.9kWh is equivalent to 1L of gasoline energy.	7.4L/100km (city) 5.4L/100km (hwy)

Based on Nissan Canada (2014).

Clean Energy Vehicle Program is an initiative led by the Government of British Columbia first announced in November 2011 with an objective to encourage further adoption of clean vehicles such as battery electric vehicles and plug-in hybrid vehicles and establish the infrastructure necessary. With $14.3 million of the total budget allocated, the program consisted of three main pillars; Charging Infrastructure Development Fund and Residential Rebate, which provide rebates for the installment and leasing of charging stations and equipment, and more importantly, CEVforBC Point-of-Sale Incentives, in which they provide between $2,500 and $5,000 incentives for the purchase of select electric and plug-in hybrid electric vehicles to the residents, businesses, non-profit organizations and government organizations in the province.

Despite the depletion of the fund and the termination of the program in early 2014, the Government of British Columbia has renewed the program starting April 2015 (Clean Energy

Vehicles for British Columbia, 2015). The government will provide the same amount of the point-of-sale incentives and an additional $1,000 for hydrogen fuel cell vehicles until March 31, 2018 or until the available $6.64 million funds are depleted. In addition to the existing rebates, vehicle purchasers are able to receive up to $2,250 additional financial rebates when replacing the existing vehicles with BC Scrap-It Program.

1.5 Research Objectives and Structure of the Study

The objective of this thesis is to investigate methods that could potentially enhance the social benefits of the reduction of environmental load such as climate change and air pollution resulting from the provision of incentives for electric vehicles in British Columbia, particularly its Metro Vancouver region. By monetizing the private benefits of incorporating under-utilized facilities such as HOV lanes and parking into the policy using existing data and simulations and investigating consumer preferences of different incentives, it attempts to quantitatively demonstrate the government is able to reach more potential electric vehicle drivers with smaller subsidies installment by implementing non-monetary incentives, resulting in larger social benefits.

This thesis consists of five chapters. In Chapter 2, the environmental load mitigation benefits of an electric vehicle adoption in Metro Vancouver will be estimated, particularly focusing on reduction of air pollution and greenhouse gas emissions. Chapter 3 then explains how incorporating non-monetary incentives in addition to the existing monetary incentives is expected to increase the overall social benefits from the policy and estimate the benefit increase of introducing HOV lane permits and complimentary street parking. In Chapter 4, the results of a questionnaire survey to investigate consumer preferences for non-monetary incentives are presented and discussed. Chapter 5 concludes the study providing policy recommendations for similar new technology incentive policies in the future, given the lessons learned through the study.

2: ESTIMATING ENVIRONMENTAL BENEFITS FROM EV ADOPTION

This chapter estimates the environmental load mitigation benefits of electric vehicle adoption in Metro Vancouver, using marginal damage costs of greenhouse gases and air pollutants emissions from select existing studies.

2.1 Background: Climate Change and Air Pollution

The present study defines environmental load as any type of anthropogenic pressure applied to the ecological system, and it focuses on the benefits associated with mitigation of the two most predominant types of environmental load in the transportation sector: greenhouse gas emissions and air pollution. This defers from negative externalities in the sense that they can be also economic or political costs of actions incurred by third parties not directly involved in the process. For instance, Faqua (2012) computed the benefits generated from reduction of oil dependence when governments provide financial incentives for purchase of new plug-in electric vehicles and battery electric vehicles, along with those generated from mitigation of climate change and air pollution. Energy security and the increase in economic competitiveness, particularly where the automobile industry occupies a significant portion of the nation's economy, such as Japan and the US, are two economic justifications of subsidizing the EV market.

As mentioned in Chapter 1, climate change mitigation through greenhouse gas emissions reduction is one of the most urgent issues on British Columbia's agenda as stated in Climate Action Plan. By quantitatively understanding how much benefits are being generated from each electric vehicle the government subsidizes, they are able to alter implementation patterns to maximize benefits for all.

Smog consists of small particles as well as ground-level ozone, which are formed by substances such as nitrogen oxides (NOx), volatile organic compounds (VOC), fine particles

(PM2.5), sulfur oxides (SOx), and ammonia (NH_3) (Metro Vancouver, 2014). The level of smog-forming pollutants (SFP) in Metro Vancouver has declined significantly over the past two decades, yet the future population growth is expected to stagnate the further decline of the SFP emissions in the region (Metro Vancouver, 2014). According to Dr. Greg Evans of the University of Toronto, the health of ten million Canadians are potentially threatened by traffic-related air pollutants such as ultrafine particles, black carbon, nitrogen oxides, carbon monoxide and volatile organic compounds (Metro Vancouver, 2014). The Canadian Medical Association finds 21,000 annual premature deaths in Canada are attributed to air pollution, despite its relatively clean air quality (Fayerman, 2013). This figure is nearly nine times higher than the number of deaths from vehicle accidents (Brauer, Reynolds, & Hystad, 2013). Approximately ten million people or 32% of Canada's population live in the so-called "exposure zones," or within 500m from either side of highways or within 100m away from major urban roads (Fayerman, 2013). A 2008 federal report states there are 306 premature deaths, 1,158 hospital admissions, and 8,763 emergency department visits due to air pollution in British Columbia annually (Fayerman, 2013). Because British Columbia derives its power supply from relatively cleaner sources, increasing adoption of electric vehicles is expected to contribute to reduced risk of air pollution-related incidents.

2.2 Method

2.2.1 Assumptions

The estimation of the environmental load mitigation benefits associated with the adoption of electric vehicles in the Metro Vancouver region requires certain generalized assumptions about the travelling patterns of drivers and the average greenhouse gas emissions of gasoline and electric vehicles, as explained below:

- The annual mileage is assumed to be 13,100km, which is the average driven by light vehicles in British Columbia in 2008, as opposed to the Canadian average of 15,200km (Natural Resources Canada, 2008).
- It assumes $5,000 incentives for 1,800 electric vehicles are paid out simultaneously; this is in order to avoid the complexity of calculations associated with discount rate, as in reality the subsidies are paid out over the course of more than a year.
- It assumes the recipients of the $5,000 incentives switch from conventional gasoline vehicles to electric vehicles.
- The recipients are assumed to own their newly purchased electric vehicles for 8 years; this is based on Nissan Leaf's battery warranty of 8 years or the accumulated mileage of 160,000km, whichever comes first, in Canada (Nissan Canada, 2014).

Table 2.1 Average Fuel Economy and CO2 Emissions of Gasoline and Electric Vehicles

	Fuel Economy	CO_2e Emissions
Gasoline Vehicles	10.3L/100km	2.326kg/L
Electric Vehicles	20kWh/100km	0.025kg/kWh

Based on the Ministry of Environment (2013)

2.2.2 Marginal Damage Cost of GHG Emissions: IPCC Report

Conventionally economists have used two basic monetization approaches to estimate the effects of climate change: (i) damage costs, which refer to the value of assets lost or damaged due to climate change and (ii) control costs, or the costs required to avoid particular damages. Intuitively speaking, if the damage costs are higher than the control costs, it is worthwhile to make an abatement investment, and if the opposite is true, reactive actions should make economic sense.

The estimation of damage costs has conventionally focused on anthropogenic damages such as loss of productivity and illness, but recently more attention has been paid to ecological, intrinsic values as well. As illustrated in Table 2.2 below, the monetized damage estimates significantly vary among different studies; their distribution is generally skewed towards the lower end, as they only consider limited costs and risks without possible catastrophic damages beyond threshold, and they discount non-economic impacts that should not be discounted (Litman, 2012).

Table 2.2: Monetized Damage Estimates of CO2 emissions

Publication	Description	Cost Value/Tonne CO_2	2007 USD/t CO_2
Tol (2005)	Minimum	-4 Euro (2000)	-$4.43
	Central	11 Euro	$12
	Maximum	53 Euro	$59
DLR (2006)	Minimum	15 Euro (2000)	$17
	Central	70 Euro	$78
	Maximum	280 Euro	$310
Jakob, Craig, & Fisher (2005)	Damage Cost	NZ$270 (2003)	$178
Hohmeyer & Gartner (1992)	Damage Cost	$220	$326
Bein (1997)	Recommended	CAD$1000	$917
	Maximum	CAD$4246	$3910

Based on Litman (2012)

The present investigation utilizes the marginal damage cost of carbon dioxide of $12 per ton, which is presented in the Intergovernmental Panel on Climate Change (IPCC) Working Group 2 Assessment Report 4 (2007). Based on the value and the aforementioned assumptions, the greenhouse gas reduction benefits from electric vehicles can be computed as follows:

CO_2 emissions/year from a gasoline car = (0.002326t/L)(10.3L/100km)(13,100km/100km)

= 3.1384718t

CO_2 emissions/year from an EV = (0.000025t/kWh)(20kWh/100km)(13,100km/100km) = 0.0655t

CO_2 emissions difference per year = 3.1384718t - 0.0655t = 3.0729718t

Δ annual GHG reduction benefits = (# EV adoption) * $12/t *

(${CO_2}$ emission of gasoline car – ${CO_2}$ emission of EV)

2.2.3 APEEP Model's Marginal Damage Cost of Air Pollutant Emissions

Conventional air pollution control policies, such as taxes and trading systems, do not take into consideration the fact that the damage cost of emissions varies depending on the emissions source. Although uniform tax or ton-for-ton basis trading system results in cost effectiveness, taxes or trading based on marginal damage of emissions actually result in efficiency, which Muller & Mendelsohn (2009) claim should be adopted.

The Air Pollution Emission Experiments and Policy (APEEP) analysis model is an integrated assessment model developed in order to evaluate the marginal damage cost of six pollutants from 10,000 distinct sources in the US, including both county-aggregated ground level sources and point (individual) sources sorted by location and height (Muller & Mendelsohn, 2009). The study includes PM2.5, PM10 (excluding particles with diameter of 2.5 micrometers to avoid double counting), NOx, NH3, volatile organic compounds (VOCs), and SO2. The emissions of those pollutants are interdependent to certain extent. For instance, NH3 emissions interact with NOx and preferentially with SO2 to form PM2.5. NOx and VOC interact to form O3, which combines with NH3 to form PM2.5.

The value of mortality risks used in the APEEP model is from a meta-analysis of the hedonic wage literature (Mrozek & Taylor, 2002). An increase in 1/10,000 chance of accidental death is worth $200 in wage per year, regardless of age; from this value, the model computes the value of statistical life (VSL) discounting any future earnings (3%). This implies the age distribution of a country is an important determinant of damage cost; younger counties are more likely to have relatively higher marginal damaged costs than older ones, especially given human health-related damages may be responsible for nearly 95% of the damages of air pollution.

The APEEP model, however, is specific to the United States, and no similar model that locally computes the marginal damage costs of air pollutants emissions was found in the Canadian context to the best of the author's knowledge. Therefore the present study utilizes the APEEP model's values from King County, Washington, where downtown Seattle is located for the geographic proximity and demographic features it shares with Metro Vancouver.

Table 2.3: Marginal Damage Costs of Dominant Air Pollutants

Pollutant	Emissions per km (t/km)	Marginal Damage ($/t)
VOC	1.664E-06	1462.5
NOx	1.1153E-06	29.2
PM10	7.0811E-09	1393.3
PM2.5	6.5983E-09	14639.7
SO_2	----	4880.4
NH_3	----	31985.4

Based on the US Environmental Protection Agency (2008)

2.2.4 Discount Rate

Since a vehicle ownership, in most cases, lasts for more than a year, any benefits and costs that emerge after the second year on needs to be discounted to compute the net present value of the environmental load mitigation benefits in the present study. Unlike discounting future income streams of individuals or financial investments, discounting environmental and social benefits has been controversial due to the irreversible nature of natural capital and ambiguity of the intrinsic value of natural capital.

Discounting practice by governments, when assessing the net present value of public investment projects, varies significantly. In Canada, the Federal Treasury Board Secretariat has recommended the use of a social discount rate of 8 percent with a sensitivity analysis of 3 percent and 10 percent since 2007, although much lower rates tend to be used for health and environment cost-benefit analyses (Boardman et al., 2011). The present study will use the discount rate of 0 percent, 7 percent, and 10 percent, with the 7 percent being the benchmark.

All the calculated values will be converted from the US dollars into the Canadian dollars at the exchange rate as of June 6, 2015 (1 USD = 1.24 CAD) for comparison with other values in the Canadian dollars introduced later in the study.

2.3 Results

Based on the aforementioned assumptions regarding driving patterns and average emissions, the environmental load mitigation benefits of an electric vehicle adoption in Metro Vancouver were estimated as shown in Table 2.4 (detailed computation found in Appendix II). With annual environmental benefits resulting from the mitigation of greenhouse gas emission effects per vehicle of $45.71, the benefit of an electric vehicle ownership in Metro Vancouver is estimated to be $292.16 per vehicle; with the majority of the province's power generated from hydropower, the benefit per km driven is considered high by North American standards. Since the annual mileage of British Columbian drivers is relatively shorter, however, the benefits could be even greater if electric vehicle drivers drive longer distances than drivers of other vehicle types.

As seen in Table 2.3, the majority of air pollution reduction benefits originates from voltaic organic compounds, VOCs ($39.53 without discounting) and NH_3 ($18.60). The marginal damage cost of VOCs is not significantly higher than other pollutants yet their average emissions amount is high at 0.0218t per annum, although the value would significantly fluctuate depending on the vehicle model drivers switch from. On the other hand, the benefits from NH_3 emissions reductions are high despite the low emissions due to its significantly high marginal damage costs. The total air pollution mitigation benefit from an electric vehicle adoption ownership is estimated to be $386.90 with 7% discounting. As opposed to climate change effects that are globally spread, the benefits of air pollution mitigation are rather locally enjoyed.

In sum, the total environmental load mitigation benefits of an electric vehicle adoption in Metro Vancouver are estimated to be $679.06. This value implies that for every $5,000 point-of-sale incentives provided for purchase of an electric vehicle, the environmental rate of return for the investment is a little more than 10%.

