The Canadian Plug-in Electric Vehicle Survey (CPEVS 2013): Anticipating Purchase, Use, and Grid Interactions in British Columbia

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Abstract

This report investigates consumer interest in plug-in electric vehicles (PEVs), summarizing preliminary results from the Canadian PEV Survey (CPEVS 2013). Between April and October 2013, 1,754 new vehicle buying Canadian households completed this survey, including 538 residents of British Columbia (BC). This three-part survey collected in-depth information from each respondent, including: background information such as vehicle ownership, electricity use, familiarity with PEV technology, and personal values and lifestyle; vehicle travel behaviour; access to vehicle charging at home and elsewhere; interest in purchasing a PEV under different conditions; interest in green electricity; and openness to enrolling in a utility controlled charging (UCC) program to increase the uptake of intermittent renewable energy sources. This report summarizes several preliminary results for the BC sample:

1. Many BC new-vehicle buyers have recharge access at home.
2. Most BC new-vehicle buyers have little awareness of PEVs.
3. BC new-vehicle buyers are much more likely to want a plug-in hybrid (PHEV) than a “pure” electric vehicle (EV).
4. The potential “early mainstream” PEV buyers in BC are unique in terms of home recharge access, age, household size and lifestyle
5. There are three different lifestyle segments of potential “early mainstream” PEV buyers in BC (differing by engagement in environment- and technology-oriented lifestyles).
6. Without incentives or policy to control recharge behaviour, PEV electricity demand will likely peak at around 6pm each day.
7. Potential “early mainstream” PEV buyers are generally open to the idea of “utility controlled charging” to support renewables—despite some privacy concerns.

Executive Summary

Study Overview

Electric-mobility may be a key component in a successful societal transition toward deep greenhouse-house (GHG) reductions (Williams et al., 2012). This report considers the potential market for plug-in electric vehicles (PEVs) in Canada's passenger (light-duty) vehicle sector. We consider two broad categories of PEVs: **Plug-in hybrid electric vehicles (PHEVs)** that can be powered by grid electricity for an initial distance, say 60 km, but are otherwise powered by gasoline until the battery is recharged (e.g. the Chevrolet Volt) and **Electric vehicles (EVs)** that are powered solely by electricity for a range of 100 to 300 km (e.g. the Nissan LEAF). Widespread uptake and use of passenger PEVs will involve meaningful shifts in social and technical systems (Sovacool and Hirsh, 2009). To investigate how consumer interest in PEVs may guide such shifts, we engage a sample of Canadian new car buyers in a mixed-mode survey process. Data were collected via the **Canadian Plug-in Electric Vehicle Survey** (CPEVS 2013).

We presently focus on British Columbia (BC) data, but note that **CPEVS 2013** includes data from other Canadian provinces with oversamples of Alberta and Ontario new vehicle buying households. This preliminary research report addresses the following objectives for the BC sample:

1. Characterize new vehicle buyers' travel patterns and recharge access, including Level 1 (110/120-V) and Level 2 (220/240-V) access.
2. Identify the potential "early mainstream" PEV market according to vehicle design interests and demographic and lifestyle characteristics.
3. Anticipate the potential usage patterns (travel and charging) of the "potential early mainstream" PEV market.
4. Assess consumer acceptance of "utility controlled charging" (UCC) as a potential means to power PEVs with intermittent, renewable electricity sources.

Method

Previous PEV market research can be categorized into three approaches: constraints analyses, rational-actor choice models, and the reflexive lifestyle approach. The CPEV 2013 survey follows the **reflexive lifestyle** approach, which assumes that consumers construct their interests and preferences as they learn about PEV technology, and that these interests may or may not be constrained by present driving patterns and home recharge access—depending on the motivations of the consumer. Our target population is new vehicle buying households in Canada, from which we seek to identify the **potential "early mainstream" PEV buyers**. This is a much larger segment than the initial "pioneer" segment of initial PEV buyers (e.g. present PEV owners), and generally has characteristics more in line with mainstream consumer values and interests. PEVs must be accepted by this market in order to become a widely used technology.