2.4 Chapter Summary

This chapter estimated the average benefit of environmental load mitigation of an electric vehicle adoption in Metro Vancouver to be $679.06, $292.16 of which is from greenhouse gas emissions reduction and $386.90 from air pollution mitigation. The Government of British Columbia needs a more strategic incentive provision for electric vehicles in order to further enhance the benefits for all from the policy.

Table 2.4: Environmental Load Mitigation Benefits of EV Adoption in Metro Vancouver

a) GHG Emissions Reduction Benefits

	0% discount rate	7% discount rate	10% discount rate
Annual Benefit per Vehicle	$45.71		
Total Benefit per Vehicle Ownership	$365.81	$292.16	$268.34
Total Benefit (1800 vehicles)	$658,451.82	$525,879.90	$483,008.88

Unit: Canadian Dollars (CAD)

b) Air Pollution Reduction Benefits per Vehicle by Pollutant (0% discount rate)

Pollutant	Annual Benefits per Vehicle
VOC	$39.53
NOx	$0.53
PM 10	$0.16
PM 2.5	$1.57
SO_2	$0.16
NH_3	$18.60
TOTAL	**$60.55**

Unit: Canadian Dollars (CAD)

c) Air Pollution Reduction Benefits

	0% discount rate	7% discount rate	10% discount rate
Total Benefit per Vehicle Ownership	$484.43	$386.90	$355.35
Total Benefit (1800 vehicles)	$871,973.60	$696,411.46	$639,638.29

Unit: Canadian Dollars (CAD)

d) Total Environmental Load Mitigation Benefits

	0% discount rate	7% discount rate	10% discount rate
Total Benefit per Vehicle Ownership	$850.24	$679.06	$623.69
Total Benefit (1800 vehicles)	$1,530,432	$1,222,308	$1,122,642

Unit: Canadian Dollars (CAD)

3: ESTIMATING BENEFITS FROM NON-MONETARY INCENTIVES

This chapter demonstrates that incorporating non-monetary incentives, namely free street parking and HOV lane permits, in addition to monetary incentives will increase the total benefit of environmental load mitigation from the policy by estimating their private benefits.

3.1 Non-Monetary Incentives to be Examined

Providing customers with financial incentives is not the only method to encourage them to switch to clean energy vehicles; the U.S. federal government and local jurisdictions have long provided various types of incentives to both manufacturers and consumers, as seen in Table 3.1 below.

Table 3.1: Examples of Clean Vehicle Incentive Policies in the US

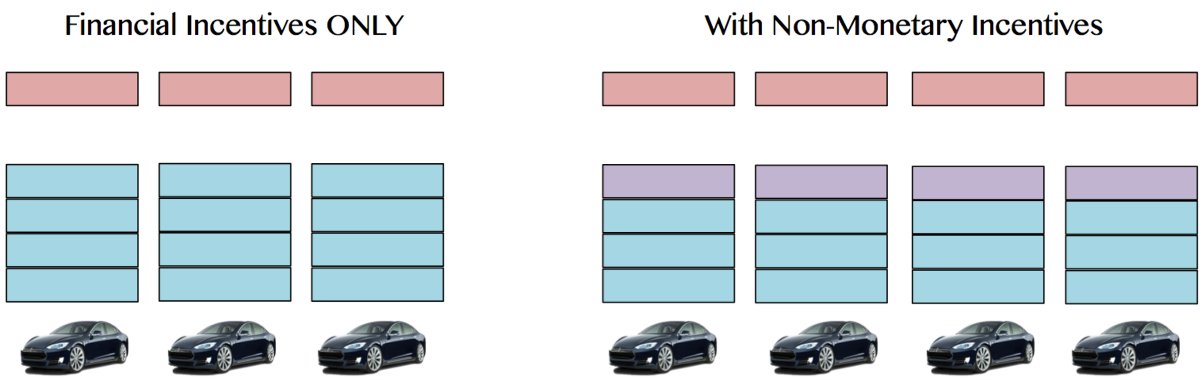
Policy	Recipients	Description
Tax Credits	Consumers	Introduced as part of the Energy Policy Act in 2005, tax credits of between $250 and $3150 were granted. The stimulus package in 2009 offered PHEV subsidies ranging from $2,500-$10,000.
Tax Credits for Manufacturers	Manufacturers	The government provides $1.7 billion in tax credits to manufacturers and businesses in infrastructure development.
Direct Loan Program	Manufacturers	As part of the Energy Independence and Security Act (2007), the government provides a loan package of up to $25 billion to cover “the costs of reequipping, expanding, or establishing manufacturing facilities” in the United States.
Loan Guarantee Program	Manufacturers	As part of the Energy Policy Act of 2005, a $4 billion loan program encourages the development of green technologies.
State Subsidy Programs	Consumers	Point-of-sales subsidies as well as non-monetary incentives such as HOV lane permits and the exemption of parking fees.

Based on McConnell & Turrentine (2010)

Existing traffic facilities such as HOV lanes and street parking tend to be underutilized. Incorporating them into the clean vehicle incentive policies as non-monetary incentives, in addition to the current point-of-sale financial incentives, is expected in order to increase the effectiveness of such policies.

As shown in Figure 3.1, when the government provides non-monetary incentives (right) in addition to financial incentives (left), the private benefits resulting to individual drivers such as travel time saving benefits and simple financial savings partially substitute the benefits from the financial incentives. That is, now the government provides less amount of the financial incentives to each electric vehicle purchase yet to a greater number of vehicles within the same budget, thus resulting in an increase in the environmental load mitigation benefits, without reducing the utility that each vehicle purchaser receives.

In this chapter, it was estimated how much increase in environmental load mitigation benefits could result from the provision of complimentary street parking and HOV lane permits in Metro Vancouver, based on the idea illustrated below.



	Financial Incentives ONLY	With Non-Monetary Incentives
Environmental Benefits	3	4
Private Benefits from Non-Monetary Incentives	0	4
Financial Subsidy	12	12

Figure 3.1: How Non-Monetary Incentives Increase the Overall Environmental Benefits

3.1.1 Street Parking in Metro Vancouver

The City of Vancouver manages parking meters throughout the town in order to "encourage more frequent turnover of parking spaces, so business patrons and visitor can find parking on busy streets." They charge between $1.00 and $6.00 per hour between the hours of 9:00am and 10:00am, mostly with the limit of two hours (The City of Vancouver, n.d.). Parking fees can be paid via credit card, coins, or recently PayByPhone mobile application, which requires drivers to register their phone numbers, credit card numbers, and license plate number. This mobile application system and the recent ubiquity of smartphones have made it easier for the government to price discriminate drivers of different types of vehicles without a large additional investment.

3.1.2 HOV Lanes in Metro Vancouver

HOV lanes, or high-occupancy vehicle lanes are installed adjacent to general-purpose lanes allowing carpoolers or public transit to travel faster. The objectives of HOV lanes are to increase the capacity of freeways, to reduce the overall congestion, to save travel time, to increase system efficiency, and to reduce greenhouse gas emissions (Kwon and Varaiya, 2007). First implemented in Virginia in 2000, the HOV exemption policy for clean vehicles such as hybrids and electric vehicles has been popular in other US states such as Florida, Georgia, California, and Arizona (Diamond, 2008).

Analyzing highway traffic data from California's vehicle detector stations, Kwon and Varaiya (2007) found 15% of vehicles on HOV lanes experienced a 5-minute time saving over 10 miles, while 7% experienced over 1-minute per mile time saving, proving HOV lanes on California highways to be more reliable then general purpose lanes. Diamond (2008) found there was a strong positive correlation between the sales of hybrid electric vehicles and HOV time savings; a strong sales impact was observed in Northern Virginia, where greater than 50% commuting time savings was expected.

HOV lanes in California are installed with different configurations; North California implements continuous access HOV lanes, which are not separated from the adjacent MF (mixed-flow) lanes, while South California implements limited-access HOV lanes, where drivers are able to switch lanes only at designated locations. Boriboonsomsin and Barth (2008) study the pollutant emissions from the two types of configurations using the models such as a microscopic traffic simulation model (PARAMICS) and a modal emissions model (CMEM) and find continuous access HOV lanes result in lower pollutant emissions in all the scenarios. The study hypothesizes the lower emissions of continuous access HOV lanes result from the abundance of lane-switching opportunities compared to limited access HOV lanes, which results in less unnatural driving behavior such as sudden acceleration and deceleration around the designated lane switch locations and thus higher emissions.

Another study by Nesamani et al. (2010) analyzed the effects of HOV lane permits issuance to hybrid vehicle drivers in California in terms of overall systemic performance, corridor level performance, and air quality by combining traditional planning method for demand estimation and PARAMICS, and found the VMT (vehicle miles travelled) and VHT (vehicle hour travelled) improved with greater number of hybrids on the network; although allowing hybrids on HOV lanes in already congested corridors would result in further congestion due to more frequent lane switches, in general HOV lane permits issuance is considered effective below certain thresholds.

On the other hand, however, some have claimed HOV lanes do not optimize the overall benefits. Konishi and Mun (2010), using an optimization model, concluded charging universal toll, or charging for general purpose lanes, results in more carpooling and lower social costs than installation of HOV lanes. Burris and Lipnicky (2009) computed user costs of single, reversible HOV lanes and having two general purpose lanes in Houston, Texas, and concluded user costs are lower for two general purpose lanes for all computation scenarios.

Under the Traffic Management Program initiated in June 1999 with the purpose of improving travel time savings, travel time reliability, accident rates, and pollutant emissions along Highway 1 in Greater Vancouver, several projects were implemented including Freeway Service Patrol and the installation of HOV lanes along the highway (The Ministry of Transportation and Infrastructure, n.d.). Now Metro Vancouver has HOV lanes installed both on highways, which are operated and managed by the provincial government, and on non-highway roads, which are under the management of respective municipal governments, as seen in Tables 3.2 and 3.3.

Table 3.2: HOV Lanes Operated by BC Government

#	**Route**	**Direction**	**Distance**
1	Highway #1 Trans Canada, Lower Mainland	West/East	16km
2	Highway #7 Lougheed, Lower Mainland	North/South	2.6km
3	Highway #17 Northbound, Lower Mainland	North	1.75km
4	Highway #99 Northbound, Lower Mainland	North	5.25km
5	Highway #99 Southbound, Lower Mainland	South	4km

Table 3.3: HOV Lanes Operated by Municipal Governments

Location	**Distance**
Hastings Street (Burnaby)	7 km
Granville Street (Vancouver)	8 blocks
Georgia Street (Vancouver)	1.8 km
St Johns Street / Clarke St. Highway 7A (Port Moody)	2.9 km
Barnet Highway 7A (Burnaby)	7.9 km

3.2 Method

3.2.1 Calculation of Benefits from Non-Monetary Incentives

Assuming that the benefits of environmental load mitigation from each electric vehicle purchase in Metro Vancouver is constant at $679.06, as presented in Chapter 2, the increase in the number of electric vehicles and environmental load mitigation benefits in case that non-monetary incentives are provided can be calculated as follows:

Increase in Benefits of Environmental Load Mitigation
= Benefits per EV Adoption * (Number of EVs Subsidized Under the New Scheme – Number of EVs Subsidized Under the Existing Scheme)
= $679.06 * (Number of EVs Subsidized Under the New Scheme – 900) (3.1)

Number of EVs Subsidized Under the New Scheme
= Total Budget / (Currently Provided Monetary Incentive – Private Benefits from Non-Monetary Incentives)
= $4,500,000 / ($5,000 – Private Benefits from Non-Monetary Incentives) (3.2)

Substituting (3.2) into (3.1),
Increase in Benefits of Environmental Load Mitigation
= $679.06 * { [$4,500,000 / ($5,000 – Private Benefits from Non-Monetary Incentives)] – 900} (3.3)

The Government of British Columbia, for the first term of the CEVforBC point-of-sale incentives until February 2014, provided subsidies enough to cover 1,800 electric vehicles throughout the province. Metro Vancouver, with the population of 2.5 million, occupies approximately half the population of the province, and it was therefore assumed that 900 electric vehicles were subsidized in Metro Vancouver under the existing scheme in the present investigation.

3.2.2 Annual Expenditure on Street Parking

According to Statistics Canada (2012), the average British Columbian household spent $10,319 on transportation annually, $161 of which was for parking fees excluding house parking, as seen in Table 3.4. Because the average number of vehicles registered per household in British Columbia was 1.47 (Natural Resources Canada, 2008), the average annual parking fee per vehicle is $109.52. The annual private benefit from free street parking in this investigation was assumed to be $109.52.

Table 3.4: Annual Transportation-Related Expenditures in British Columbia

	2010	2011	2012
Annual Transportation-Related Expenditure per Household	$11,202	$10,980	$10,319
Parking Expenditure Penalty Fees	$253	$198	$161

Unit: Canadian Dollars (CAD)

3.2.3 Benefits of Time Savings from HOV Lanes

(i) Calculating Benefits of Time Savings from HOV Lanes

For simplicity, the present study divides Metro Vancouver into 12 smaller districts or cities: Burnaby, Coquitlam, Delta, Maple Ridge, New Westminster, North Vancouver City, North Vancouver District, Port Coquitlam, Richmond, Surrey, the City of Vancouver, and West Vancouver. Since commuting between certain cities requires the use of particular highways assuming drivers choose the shortest routes possible, as seen in Figure 3.2, investigation of between which Metro Vancouver cities a driver commutes determines if he receives direct time savings benefit from HOV lanes, thus roughly estimating time savings in minutes. The annual time savings benefits from HOV lanes in Metro Vancouver were calculated as follows:

Benefits of Annual Time Savings

= Number of Workdays per Year * Monetary Time Savings per Workday

= Number of Workdays per Year * Time Savings Benefits per Hour * Hour Savings per 1km of HOV Lane Used * HOV Lanes Used per Day

= 250 days/year * Time Savings Benefits per Hour * 1/60h-savings / km of HOV lane used * HOV Lanes Used per Day (3.4)

Based on Eqn. 3.4, the following three variables were investigated in order to calculate the benefits of time savings from HOV lanes in Metro Vancouver: (i) time savings in minutes from HOV lanes during the morning and afternoon commuting hours, as they are the hours when most time savings are expected, (ii) the vehicle commuting patterns among the cities in the region, which show how many people and on what route HOV lanes affect, and (iii) the value of travel time based on British Columbia's transportation cost benefit analyses (Waters, 1992).

For each route, their distance and location were checked using Google Map's satellite images, and traffic volume and flow using traffic data from the Ministry of Transportation and Infrastructure.

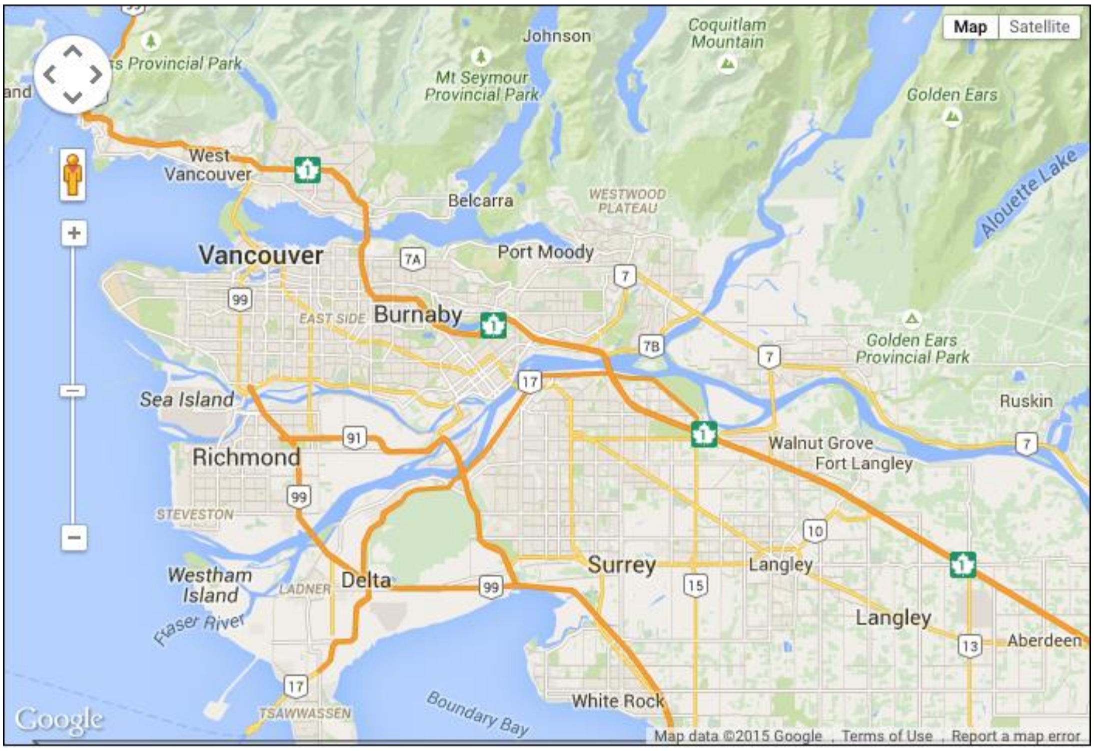


Figure 3.2: Metro Vancouver's Highway System (Retrieved from Google Maps)

(ii) Metro Vancouver's Commuting Patterns

Statistics Canada's National Household Survey (2011) showed the commuting trend in Metro Vancouver by city; as a pattern, a large portion of Metro Vancouver residents commutes within the cities of their residence, and the trend is more apparent in the suburbia.

The figures, however, does not indicate the means of commuting travel, and are not applicable to estimate the number of commuters who are expected to receive HOV lane benefits in the region; those residing in city centers such as the City of Vancouver and the City of Burnaby should intuitively tend to use mote public transit and thus less private vehicles to commute than other cities in the region.

Statistics Canada conducts surveys and compiles data by diving census metropolitan areas (CMAs) and larger census agglomerates (CAs) into small and stable geographic areas with population of between 2,500 and 8,000 called census tracts. Since Statistics Canada publicizes the percentage of commuters commuting by car in each census tract, the vehicle commuting population in each city was estimated by computing the average, as seen in Tables 3.5 and 3.6, which was then multiplied by the overall commuting patterns.

As seen in Tables 3.5 and 3.6, a large portion of the population commutes short distances within the cities of their residence, and only those who commute long distances using highways are expected to receive direct time savings from HOV lanes. Particularly those who commute from Delta and Maple Ridge to the city centers are able to expect significant time savings.

(iii) Cost of Travel Time

The idea that travel time has values originates from a simple theoretical economic model of income-leisure tradeoffs, given there is no disutility of work and people can freely choose number of work hours, which are not realistic (Waters, 1992). Because people must sacrifice leisure to be productive and earn wages, the wage rate is an indication of the marginal value of time, although not perfectly precisely. If one is willing to work for more than 40 hours a week yet it is not possible, his marginal value of time is less than the hourly wage, and if he is willing to work less than 40 hours a week, the marginal value of time is more than the wage provided by the work.

Table 3.5: Vehicle Commuting Patterns in Metro Vancouver

FROM \ TO	Burnaby	Coquitlam	Delta	Maple Ridge	New Westminster	North Vancouver City	North Vancouver District	Port Coquitlam	Richmond	Surrey	Vancouver	West Vancouver	% Commuting by Car
Burnaby	19410	1538	1050	148	1861	1183	757	457	4104	2058	19910	318	65.01%
Coquitlam	7451	8668	691	537	1455	652	425	2517	1296	1930	8131	158	77.4%
Delta	2182	270	9236	19	586	93	69	166	5273	5019	6206	89	82.1%
Maple Ridge	2093	1992	276	8474	648	168	140	2161	480	1216	2561	0	86.0%
New Westminster	3586	678	817	32	3092	214	104	167	1389	1291	4902	40	62.0%
North Vancouver City	970	109	52	0	89	3679	1915	69	326	166	3747	822	61.5%
North Vancouver District	2226	261	120	25	189	4496	5212	69	632	516	8110	1504	78.0%
Port Coquitlam	2720	3251	343	454	717	271	214	3907	557	1034	3384	72	82.0%
Richmond	3172	266	1664	0	479	266	138	82	28888	1437	14347	43	76.2%
Surrey	10315	2576	9433	350	3057	666	431	939	10819	60266	17534	150	82.7%
Vancouver	11862	1014	1561	114	1111	2028	1325	427	11070	2639	86496	808	53.4%
West Vancouver	678	31	38	0	86	947	509	28	231	114	3308	2234	73.9%

Unit: Number of People

Legend: 0-2,000 | 2,001-5,000 | 5,001-10,000 | 10,001+

Table 3.6: Distribution of Car Commuters in Metro Vancouver

FROM \ TO	Burnaby	Coquitlam	Delta	Maple Ridge	New Westminster	North Vancouver City	North Vancouver District	Port Coquitlam	Richmond	Surrey	Vancouver	West Vancouver
Burnaby	3.8771%	0.3071%	0.2098%	0.0296%	0.3718%	0.2364%	0.1511%	0.0913%	0.8198%	0.4111%	3.9768%	0.0635%
Coquitlam	1.4882%	1.7314%	0.1381%	0.1072%	0.2906%	0.1302%	0.0849%	0.5028%	0.2589%	0.3855%	1.6242%	0.0316%
Delta	0.4358%	0.0539%	1.8449%	0.0038%	0.1170%	0.0185%	0.0139%	0.0331%	1.0533%	1.0025%	1.2397%	0.0177%
Maple Ridge	0.4180%	0.3980%	0.0551%	1.6926%	0.1295%	0.0336%	0.0280%	0.4316%	0.0959%	0.2429%	0.5115%	0.0000%
New Westminster	0.7162%	0.1355%	0.1632%	0.0063%	0.6176%	0.0427%	0.0208%	0.0334%	0.2774%	0.2578%	0.9792%	0.0081%
North Vancouver City	0.1939%	0.0217%	0.0103%	0.0000%	0.0177%	0.7348%	0.3826%	0.0137%	0.0652%	0.0332%	0.7485%	0.1641%
North Vancouver District	0.4447%	0.0522%	0.0239%	0.0051%	0.0377%	0.8981%	1.0410%	0.0138%	0.1262%	0.1030%	1.6199%	0.3003%
Port Coquitlam	0.5434%	0.6493%	0.0686%	0.0907%	0.1433%	0.0541%	0.0427%	0.7804%	0.1113%	0.2065%	0.6760%	0.0145%
Richmond	0.6337%	0.0532%	0.3324%	0.0000%	0.0957%	0.0532%	0.0276%	0.0163%	5.7703%	0.2871%	2.8657%	0.0085%
Surrey	2.0603%	0.5145%	1.8842%	0.0700%	0.6106%	0.1330%	0.0861%	0.1876%	2.1610%	12.0379%	3.5022%	0.0300%
Vancouver	2.3694%	0.2025%	0.3118%	0.0228%	0.2219%	0.4051%	0.2646%	0.0854%	2.2111%	0.5272%	17.2771%	0.1613%
West Vancouver	0.1354%	0.0062%	0.0076%	0.0000%	0.0172%	0.1891%	0.1018%	0.0055%	0.0461%	0.0227%	0.6607%	0.4462%

Routes with HOV Lanes

Scholars have long attempted to accurately monetize the value and cost of travel time using various analytical techniques, particularly in the Great Britain; The development of disaggregate choice model based on random utility theory has improved time value studies since 1970s, as well as other new experiments using transfer price, ranking tasks, metric rating scales, stated choice, and priority evaluator (Wardman, 1998). Although many past studies have constrained the value of travel time to be the same across different transportation modes, as Litman (2012) claims, it is the quality of the time people spend in a particular mode that determines the value of travel time. Wardman (1998) made a similar claim that "the opportunity cost of time spent travelling" and "the disutility of time spent travelling" were the two key determinants of travel time values.

In British Columbia, the Ministry of Transportation uses the travel time value estimates of 50% of the median hourly household income for the cost-benefit analyses of their transportation projects, which is the value first recommended for the User Benefit Cost Spreadsheets (UBCS) model in 1994 (Apex Engineering Limited, 2012). The average BC median household income was $66,310 in 2012, which makes the current value of travel time $15.94 per hour, and the value was adopted to estimate the value of travel time saving from HOV lanes in the present study.

As seen in Table 3.7, the value of travel time in British Columbia is based on Waters' investigation of 20 different studies of value of commuting time, arbitrarily excluding the highest and lowest values, and results in the mean value of 58.4 percent of the wage rate. Comparing Miller's (1989) list and Waters' compilation, they concluded the estimate of the value of travel time for auto commuting is within 40 and 60% of the wage rate, with the North American value at the upper end of the range.

Table 3.7: Value of Travel Time

Author	Country	Travel Time Cost (% Wage)
Beesley (1965)	UK	33-50%
Quarnby (1967)	UK	20-25%
Stopher (1968)	UK	21-32%
Oort (1969)	USA	33%
Thomas et al. (1970)	USA	86%
Lee et al. (1971)	UK	40%
Wabe (1971)	UK	43%
Talvittie (1972)	USA	12-14%
Hensher et al. (1974)	Australia	2.7%
Kraft (1974)	USA	38%
McDonald (1975)	USA	45-78%
Ghosh et al. (1975)	UK	73%
Guttman (1975)	USA	145%

Author	Country	Travel Time Cost (% Wage)
Hensher (1977)	Australia	39%
Nelson (1977)	USA	33%
Hauer (1982)	Canada	67-101%
Edmonds (1983)	Japan	42-49%
Deacon et al. (1985)	USA	52-254%
Hensher et al. (1985)	Australia	105%
Guttman et al. (1986)	Israel	59%
Fowkes (1986)	UK	27-59%
Hau (1986)	USA	46%
Chui et al. (1987)	USA	82%
Mohring et al. (1987)	Singapore	60-120%
Cole (1990)	Canada	93%

Based on Waters (1992)

3.3 Results

3.3.1 Benefit of Financial Savings from Complimentary Street Parking

Based on the $109.52 annual private benefits from free street parking, assuming 7% discount rate, when the government of British Columbia provides complimentary street parking to the drivers of electric vehicles for 1, 3, and 5 years, the estimated increase in environmental load mitigation benefits would be 2.2%, 6.6%, and 10.6%, respectively.

Table 3.8: Environmental Load Mitigation Benefits from Complimentary Street Parking

Duration	Estimated Private Benefits (7% discount rate)	Resulting Increase in Environmental Load Mitigation Benefits
1 year	$109.52	$13,686.51 (2.24% increase)
3 years	$307.53	$40,053.15 (6.55% increase)
5 years	$480.49	$64,974.61 (10.63% increase)

Unit: Canadian Dollars (CAD)

3.3.2 Benefits of Time Savings Obtained from HOV Lane Permits

Combining the vehicle commuting patterns and the estimated annual HOV lane time savings benefits, the most apparent trend shown is the divergence between the routes where most people commute the most and those where HOV lanes are installed. In Metro Vancouver, approximately 75% of the population either lives and commutes within the same city, or commutes to the city centers, the City of Vancouver and the City of Burnaby; this could explain lower vehicle mileages of British Columbian drivers and relatively organized public transportation systems in the city center. The proportion of the population who are expected to receive direct time savings benefits from HOV lanes during commuting hours is 7.13%, mostly those commuting long distances.

Table 3.11 shows the estimated annual HOV lane monetary benefits, assuming 250 working days per annum based on Equation 3.3. The figures illustrate even among the 7.13% who are expected to receive the direct time savings benefits from HOV lanes, the amount of benefits differs significantly depending on the commuting distance; the annual benefits varies between $116.23, a little over one minute of time saving per commuting day, and $2470.70, or over 150 hours of commuting time savings annually.

Table 3.9: Distribution of Commuters Receiving Direct HOV Lane Benefits

Annual Monetized Benefits	% Metro Vancouver Car Commuters
$2470.70	0.480%
$2125.33	2.307%
$730.58	2.343%
$345.37	1.567%
$116.23	0.436%
TOTAL	**7.132%**

Units: Canadian Dollars (CAD)

On average, the annual monetary time savings benefits from HOV lanes in Metro Vancouver becomes $64; the total time savings benefits from HOV lane permits divided by the estimated total number of drivers in Metro Vancouver who purchase electric vehicles with the program's point-of-sale incentives. Assuming those private benefits are equally shared among all the electric vehicle buyers, the total environmental load mitigation benefits from the program increase as shown on Table 3.10 below when the government provides HOV lane permits in addition on the monetary incentives.

Table 3.10: Private Benefits and Environmental Load Mitigation Benefits from Implementing HOV Lane Permits in Metro Vancouver

Duration	Estimated Private Benefits (7% discount rate)	Environmental Load Mitigation Benefits
1 year	$64	$7,924.20 (1.30% increase)
3 years	$179.71	$22,785.04 (3.73% increase)
5 years	$280.78	$36,361.90 (5.95% increase)

Unit: Canadian Dollars (CAD)

Table 3.11: Estimated Annual HOV Lane Monetary Benefits

TO / FROM	**Burnaby**	**Coquitlam**	**Delta**	**Maple Ridge**	**New Westminster**	**North Vancouver City**	**North Vancouver District**	**Port Coquitlam**	**Richmond**	**Surrey**	**Vancouver**	**West Vancouver**
Burnaby												
Coquitlam						**$2125.33**	**$2125.33**					**$2125.33**
Delta	**$116.23**					**$730.58**	**$730.58**		**$730.58**		**$730.58**	**$730.58**
Maple Ridge	**$2470.7**	**$345.37**			**$345.37**	**$2470.7**	**$2470.7**	**$345.37**	**$345.37**		**$345.37**	**$2470.70**
New Westminster												
North Vancouver City												
North Vancouver District												
Port Coquitlam												
Richmond												
Surrey	**$2125.33**											
Vancouver												
West Vancouver												

Unit: Canadian Dollars (CAD)

3.4 Chapter Summary

In this chapter, the private benefits associated with provision of non-monetary incentives, namely free street parking and HOV lane permits in Metro Vancouver were estimated. It was quantitatively demonstrated that with the private benefits from non-monetary incentives partially substituting the monetary incentives, the government is able to provide subsidies to a larger number of electric vehicles within the same budget constraint, thus increasing the total environmental load mitigation benefits out of the policy.

The average driver is expected to save $109.52 annually from complimentary street parking. The monetary time savings benefits from HOV lanes varied significantly, from $116.23 and $2470.70 annually; only 7.1% of drivers in the region commuted the routes where HOV lanes were installed, however, and the remaining 92.9% did not receive direct time savings benefits.

4. CONSUMER PREFERENCES OF ELECTRIC VEHICLE INCENTIVES

In this chapter, the results of a consumer questionnaire survey targeting Metro Vancouver residents are presented. The aim of the survey is to understand their preferences for different non-monetary incentives compared to the currently implemented monetary incentives.

4.1 Factors Affecting the Benefits of Non-Monetary Incentives and Willingness to Accept

The previous chapter investigated the private benefits associated with the provision of HOV lane permits, or monetized time savings benefits, and complimentary street parking, which results in an increase in consumers' disposable income. The investigation showed that it is not realistic to reduce the same amount of monetary incentives in return for non-monetary incentives, as their private benefits differ significantly based on driving patterns and demographics. Additionally, those observable benefits are not the only factor determining consumer's willingness to pay for certain incentives, or in this case willingness to accept reduction in monetary incentives in return for the provision of HOV lane permits and complimentary parking (referred to as "willingness to accept" or "WTA" hereafter).

Conventional models of consumer behavior looked at decision making for consumption from an individual, rational perspective, and assumed that individual preferences are the predominant key factor of consumption behavior. Theory of Reasoned Action (TRA) states intentions to make certain actions are the good indicator of actual behavior, which is controlled by "consequential beliefs," or what actual benefit and cost result due to the behavior and "normative beliefs," or the expectations from the social groups one belongs to, such as families or a group of friends (Ajzen & Fishbein, 1980). Theory of Planned Behavior (TPB) extends TRA by adding "control beliefs," or actual real-world constraints that keep one from behaving certain way (Ajzen, 1991).

The normative beliefs and control beliefs presented in TPB indicate that society and "others" are as important of key determinants as individual preferences in consumption pattern formation, particularly in pro-environmental consumption behavior (Jackson, 2005; Mead, 1934).

The concepts are applicable to the case of non-monetary incentives provision for electric vehicles as well. For the particular non-monetary incentives focused in the present study, it can be assumed there are mainly four types of private benefits received by consumers, which correspond to each of the beliefs introduced by TPB and collectively determine their willingness to pay for the incentives, as seen in Figure 4.1: (i) actual monetary benefits or savings, (ii) non-monetary benefits such as time savings, (iii) benefits from receiving status as an environmentally-conscious person, and (iv) benefits resulting from convenience and reduced psychological stress. Those that are initially intended as primary benefits by the government can be called private direct benefits, while those that are not intended by the government but perceived as benefits by consumers and add more values to incentives can be called private indirect benefits. Both types of the benefits together determine willingness to pay or accept for certain products and services. This is not to be confused with primary and secondary market effects in typical cost benefit analyses, which focus on macro-level changes in demand and supply reacting to certain investments.

In case of HOV lane permits, for instance, even if one does not reside or commute in the area where direct time savings benefits from HOV lanes are expected, which are considered private direct benefits, she could still be willing to pay for the fact she has an access to them anytime as necessary, or for the HOV lane exemption sticker, which can be put on vehicles and enjoy being recognized as an environmentally-conscious consumer. Similarly, a consumer who does not regularly use street parking could still be willing to pay for the service for benefits other than financial savings, such as convenience of having access to free parking anytime.

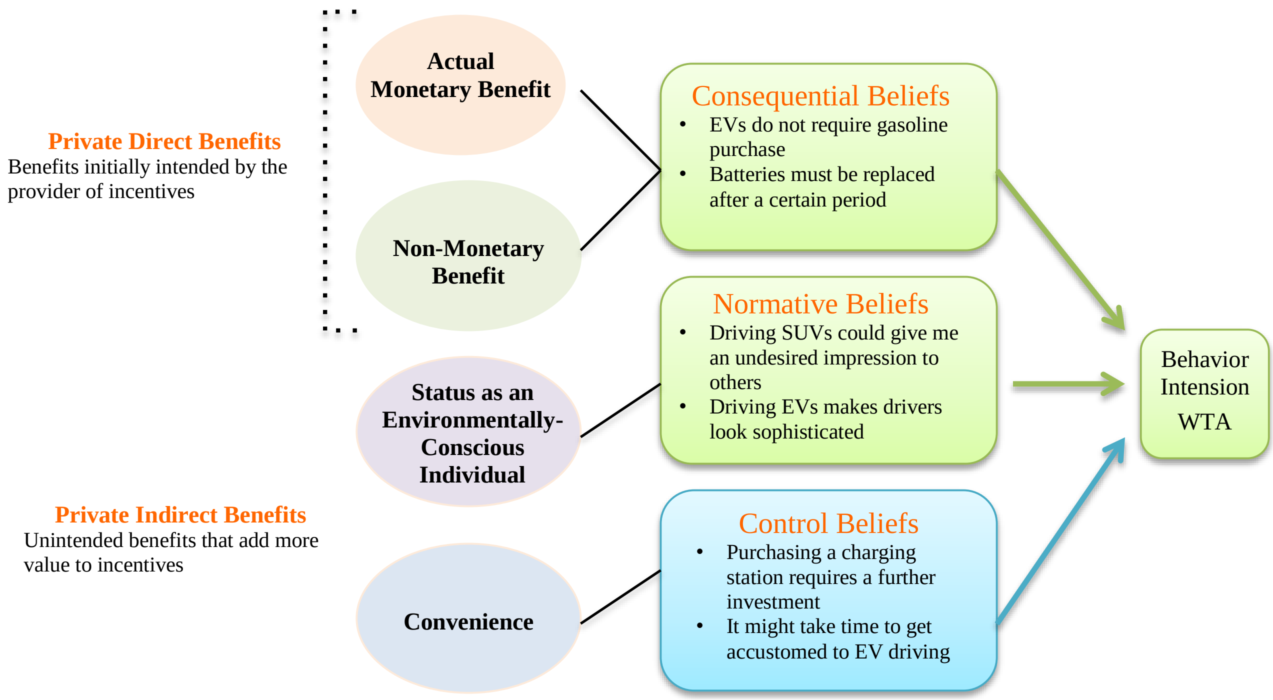


Figure 4.1: Theory of Planned Behavior and Private Direct and Indirect Benefits

4.2 Method of Consumer Preferences Survey

4.2.1 Questions and Intentions

In order to estimate consumers' WTA for reductions in the existing $5,000 financial incentives in return for HOV lane permits and complimentary street parking and investigate what factors affect the WTA, an online questionnaire survey was conducted for Metro Vancouver residents between May 11 and May 24, 2015, with Survey Monkey services (Refer to Appendix III for the entire survey questions). The survey collected 60 responses in total, 52 of which were valid and used for the analysis, and 8 invalid due to the residency outside of Metro Vancouver or incomplete responses.

Prior to the survey, the following were hypothesized based on the estimated environmental load mitigation benefits of non-monetary incentives and informal interview sessions with members of Vancouver Electric Vehicle Association (VEVA), whose details can be found in Appendix IV.

- Those who commute long distances or reside in suburbs are willing to accept higher reduction in the monetary incentives in return for HOV lane permits, as time savings expected from them are substantially larger, as seen in Chapter 3.
- On the other hand, those who live in the commuting centers of the region, in or proximity of the City of Vancouver, tend to drive for non-commuting purposes more and thus are willing to accept higher reduction amount for the provision of free street parking.
- Those with higher income are expected to indicate higher willingness to accept for HOV lane permits.
- Even though consumers do not expect to directly receive benefits out of the incentives, some consumers prefer provision of non-monetary incentives and their benefits such as reduction of psychological stress and status as seen earlier. These consumers who expect indirect unintended benefits are willing to accept reduction of the monetary incentives for receiving non-monetary incentives.

As seen in Table 4.1, the questionnaire consists of four main components. The first part asks about respondents' driving behavior and commuting patterns as well as their general knowledge about both pure electric vehicles and hybrid electric vehicles. Those who cannot distinguish the two are given a brief description of the two types of electric vehicles so they know the survey particularly focuses on pure electric vehicles.

The second part of the survey examines factors affecting respondents' decision to purchase electric vehicles. The question attempts to understand, from a broad perspective, what features make electric vehicles attractive particularly in Metro Vancouver. For instance, economic motives should play a key role where gasoline is expensive, and social benefits are important where environmental consciousness of the public is high. Based on Ozaki &

Sevastyanova (2011), the following five criteria were set: (i) the social benefits associated with reduction of environmental issues, (ii) interest in new technologies, (iii) being perceived as an environmentally conscious person, (iv) government incentives such as financial rebates, parking, and HOV lane permits, and (v) personal benefits associated with less spending on fuel and vehicle maintenance costs.

The third section asks more specifically what non-monetary incentive policies are likely to positively affect respondents' electric vehicle purchase *in addition to* the existing financial rebates. The respondents are given a brief description for each of the following non-monetary incentives: (i) charging station rebates, (ii) free street parking, (iii) HOV lane permits, (iv) better public charging station availability, and (v) charging station installments at condominiums.

The fourth part, where respondents are asked about their WTA for reduction in financial rebates in return for HOV lane permits and free street parking for five years, utilizes dichotomous choice contingent valuation method (CVM). At first respondents answer whether they are willing to accept reduction without any specific amount presented. Then after being presented a specific amount, \$500, or B_i in this particular case, the respondents are asked whether they are willing to accept it. If yes, they are further asked if they are willing to accept \$750 (B_i^u) reduction, and if no, they are asked if they are willing to accept \$250 (B_i^d) reduction. For such studies, the first amount presented must be carefully considered as it determines respondents' price perception. Since the investigation in Chapter 3 revealed the average discounted monetized benefits of complementary street parking and HOV lanes (times savings benefits) for 5 years are \$480.49 and \$280.78 respectively, the first reference amount will be \$500, and the amount increases or decreases by \$250 based on whether \$500 is accepted.

Such method, compared to other contingent valuation methods, is known to reduce respondents' confusion and biases instead of being asked to openly answer their willingness to pay (Kuriyama, 2011). This "double-bounded" dichotomous choice method of estimating willingness to pay with random utility model was first introduced by Hanemann (1984).

Table 4.1: Structure of the Questionnaire

Section	Intention/Objectives
1. Driving Patterns (Q1-5)	• Respondents' knowledge of electric vehicles • Commuting and driving patterns
2. Factors Affecting Electric Vehicle Purchase (Q6)	• What features of electric vehicles attract consumers? • Environmental benefits, interest in new technologies, status as an environmentally conscious consumer, government incentives, and financial savings
3. Non-Monetary Incentives Affecting EV Purchases (Q7-8)	• Which non-monetary incentives affect consumers' electric vehicle purchases *in addition to* monetary incentives?
4. Willingness to Accept for Non-Monetary Incentives (Q9-16)	• Comparison of estimated incentive benefits and actual willingness to accept of consumers
5. Demographics (Q17-20)	• Age, Sex, Income

4.2.2 Estimation of WTA from the Survey Results

Willingness to accept for non-monetary incentives can be estimated by utilizing the results of dichotomous choice analysis with random utility model. As shown in Figure 4.2, respondents can be categorized into four groups as a result of the double-bounded dichotomous choice questions: NN, who are willing to accept reduction of monetary incentives of between \$0 and \$250, NY between \$250 and \$500, YN between \$500 and \$750, and YY, who are willing to accept reduction of greater than \$750. Assuming utility-maximizing behavior of the respondents, the cumulative distribution function of willingness to accept, *G*, at a particular price *B* of a respondent *i* can be written as:

$$G(B_i)=1/1+\exp(\beta_0+\beta_B \ln B_i+\sum\beta_k X_k) \qquad (4.1)$$

where X_k is an explanatory variable determining one's willingness to accept, β_k is their parameter, and k is the number of explanatory variables.

Then the probability of each respondent falling into each group (YY, NN, YN, NY), π^{YY}, π^{NN}, π^{YN}, and π^{NY} can be written as :

$$\pi^{YY} = P\{B_i \leq \text{Max WTA and } B_i^u \leq \text{Max WTA}\}$$
$$= P\{B_i \leq \text{MaxWTA}|B_i^u \leq \text{MaxWTA}\}\ P\{B_i^u \leq \text{MaxWTA}\}$$
$$= P\{B_i^u \leq \text{MaxWTA}\} \qquad (P\{B_i \leq \text{MaxWTA}|B_i^u \leq \text{MaxWTA}\} = 1)$$
$$= 1 - G(B_i^u) \tag{4.2}$$

(Similarly,)

$$\pi^{NN} = G(B_i^d) \tag{4.3}$$
$$\pi^{YN} = G(B_i^u)\text{-}G(B_i^d) \tag{4.4}$$
$$\pi^{NY} = G(B_i)\text{-}G(B_i^d) \tag{4.5}$$

The log likelihood function, L, with N responses will be:

$$\ln L(\theta) = \sum_{i=1}^{N} \{d_i^{YY} \ln\pi^{YY}(B_i, B_i^u) + d_i^{NN} \ln\pi^{NN}(B_i, B_i^d) + d_i^{YN} \ln\pi^{YN}(B_i, B_i^u) + d_i^{NY} \ln\pi^{NY}(B_i, B_i^d)\} \tag{4.6}$$

where θ is a parameter vector and d_i^{YY}, d_i^{NN}, d_i^{YN}, and d_i^{NY} are dummy variables for each of the response patterns. Using the maximum likelihood estimation, each parameter is estimated so that the first order condition of the above function will be

$$\partial \ln L(\theta)/\partial \theta = 0. \tag{4.7}$$

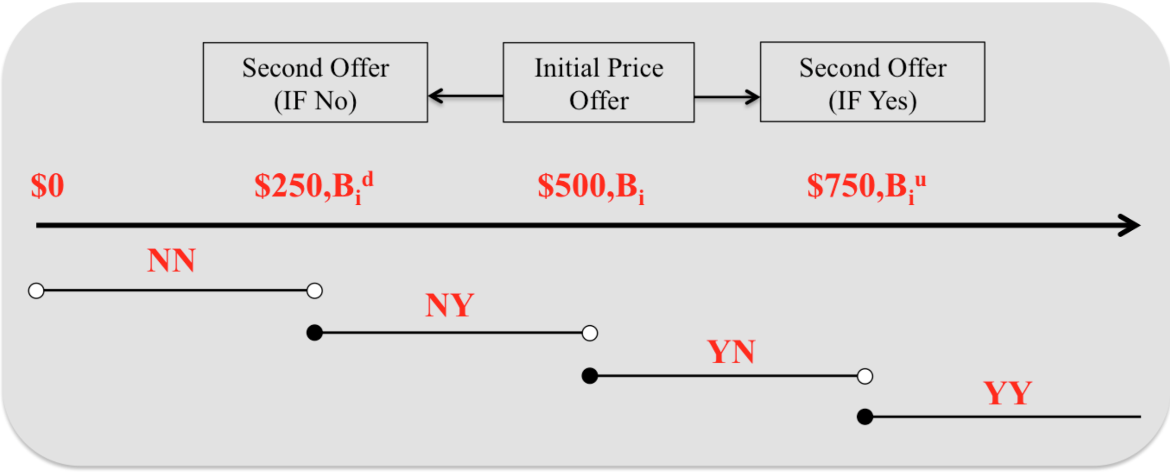


Figure 4.2: Double-Bounded Dichotomous Choice Analysis Method

4.3 Results

4.3.1 General Characteristics of the Respondents

Table 4.2 shows the results of the simple tabulation. Three quarters of the respondents drive at least once a week, and half of the respondents drive primarily for commuting, showing Metro Vancouver's strong automobile dependency despite 30% of the respondents living in the City of Vancouver with a web of bus and train routes.

As Ozaki & Sevastyanova (2011) showed environmental concerns are the strongest motive behind hybrid vehicle purchases in London, 67.3% of the respondents answered social benefits of mitigated environmental issues are a strong motivation behind electric vehicle purchases, and intuitively 75% answered less spending on fuels and maintenance costs are attractive. Provision of government incentives, both monetary and non-monetary, however, was supported only by 15.4%, indicating even financial incentives as provided in Clean Energy Vehicle Program are not the primary trigger of electric vehicle purchases for most.

Table 4.2: Responses in Consumer Preferences Survey

How often do you drive a car?		
Answer Options	**Response Percent**	**Response Count**
5+ days a week	57.7%	30
1-4 days a week	17.3%	9
Once every few weeks	3.8%	2
Rarely (less than once a month)	13.5%	7
Never	7.7%	4

Select the primary purpose you drive your car.		
Answer Options	**Response Percent**	**Response Count**
Commuting	47.9%	23
Daily Errands (ex: shopping, picking up children)	35.4%	17
Recreation	12.5%	6
Other	4.2%	2

Assume you are considering the purchase of a new electric vehicle to replace a gasoline vehicle. Which of the following features are likely to affect your purchase positively? Please select up to two.		
Answer Options	**Response Percent**	**Response Count**
Driving an electric vehicle results in the social benefit of reduced environmental issues.	67.3%	35
Driving an electric vehicle characterizes me as a person familiar with new technologies.	9.6%	5
Driving an electric vehicle characterizes me as an environmentally conscious individual.	19.2%	10
Driving an electric vehicle gives me various government incentives, such as financial rebates, parking, and HOV lane permits.	15.4%	8
Driving an electric vehicle results in less spending on fuels and maintenance costs.	75.0%	39
None of the above would affect my hypothetical purchase.	1.9%	1
Other (please specify below)	5.8%	3

Which of the following incentives are most likely to affect your hypothetical electric vehicle purchase in addition to point-of-sale incentives? Please select two.		
Answer Options	**Response Percent** ***Does not add up to 100%**	**Response Count**
Charging Station Rebates	17.3%	9
Free Street Parking	42.3%	22
HOV Lane Permits	28.8%	15
Better Public Charging Stations Availability	53.8%	28
Charging Stations Installment at Condominiums	38.5%	20
None of the above would affect my hypothetical purchase.	7.7%	4

If you had an HOV lane permit for the routes below, would you use it?		
Answer Options	**Response Percent**	**Response Count**
Yes	84.7%	46
No	15.3%	6

Are you willing to accept reduction in $5,000 monetary incentive in return for provision of HOV lane permits or free street parking for 5 years?					
	Willing to Accept Reduction				**Not Willing to Accept**
	YY	**YN**	**NY**	**NN**	
HOV Lane Permits	10	4	0	4	34
Free Street Parking	8	7	0	4	33

Please select your age group.		
Answer Options	**Response Percent**	**Response Count**
16-24	13.5%	7
25-34	23.1%	12
35-49	17.3%	9
50-64	32.7%	17
65 and over	13.5%	7

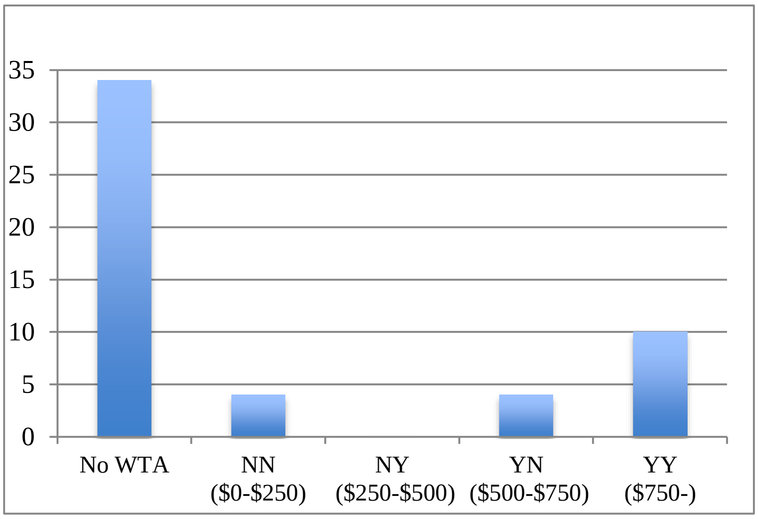
What is your net annual household income? Select one.		
Answer Options	**Response Percent**	**Response Count**
$90,000 or more	23.1%	12
$60,000-$89,999	17.3%	9
$40,000-$59,999	21.2%	11
$25,000-$39,999	15.4%	8
Less than $25,000	7.7%	4
N/A	15.4%	8

More than half of the respondents, or 53.8% answered better availability of public charging stations would positively affect their hypothetical electric vehicle purchase in addition to the point-of-sale incentives, as opposed to provision of non-monetary incentives: 42.3% for free street parking and 28.8% for HOV lane permits. The figures suggest the organization of charging infrastructure throughout the region to ameliorate drivers' range anxiety is as important as the benefits associated with private incentive policies.

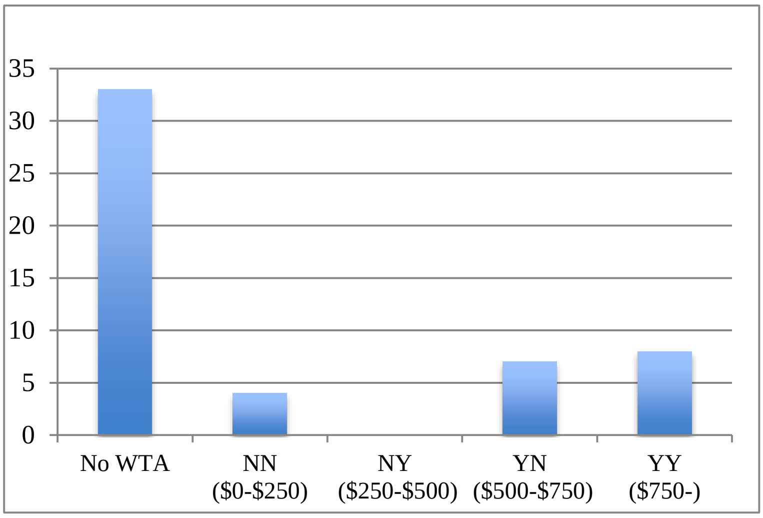
As seen in Table 4.2 and Figure 4.3, when asked how much reduction in monetary incentives they are willing to accept for non-monetary incentives for 5 years, the majority, 34 for HOV lane permits and 33 for free street parking, responded they are not willing to accept any reduction at all. In total, 28 respondents, or 53.8% answered they are not willing to accept any reduction in monetary incentives for either of the two non-monetary incentives. Since those who showed no intention of accepting reduction were filtered out and not given dichotomous choice questions with specific reduction amounts, the distribution of those who are willing to accept showed up uneven, making it difficult to compute the median willingness to accept using the prepared aforementioned random utility model.

Figure 4.3: Distribution of Willingness to Accept

a) Distribution of WTA for HOV Lane Permits



b) Distribution of WTA for Free Street Parking



Among those who are willing to accept reduction for HOV lane permits, more than 10 showed willingness to accept greater than $750 reduction, and 4 respondents greater than $500 reduction. Just one of those ten respondents, however, lives and commutes where annual direct time savings benefits of HOV lanes of $2125.33 is expected, or from the City of Burnaby to Surrey, and the remainder of the respondents still showed willingness to accept despite not commuting the relevant routes. The distribution, along with the fact 84.6% of respondents are willing to *use* HOV lane permits for the designated routes if they had one, suggests private indirect benefits, such as convenience of having access to HOV lanes when necessary and having HOV lane exemption stickers on vehicles, significantly determine one's willingness to accept for HOV lane permits.

As mentioned in Chapter 3, the average savings from free street parking, at 7% discount rate, is $480.49; yet 15 respondents answered they are willing to accept reduction of greater than $500. Although the survey questionnaire did not ask how much respondents spend on non-registered street parking, further research on drivers' parking behavior would be necessary to understand the determinants of their willingness to accept for street parking incentives.

4.3.2 Willingness to Accept

In order to investigate the demographic differences between those who are willing to accept reduction in monetary incentives for non-monetary incentives and those who are not, cross tabulation was performed.

Figures 4.4, 4.5, 4.6, and 4.7 show the age and income distribution of the two groups for both of the incentives. T-test was conducted to investigate the difference in income level and age for the two groups for each of the incentives as shown in Tables 4.3, 4.4, 4.5, and 4.6, and the differences were not statistically significant for a 95% confidence interval; indicating income levels were not likely to be associated with one's willingness to accept reduction of monetary incentives for both HOV lane permits and free street parking.

Tables 4.7 and 4.8 show the select results of cross tabulation between the two groups (those who belong to YY, YN, or NN groups) for each of the non-monetary incentives. For both, much higher percentages of those with willingness to accept answered their primary driving purpose is commuting, and higher proportion of those without willingness to accept answered they primarily drive for daily errands. Regardless of the frequency of driving, it is intuitive commuters are willing to accept reduction of greater amount, as most time savings benefits are expected from HOV lanes during commuting peak hours.

Figure 4.4: Age Distribution: HOV Lane Permits Willingness to Accept

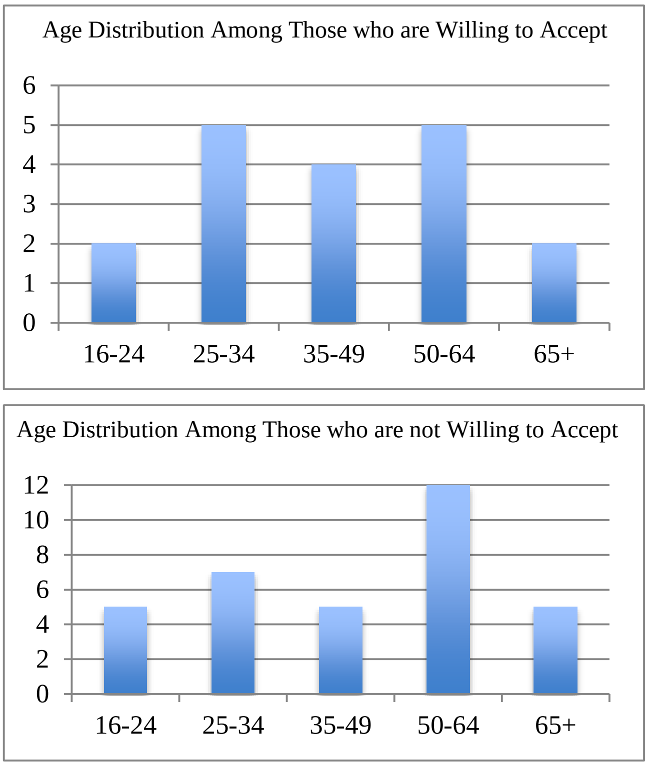


Figure 4.5: Income Distribution: HOV Lane Permits Willingness to Accept

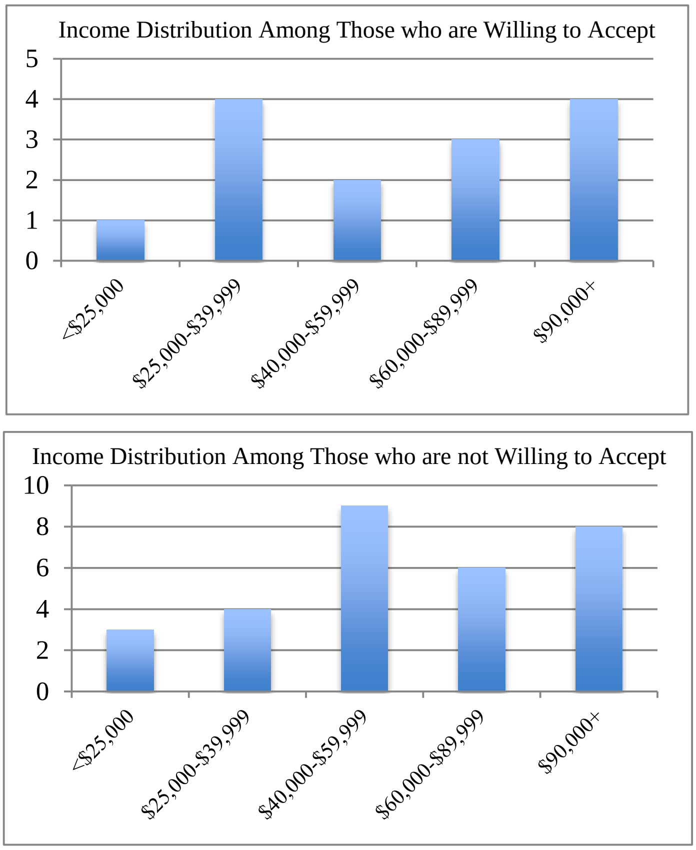
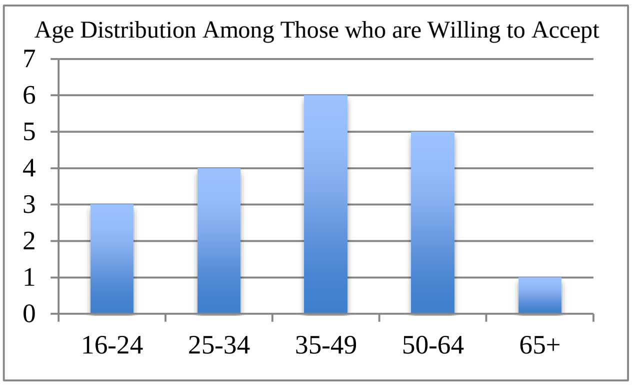


Figure 4.6: Age Distribution: Free Parking Willingness to Accept



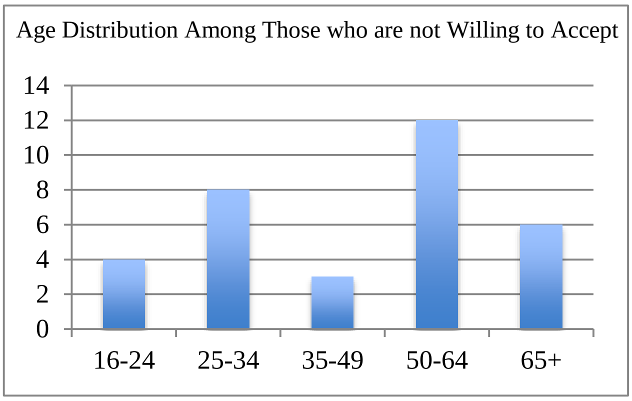
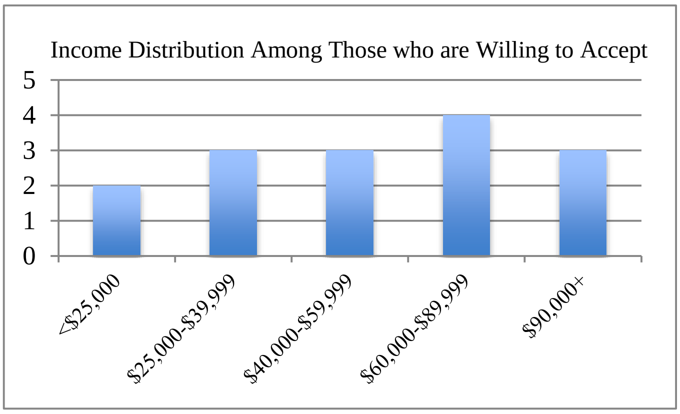


Figure 4.7: Income Distribution: Free Parking Willingness to Accept



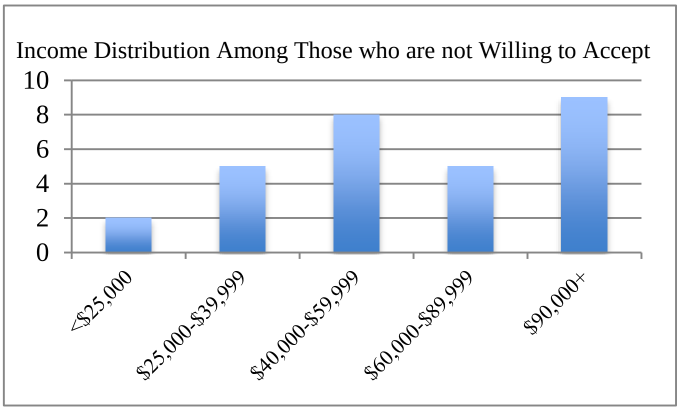


Table 4.3: T-Test for Age Difference (HOV Lane Permits Willingness to Accept)

	Sample Size	Mean	Variance
Willing to Accept	17	43.7	229.8
Not Willing to Accept	33	45.7	244.7

p-level	**0.6638**	t Critical Value	**2.010**

Table 4.4: T-Test for Income Difference (HOV Lane Permits Willingness to Accept)

	Sample Size	Mean	Variance
Willing to Accept	13	62115	659214743
Not Willing to Accept	29	62068	528602216

p-level	**0.9953**	t Critical Value	**2.021**

Table 4.5: T-Test for Age Difference (Free Parking Willingness to Accept)

	Sample Size	Mean	Variance
Willing to Accept	18	42.3	188.0
Not Willing to Accept	32	46.5	262.9

p-level	**0.3552**	t Critical Value	**2.010**

Table 4.6: T-Test for Income Difference (Free Parking Willingness to Accept)

	Sample Size	Mean	Variance
Willing to Accept	10	66250	373958333
Not Willing to Accept	32	60781	616708669

p-level	**0.5279**	t Critical Value	**2.021**

Table 4.7: HOV Lane Permits Willingness to Accept: Cross Tabulation

Select the primary purpose you drive your car.					
	Commuting	Daily Errands	Recreation	Other	Responses
All	47.9%	35.4%	12.5%	4.2%	48
Willing to Accept	73.3%	6.7%	13.3%	6.7%	15
Not Willing to Accept	36.4%	48.5%	12.1%	3.0%	33

Which of the following incentives are most likely to affect your hypothetical electric vehicle purchase in addition to point-of-sale incentives? Please select two.						
	Charging Station Rebates	Free Parking	HOV Lane Permits	Better Public Charging Station Availability	Condominiums Charging Infrastructure	None
All	17.3%	42.3%	28.8%	53.8%	38.5%	7.7%
Willing to Accept	33.3%	55.6%	22.2%	33.3%	33.3%	11.1%
Not Willing to Accept	8.8%	35.3%	32.4%	64.7%	41.2%	5.9%

Table 4.8: Free Street Parking Willingness to Accept: Cross Tabulation

Select the primary purpose you drive your car.					
	Commuting	Daily Errands	Recreation	Other	Responses
All	47.9%	35.4%	12.5%	4.2%	48
Willing to Accept	62.5%	25.0%	12.5%	0.0%	16
Not Willing to Accept	40.6%	40.6%	12.5%	6.3%	32

Which of the following incentives are most likely to affect your hypothetical electric vehicle purchase in addition to point-of-sale incentives? Please select two.						
	Charging Station Rebates	Free Parking	HOV Lane Permits	Better Public Charging Station Availability	Condominiums Charging Infrastructure	None
All	17.3%	42.3%	28.8%	53.8%	38.5%	7.7%
Willing to Accept	26.3%	47.4%	36.8%	47.4%	31.6%	5.3%
Not Willing to Accept	12.1%	39.4%	24.2%	57.6%	42.4%	9.1%

When asked what incentives would positively affect hypothetical electric vehicle purchase in addition to monetary incentives, higher proportion of those who are willing to accept reduction for both of the non-monetary incentives listed charging station rebates, free street parking, and HOV lane permits, which directly benefit individual drivers when purchasing electric vehicles. On the other hand, however, higher proportion of those who are not willing to accept listed better public charging station availability and installment of charging infrastructure at condominiums. The values seem to imply that for many, it is necessary that organized charging infrastructure exists before they are able to start considering purchasing electric vehicles in the first place, and it is essential how the government allocates its limited financial resources on different types of incentives.

4.4 Chapter Summary

This chapter presented the results of the EV incentives preferences survey in Metro Vancouver and discussed their implications. The following insights were obtained from the results:

- Only 3.85% of the respondents (2 out of 52 valid responses) live and commute where direct time savings benefits from HOV lanes are expected, yet 84.7% answered they would *use* HOV lane permits if provided free of charge; 34.6% showed willingness to accept for HOV lane permits for 5 years. This indicates many are willing to accept reduction in monetary incentives for HOV lanes for benefits other than direct time savings, such as convenience or status as an environmentally-conscious individual.
- For both HOV lane permits and free street parking, higher proportion of those who showed willingness to accept drive primarily for commuting than those who did not.
- Differences in mean income and age between those who are willing to accept and those who are not for both of the non-monetary incentives were not statistically significant.

5. CONCLUSION

This chapter concludes the study. Based on the results of the preferences survey, the study provides two policy recommendations for the further enhancement of the total welfare from Clean Energy Vehicle Program in Metro Vancouver: provision of choices between monetary and non-monetary incentives, and organization of further charging infrastructure throughout the province.

5.1 Consumer Preferences and Policy Recommendations

Successful implementation of LiveSmartBC as well as Clean Energy Vehicle Program and further enhancement of the total welfare from the policy is dependent on more input from consumers and understanding their preferences for different incentives. More interaction of the two shall lead to better utilization of traffic resources and strategic allocation of financial resources to increase environmental load mitigation benefits.

5.1.1 Provision of Incentive Choices

Given the diversity of consumer preferences for electric vehicle incentives as seen in the questionnaire survey, it would be important that right incentives go to those who highly value them instead of giving them away to all EV purchasers. British Columbia's Climate Action Plan and LiveSmartBC Program have emphasized the significance of providing the citizens with choices to reduce their greenhouse gas emissions, as the government states "All British Columbians will be able to choose their own ways to reduce their greenhouse gas emissions, increase efficiency, and save money related to transportation, home energy use, and other aspects of daily life" (The Government of British Columbia, 2008).

There are various ways in which governments allocate non-monetary incentives. In case of HOV lane permits in the United States, for instance, some states provide permits with expiry dates, while others only issue a certain number of permits without expiry dates, and any returned permits are reallocated to those on waitlists. As opposed to providing non-monetary incentives to all the EV buyers, the scheme in which drivers are allowed to choose between non-monetary incentives in return for portion of monetary incentives and full amount of monetary incentives is expected to: (i) increase the total number of electric vehicles subsidized as seen throughout the study, (ii) distribute non-monetary incentives to those who really value them, resulting in the enhancement of consumer utility, and (iii) avoid the congestion of parking space and HOV lanes and associated costs to non-EV drivers.

According to the results of the questionnaire survey, 27% and 29% of the respondents answered they are willing to accept reduction of greater than or equal to $500 for HOV lane permits and free street parking for 5 years. In addition, since the survey showed no correlation between income levels and willingness to accept for HOV lane permits and free street parking, the government does not need to price discriminate electric vehicle drivers based on their income levels or geographic location. Assuming $500 would be subtracted from the $5,000 point-of-sale incentives for each of the non-monetary incentives provided and 30% of new electric vehicle buyers in Metro Vancouver would receive HOV lane permits and free street parking, the total number of electric vehicles subsidized and the resulting environmental load mitigation benefits would change as shown in Table 5.1, based on Eqs. 3.1 and 3.2. The figures assume the total number of electric vehicles subsidized under Clean Energy Vehicle Program in British Columbia up to February 2014 was 1800, and 50% were purchased in Metro Vancouver, which constitutes 50% of the total British Columbia’s population.

Table 5.1: Increase in Benefit of Environmental Load Mitigation Benefits

with Incentive Choices

	Number of EVs Subsidized in Metro Vancouver	Benefits of Environmental Load Mitigation
$5,000 Point-of-Sale Incentive ONLY	900*	$611,154
With Non-Monetary Incentives	954	$647,823 **(6% Increase)**

Although the total benefit of environmental load mitigation under such scheme are smaller than in the scenario where incentives are provided to all new electric vehicle buyers as seen in Chapter 3, the selection scheme should not be substantially inferior in terms of the total welfare change from the policy, taking into consideration the amelioration of congested facilities.

Table 5.2 below shows the average peak hour traffic volume of the five highway HOV lane routes focused in the present study. Given that 93.1% of drivers in Metro Vancouver are solo drivers without access to HOV lanes, it is assumed the traffic volume of those HOV lanes is not significantly large; Kwon &Varaiya (2008) estimate the traffic volume of efficiently operating freeway HOV lanes, or being able to constantly drive at 45miles per hour or faster, is 1400-1600 vehicles per hour per lane (vphpl). Because the present study assumes approximately 30% of new electric vehicle drivers, or 270, would select HOV lane permits as an option, it is expected additional 270 permits would not significantly reduce time savings from HOV lanes.

Table 5.2: Peak Hour Traffic Volume at HOV Lane Routes

Route	Lanes	AM Peak Traffic Volume	PM Peak Traffic Volume
Highway #1 Trans Canada Lower Mainland	3	4568 (2008.07.16-17)	4586 (2009.09.28-29)
Highway #7 Lougheed Lower Mainland	---	2769 (2008.07.15-16)	2205 (2008.07.15-16)
Highway #17 Northbound Lower Mainland	2 ?	1742 (2014.09)*	----
Highway #99 Northbound Lower Mainland	2 ?	3297 (2014.07.02-28)*	----
Highway #99 Southbound Lower Mainland	3	----	4199 (2014.09)*

* Data from the Ministry of Transportation
Hour with the maximum traffic volume is considered the peak. AM peak is at 7AM and PM peak at 4PM. The average of workdays, excluding holidays.

5.1.2 Further Organization of Charging Infrastructure

The further development of charging infrastructure, both public and in residential and commercial buildings, is essential to incentivize potential electric vehicle buyers, particularly in Metro Vancouver. As seen in the questionnaire survey, better public charging station availability was the strongest factor that positively affects electric vehicle purchases in addition to monetary incentives, with 53.8% of the respondents selecting it as either first or second choices. Charging infrastructure needs to come first as an incentive to make consumers consider purchases, only after which point-of-sale incentives, HOV lane permits, and free street parking function as incentives.

According to Vancouver Electric Vehicle Association (2014), currently more than 95% of electric vehicle owners in British Columbia lives in single-detached houses, as opposed to 63% of the Vancouver of City residents living in multi unit residential buildings (MURBs), where they need to share parking facilities with other tenants and installment of charging equipment is not easy. Approval from more than 75% of owners in strata is necessary in order to install charging stations at the parking of MURBs. In the interview with members of

Vancouver Electric Vehicle Association, drivers claimed organized charging infrastructure has to come first before they are able to consider purchasing electric vehicles. As seen in Table 5.3, full charge of an electric vehicle takes hours, and drivers are not able to solely rely on public charging stations.

Table 5.3: Relative Charge Time of Electric Vehicles

EV Configuration	Usable Battery Capacity (kWh)	120 VAC, 15 amp 1.2 kW	120 VAC, 20 amp 1.6 kW	240 VAC, 40 amp 3.3 kW	240 VAC, 85 amp 6.6 kW
BEV	24	20 hr.	15 hr.	3 hr. 40 min.	24 min.
BEV	35	29 hr. 10 min.	21 hr. 50 min.	5 hr. 20 min.	35 min.

Based on ECOtality North America (2014)

The survey did not ask consumers' willingness to accept for better public charging infrastructure availability or charging stations installment at MURBs, yet better availability of public charging stations and condominium charging were the first and third incentives respondents answered would positively affect their EV purchase in addition to monetary incentives (refer to Table 4.2). Studies that further investigate strength of preferences between monetary incentives, non-monetary incentives, and charging infrastructure would be necessary. Such studies help policymakers efficiently allocate the limited budget to different incentives in a manner that increases consumer's utility and further encourages EV adoption.

5.2 Concluding Remarks

The present study demonstrated quantitatively environmental load mitigation benefits from Clean Energy Vehicle Program for electric vehicles in Metro Vancouver can be enhanced by incorporating non-monetary incentives into the existing $5,000 point-of-sale incentives. Each adoption of an electric vehicle in Metro Vancouver results in $679.06 of environmental load mitigation benefits. HOV lane permits and complementary street parking result in annual private benefits of $116.23-$2470.70 and $109.52, respectively. When the government provides each of those non-monetary incentives for 5 years for $500 to 30% of new electric vehicle buyers, they are able to enhance the total environmental load mitigation benefits from the policy by 6%.

The questionnaire survey revealed better public charging stations availability was the strongest incentive to positively affect electric vehicle purchases, and further development of charging infrastructure throughout the region would be more important as more drivers adopt electric vehicles. The government is expected to strategically combine and allocate limited financial resources to monetary and non-monetary incentives as well as installment of charging facilities to reduce drivers' range anxiety.

Finally, the limitations of this thesis and possible future studies are to be pointed out. First, the study only focused on air pollution and climate change effects as environmental loads, yet it is necessary to incorporate other types of environmental effects to capture benefits and costs in a more comprehensive manner. Secondly, the study did not take HOV lanes on non-highways into consideration due to the limited traffic data and difficulty of predicting travel patterns. The private benefits from HOV lane permits should be higher when the permits allow access to non-highway HOV lanes as well. Thirdly, the prepared random utility model was not functional due to the small sample size and uneven distribution of responses for dichotomous choice willingness to accept questions. A questionnaire survey on a much larger scale would be necessary in order to accurately and statistically investigate relationships between willingness to accept and demographics.

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APPENDIX I: ELECTRIC VEHICLE OWNERSHIP COST CALCULATION

The below is an effort to estimate how much it costs to purchase, drive, and maintain a Nissan Leaf 2014 model compared to a Nissan Note from the same year in Vancouver, British Columbia. The Leaf was selected, as it is the most popular introductory pure EV model sold, and more than 80% of passenger cars excluding trucks and SUVs sold in Canada in 2013 are priced below MSRP (Manufacturers Suggested Retail Price) of $30,000.

The following assumptions are made in the computation for simplification:

- According to Metro Vancouver's Trip Diary 2011 results, the average driving trip made on a regular working day is 9.9km (more specifically, 13.2km for work, 7.1km for shopping and personal business, and 7.7km for social and recreational dining). Therefore it is assumed the average daily driving distance on a weekday is 40.6km, assuming one round trip from work (13.2km one way) and another for personal errands (7.1km one way). Because there were 250 working days in British Columbia in 2013 (http://www.workingdays.ca), the annual distance travelled on weekdays on average is 10,150km. Similarly, assuming one round trip for shopping and personal business on a non-working day, the total annual distance travelled would be 1,633km, which is: (115 non-working days) x (14.2km/day). Adding up the two, the average *underestimated* annual driving distance is 11,783km for Case 1.
- For Case 2, the annual mileage travelled by light vehicles, which include cars, station wagons, vans, SUVs, and pickup trucks, in British Columbia of 13,100km is used; this compares to the national average of 15,200km and is the lowest among all provinces and territories (National Resources Canada, 2008).
- It is also assumed all the driving occurs in an urban or suburban condition where frequent stops must be made; thus the fuel economy of 7.1L/100km is used for the cost computation of Versa Note.
- BC Hydro charges 6.9 cents/kWh up to 1350kWh and 10.54 cents/kWh beyond the threshold during a two-month billing cycle. The average BC household consumes around 11,000kWh annually, or 1833kWh every two months, and thus the rate is assumed to be 7.86 cents/kWh, taking the weighted average.
- The Leaf comes with an eight-year or 160,000km battery warranty, whichever comes first.
- The Leaf's range after full charging is assumed to be 84 miles, or 135km, based on the EPA's evaluation of the US 2014 model.
- The gas prices in British Columbia have fluctuated significantly the past five years and tend to be higher than the Canadian average. Three price cases will be tested in this study: high, medium, and low.

Case 1: The following shows the results of computations in three scenarios with different gas prices: (i) 148 cents/L, (ii) 98 cents/L, and (iii) 123 cents/L, with the annual mileage of 11,783km.

(i)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	16916.16
2	27027.29	18154.32
3	27191.94	19392.48
4	27356.59	20630.64
5	27521.24	21868.8
6	27685.89	23106.96
7	27850.54	24345.12
8	28015.19	25583.28
9	28179.84	26821.44
10	28344.49	28059.6

(ii)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	16497.86
2	27027.29	17317.72
3	27191.94	18137.58
4	27356.59	18957.44
5	27521.24	19777.3
6	27685.89	20597.16
7	27850.54	21417.02
8	28015.19	22236.88
9	28179.84	23056.74
10	28344.49	23876.6

(iii)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	16707.01
2	27027.29	17736.02
3	27191.94	18765.03
4	27356.59	19794.04
5	27521.24	20823.05
6	27685.89	21852.06
7	27850.54	22881.07
8	28015.19	23910.08
9	28179.84	24939.09
10	28344.49	25968.1

Case 2: The following tables show the results of computations in three scenarios with different gas prices: (i) 148 cents/L, (ii) 98 cents/L, and (iii) 123 cents/L, with the annual mileage of 13,100km.

(i)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	17054.55
2	27027.29	18431.1
3	27191.94	19807.65
4	27356.59	21184.2
5	27521.24	22560.75
6	27685.89	23937.3
7	27850.54	25313.85
8	28015.19	26690.4
9	28179.84	28066.95
10	28344.49	29443.5

(ii)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	16589.5
2	27027.29	17501
3	27191.94	18412.5
4	27356.59	19324
5	27521.24	20235.5
6	27685.89	21147
7	27850.54	22058.5
8	28015.19	22970
9	28179.84	23881.5
10	28344.49	24793

(iii)

Year	Nissan Leaf	Nissan Versa Note
0	26698	15678
1	26862.64	16822.02
2	27027.29	17966.04
3	27191.94	19110.06
4	27356.59	20254.08
5	27521.24	21398.1
6	27685.89	22542.12
7	27850.54	23686.14
8	28015.19	24830.16
9	28179.84	25974.18
10	28344.49	27118.2

From the results computed above, the following computations can be conducted:

- In order for the Nissan Leaf to be competitive with the Versa Note with its eight-year battery warranty and the average gas price of 123 cents per liter, the annual mileage has to be 17,658.88km or more. Similarly, for the gas price of 148 cents per liter and 98 cents per liter, it has to be 14,675km and 22,164km, respectively.

The present investigation is subject to the following limitations and issues:

- It is questionable to compare the Nissan Leaf and Verse Note as competing models despite the similar specifications in the first place; the consumer demographics of the emerging EVs and the entry-level ICE-powered hatchbacks should be very different and so are the target consumers.
- According to Natural Resources Canada (2008), 6.2 millions or approximately 30% of light vehicles on road are 10 years or older, while the study only assumed an eight-year ownership due to the Leaf's battery warranty. It did not take into consideration the cost of battery replacement, as it is ambiguous and unpredictable how the cost will fluctuate for the next eight-year period.
- The residual value of electric cars is not clear at the moment, as there is no established second-hand market for electric vehicles yet.
- The price of lithium-ion batteries used for EVs have dropped substantially from $1,000/kWh in 2008 to $600/kWh today; according to one estimate, it is further expected to drop to $300-$325/kWh range by 2020.
- With the total eight-year ownership cost difference of between $2,000 and $5,000 after the point-of-sale rebate according to the present study, the government still has much they could do to further encourage the EV adoption by implementing non-monetary incentives such as HOV lane permits and priority parking.
- Ownership cost should not be the sole determinant of all consumers' vehicle selection; some might be willing to pay the premium to own "environmentally-friendly" vehicles, as social status and cars are strongly associated to each other.

APPENDIX II: Environmental Load Mitigation Benefits Calculation Details

All the calculations assume 900 electric vehicles are subsidized in Metro Vancouver.
All monetary values are in the US dollars and converted into Canadian dollars in the study.

Climate Change Mitigation Benefits

CO2 Annual for gasoline car = (0.002326t/L)(10.3L/100km)(13,100km/100km) = 3.1384718t

CO2 Annual for EV = (0.000025t/kWh)(20kWh/100km)(13,100km/100km) = 0.0655t

CO2 Difference/year = 3.1384718t - 0.0655t = 3.0729718t

Annual Benefit = 3.0729718t * $12/t = $36.8756616

Year	Conversion Factor	Benefit	PV
0	1	36.8756616	36.8756616
1	0.934579439	36.8756616	34.46323514
2	0.873438728	36.8756616	32.20863097
3	0.816297877	36.8756616	30.10152427
4	0.762895212	36.8756616	28.13226568
5	0.712986179	36.8756616	26.29183708
6	0.666342224	36.8756616	24.57181036
7	0.622749742	36.8756616	22.96430874
		Total	**235.6092738**

Grand Total **212048.3465**

Air Pollution Mitigation Benefits

Pollutant	Emissions per km (t/km)	Marginal Damage ($/t)
VOC	1.664E-06	1462.5
NOx	1.1153E-06	29.2
PM10	7.0811E-09	1393.3
PM2.5	6.5983E-09	14639.7
SO_2	----	4880.4
NH_3	----	31985.4

VOC annual for gasoline car (t)	0.021799154
Annual Benefit ($)	31.87690295

Year	Conversion Factor	Benefit	PV
0	1	31.8769029	31.8769029
1	0.934579439	31.8769029	29.79149804
2	0.873438728	31.8769029	27.84252153
3	0.816297877	31.8769029	26.02104816
4	0.762895212	31.8769029	24.3187366
5	0.712986179	31.8769029	22.72779121
6	0.666342224	31.8769029	21.24092637
7	0.622749742	31.8769029	19.85133305
		Total	**203.6707579**

Grand Total **183303.6821**

PM2.5 annual for gasoline car (t)	8.64377E-05
Annual Benefit ($)	1.265421285

Year	Conversion Factor	Benefit	PV
0	1	1.265421285	1.265421285
1	0.934579439	1.265421285	1.182636715
2	0.873438728	1.265421285	1.105267958
3	0.816297877	1.265421285	1.032960708
4	0.762895212	1.265421285	0.96538384
5	0.712986179	1.265421285	0.902227887
6	0.666342224	1.265421285	0.843203633
7	0.622749742	1.265421285	0.788040779
		Total	**8.085142805**

Grand Total **7276.628524**

NOx annual for gasoline car (t)	0.014610071
Annual Benefit ($)	0.426614083

Year	Conversion Factor	Benefit	PV
0	1	0.42661408	0.42661408
1	0.934579439	0.42661408	0.398704748
2	0.873438728	0.42661408	0.372621259
3	0.816297877	0.42661408	0.348244168
4	0.762895212	0.42661408	0.325461839
5	0.712986179	0.42661408	0.304169943
6	0.666342224	0.42661408	0.284270975
7	0.622749742	0.42661408	0.265673808
		Total	**2.72576082**

Grand Total **2453.184738**

SO2 annual for gasoline car (t)	2.70912E-05
Annual Benefit ($)	0.132216091

Year	Conversion Factor	Benefit	PV
0	1	0.132216091	0.132216091
1	0.934579439	0.132216091	0.12356644
2	0.873438728	0.132216091	0.115482654
3	0.816297877	0.132216091	0.107927714
4	0.762895212	0.132216091	0.100867023
5	0.712986179	0.132216091	0.094268246
6	0.666342224	0.132216091	0.088101164
7	0.622749742	0.132216091	0.082337537
		Total	**0.844766869**

Grand Total **760.2901821**

PM10 annual for gasoline car (t)	9.27624E-05
Annual Benefit ($)	0.129245793

Year	Conversion Factor	Benefit	PV
0	1	0.12924579	0.12924579
1	0.934579439	0.12924579	0.120790458
2	0.873438728	0.12924579	0.112888278
3	0.816297877	0.12924579	0.105503064
4	0.762895212	0.12924579	0.098600994
5	0.712986179	0.12924579	0.092150462
6	0.666342224	0.12924579	0.086121927
7	0.622749742	0.12924579	0.080487782
		Total	**0.825788756**
		Grand Total	**743.2098806**

NH3 annual for gasoline car (t)	0.000469065
Annual Benefit ($)	15.003247

Year	Conversion Factor	Benefit	PV
0	1	15.003247	15.003247
1	0.934579439	15.003247	14.02172617
2	0.873438728	15.003247	13.10441698
3	0.816297877	15.003247	12.24711867
4	0.762895212	15.003247	11.4459053
5	0.712986179	15.003247	10.69710776
6	0.666342224	15.003247	9.99729697
7	0.622749742	15.003247	9.343268197
		Total	**95.86008705**
		Grand Total	**86274.07834**

APPENDIX III: Consumer Preferences Survey

Question 1
How often do you drive a car?
( ) 5+ days a week
( ) 1-4 days a week
( ) Once every few weeks
( ) Rarely (less than once a month)
( ) Never

Question 2
Select the *primary* purpose you drive your car.
( ) Commuting
( ) Daily Errands (ex: shopping, picking up children)
( ) Recreation
( ) Other

Question 3
Select the location of your workplace/school.
( ) Burnaby
( ) Coquitlam
( ) Delta
( ) Maple Ridge
( ) New Westminster
( ) North Vancouver City
( ) North Vancouver District
( ) Port Coquitlam
( ) Richmond
( ) Surrey
( ) Vancouver
( ) West Vancouver
( ) Elsewhere in Metro Vancouver
( ) Other
( ) I do not commute.

Question 4
Have you ever considered purchasing a plug-in electric vehicle?
( ) Yes
( ) No

Question 5
Are you familiar with the difference between pure electric vehicles and hybrid electric vehicles?
( ) Yes
( ) No

Hybrid electric vehicles (e.g. Toyota Prius and Honda Insight) are vehicles powered by both gasoline and internal electric batteries, as opposed to pure electric vehicles (e.g. Nissan Leaf and Tesla Model S), which operate solely on electricity supplied from outside sources.

The table below shows some of pure electric vehicle models in the market and their specifications.

Vehicle Model	**Battery Size**	**Drive Range**	**Charging Time (from 0 to 100%)**	**Charging Time (per 10km)**
Nissan Leaf (2015)	24kWh	Up to 135km	4 hours (240V charging deck)	18 minutes
			16 hours (110V charger)	71 minutes
BMW i3 (2015)	22kWh	Up to 160km	3-6 hours (with BMW i charging station)	11-23 minutes
			20 hours (120V outlet)	75 minutes
Tesla Model S, 70D (2015)	60kWh	385km	8.5 hours (240V wall connector)	13 minutes
			73.5 hours (standard 110V charger)	115 minutes

This survey and the following questions ask your preferences regarding PURE ELECTRIC VEHICLES whose batteries need to be regularly recharged for operation.

Question 6

Assume you are considering the purchase of a new electric vehicle to replace a gasoline vehicle. Which of the following features are likely to affect your purchase positively? Please select up to two.

	Driving an electric vehicle results in the social benefit of reduced pollution and environmental issues.
	Driving and electric vehicle characterizes me as a person familiar with new vehicles and technologies.
	Driving an electric vehicle characterizes me as an environmentally conscious individual.
	Driving an electric vehicle gives me various government incentives, such as financial rebates, parking, and HOV lane permits.
	Driving an electric vehicle results in less spending on fuels and maintenance costs.
	None of the above would affect my hypothetical purchase.
	Other (please specify)

Question 7
Which of the following incentives are most likely to affect your *hypothetical* electric vehicle purchase in addition to point-of-sale incentives? Please select two. Leave the second row blank if none.

	Charging Station Rebates
	Free Street Parking
	HOV Lane Permits
	Better Availability of Public Charging Stations
	Charging Station Installments at Condominiums
	None of the above would affect my hypothetical purchase.

	Charging Station Rebates
	Free Street Parking
	HOV Lane Permits
	Better Availability of Public Charging Stations
	Charging Station Installments at Condominiums

* Respondents were provided with the description of each of the incentives as shown on the next page.

Nissan Leaf, one of the most popular introductory electric vehicle models, sells for Manufacturer's Suggested Retail Price (MSRP) of $31,798 without provincial rebates, but results in the annual average fuel savings of $750, assuming annual mileage of 13,100km and gasoline price of $1.23 per liter.

There are various types of incentives governments implement in order to encourage wider adoption of clean energy vehicles, as follows:

POINT-OF-SALE INCENTIVES

The Government of British Columbia used to provide $5,000 incentives for the purchase of new electric vehicles of select models.

CHARGING STATION REBATES

The Government also used to provide up to $500 rebates for the installment of faster Level 2 residential charging stations.

FREE STREET PARKING

The average BC household spends $110 on street parking annually. Some North American jurisdictions provide free street parking for clean energy vehicles.

HOV LANE PERMITS

With HOV lane permits, you would have access to dedicated fast lanes on select highway routes indicated below without having 2+ passengers.

Highway	Location	Direction	Distance
Highway #1 Trans Canada Lower Mainland	Boundary Road to Cape Horn, then continuing over the Port Mann Bridge, then continuing to 202 Street, Langley	West/East	16km
Highway #7 Lougheed Lower Mainland	Harris Road to Pitt River Bridge	North/South	2.6km
Highway #17 Northbound Lower Mainland	Ladner Trunk Road to Highway #99	North	1.75km
Highway #99 Northbound Lower Mainland	Matthews Interchange (Ladner Trunk) to Highway #17,Highway #17 to George Massy Tunnel	North	5.25km
Highway #99 Southbound Lower Mainland	Westminster Highway to Steveston Interchange	South	4km

BETTER PUBLIC CHARGING STATION AVAILABILITY

You are able to charge electric vehicles free of charge at many public charging stations at public and commercial facilities. You are able to check nearby charging stations at http://www.plugshare.com.

CHARGING STATION INSTALLMENTS AT CONDOMINIUMS

Despite a large Metro Vancouver population living in multi-unit residential buildings, the majority cannot install charging stations for electric car drivers.

Question 8
If you had an HOV lane permit for the routes below, would you use it?
( ) Yes
( ) No

Highway	Location	Direction	Distance
Highway #1 Trans Canada Lower Mainland	Boundary Road to Cape Horn, then continuing over the Port Mann Bridge, then continuing to 202 Street, Langley	West/East	16km
Highway #7 Lougheed Lower Mainland	Harris Road to Pitt River Bridge	North/South	2.6km
Highway #17 Northbound Lower Mainland	Ladner Trunk Road to Highway #99	North	1.75km
Highway #99 Northbound Lower Mainland	Matthews Interchange (Ladner Trunk) to Highway #17,Highway #17 to George Massy Tunnel	North	5.25km
Highway #99 Southbound Lower Mainland	Westminster Highway to Steveston Interchange	South	4km

Question 9
The Government of British Columbia used to provide $5,000 point-of-sale incentives for select electric vehicle models. Are you willing to accept reduction in the point-of-sale incentive in return for provision of HOV lane permits for 5 years?

YES NO

Question 10
(If YES) Are you willing to accept $500 reduction in the point-of-incentive in return for provision of HOV lane permits for 5 years?

YES NO

Question 11
(If YES for $500) Are you willing to accept $750 reduction in the point-of-incentive in return for provision of HOV lane permits for 5 years?

YES NO

Question 12
(If NO for $500) Are you willing to accept $250 reduction in the point-of-incentive in return for provision of HOV lane permits for 5 years?

YES NO

Question 13
The Government of British Columbia used to provide $5,000 point-of-sale incentives for select electric vehicle models. Are you willing to accept reduction in the point-of-sale incentive in return for provision of free street parking for 5 years?

YES NO

Question 14
(If YES) Are you willing to accept $500 reduction in the point-of-incentive in return for provision of free street parking for 5 years?

YES NO

Question 15
(If YES for $500) Are you willing to accept $750 reduction in the point-of-incentive in return for provision of free street parking for 5 years?

YES NO

Question 16
(If NO for $500) Are you willing to accept $250 reduction in the point-of-incentive in return for provision of free street parking for 5 years?

YES NO

Question 17
Please select the location of your residency.
( ) Burnaby
( ) Coquitlam
( ) Delta
( ) Maple Ridge
( ) New Westminster
( ) North Vancouver City
( ) North Vancouver District
( ) Port Coquitlam
( ) Richmond
( ) Surrey
( ) Vancouver
( ) West Vancouver
( ) Elsewhere in Metro Vancouver
( ) Other

Question 18
Please select your age group.
( ) 16-24
( ) 25-34
( ) 35-49
( ) 50-64
( ) 65 and over

Question 19
Please select your gender.
( ) Male
( ) Female
( ) N/A

Question 20
What is your net annual household income? Select one.
( ) $90,000 or more
( ) $60,000-$89,999
( ) $40,000-$59,999
( ) $25,000-$39,999
( ) Less than $25,000
( ) N/A

APPENDIX IV: VANCOUVER ELECTRIC VEHICLE ASSOCIATION INTERVIEW

Vancouver Electric Vehicle Association (VEVA), a chapter of the Electric Automobile Association, is a non-profit organization founded in 1988 with the mission to promote further adaptation of electric vehicles through education at events and cooperation with the general public and the EV industry. Further information about the organization can be found at: http://www.veva.bc.ca/

An interview session with five members of Vancouver Electric Vehicle Association took place on February 15, 2014 at Hillcrest Community Center, 4575 Clancy Loranger Way, Vancouver, BC between 1100 and 1300, after a casual meeting with Mr. Bruce Stout, President of the association, and Mr. Robert Shaw, the former Treasurer on February 14, 2014. The present document is a summary of some of the key findings from the interview session. The interview as a whole attempted to study what non-monetary incentives besides point-of-sale rebates and tax credits EV drivers expect from the government, and what conditions would be necessary in order to further encourage EV driving in Metro Vancouver.

As expected, many EV drivers claim the issue of HOV lane and parking permits from the government would significantly make electric vehicle more attractive due to its direct and indirect benefits; for instance, with firms encouraging and supporting their employees to drive EVs, they will be able to avoid productivity loss due to congestion and furthermore EVs parked at their parking makes a better corporate image towards the public. The location of charging stations was the second issue; although the number of charging stations in the region has increased in the past few years, public stations are still rare. Drivers often times need to pay to park at commercial facilities although what they really need is just to recharge their vehicles.

VEVA hypothesizes manufacturers are intentionally not exporting EVs to Canada due to the US Corporate Annual Fuel Standard policy; they rather sell fuel-efficient vehicles in the US in order to receive credits and make profit. They claim the government needs to implement policies that would benefit not only drivers but also manufacturers. EVs are expected to play a key role not only in private passenger vehicles but also public transportation in the future. The Car2Go service run by a subsidiary of Daimler has increasingly received more popularity in the recent years in Vancouver, also leading to more awareness towards EVs.

The interview overall revealed Metro Vancouver still has a long way to EV adoption in terms of the consistency and coherence of the government support, coordination with manufacturers and dealers, improvement of alternative transportation means for the less wealthy, and greater awareness of the general public towards EVs.