CPEVS 2013 is a three-part survey that elicits many details about the respondent (Part 1), then provides respondents with opportunities to learn about their own interest in PEVs and how the technology may relate to their lifestyle (Part 2), and finally elicits respondent interest in buying a PEV and how they may recharge it under various conditions (Part 3). The overall flow of the three-part survey is depicted in Figure E-1.

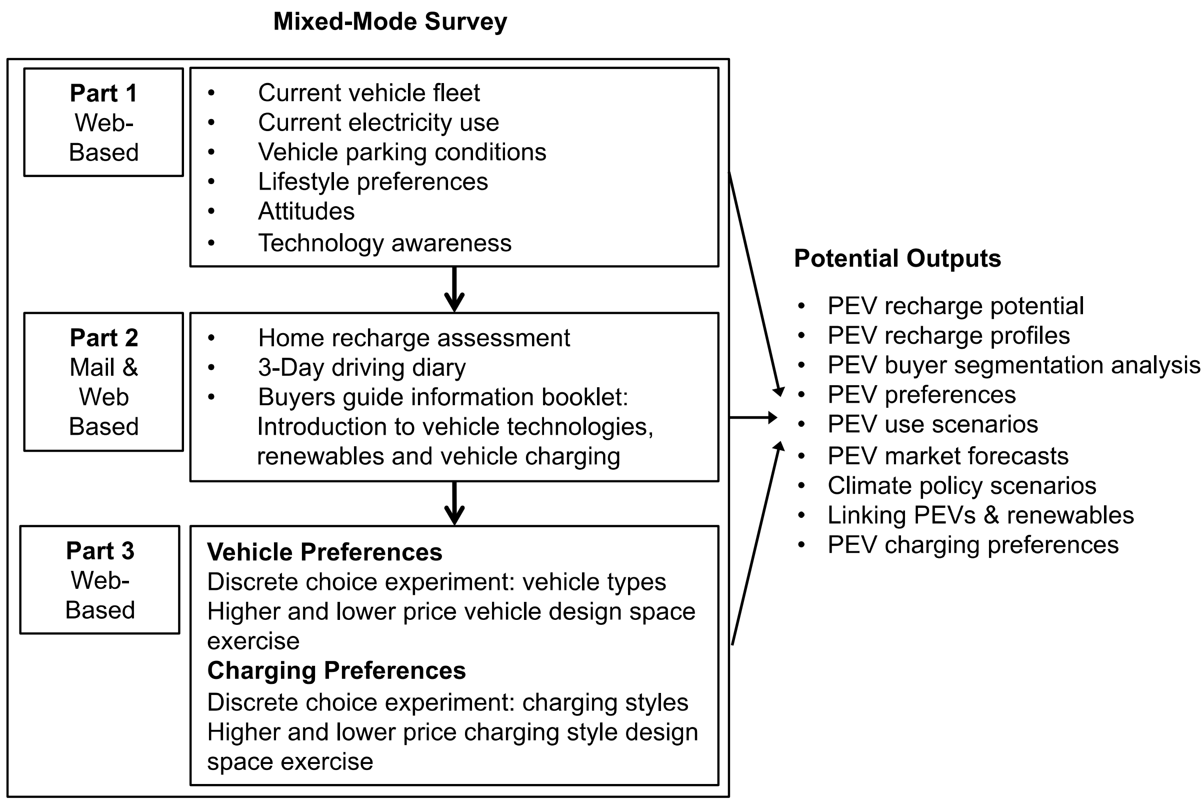

Figure E-1: Summary of CPEVS 2013 three-part method and potential outputs

Sample

Sentis Market Research was hired to recruit survey respondents for **CPEVS 2013**. Screener data was collected to ensure that the realized sample would match the target population (new vehicle buying households) in terms of basic demographic information (e.g. age and gender). In total, 1754 respondents completed all three parts of the survey, with 538 respondents from BC (Figure E-2). The full Canadian sample includes all provinces except for Quebec. Comparing the BC sample to the corresponding Census data, we find that the recruited sample is generally representative of new car buyers, which are typically older, of higher income, more highly educated, and more likely to own their own home, relative to the general population.

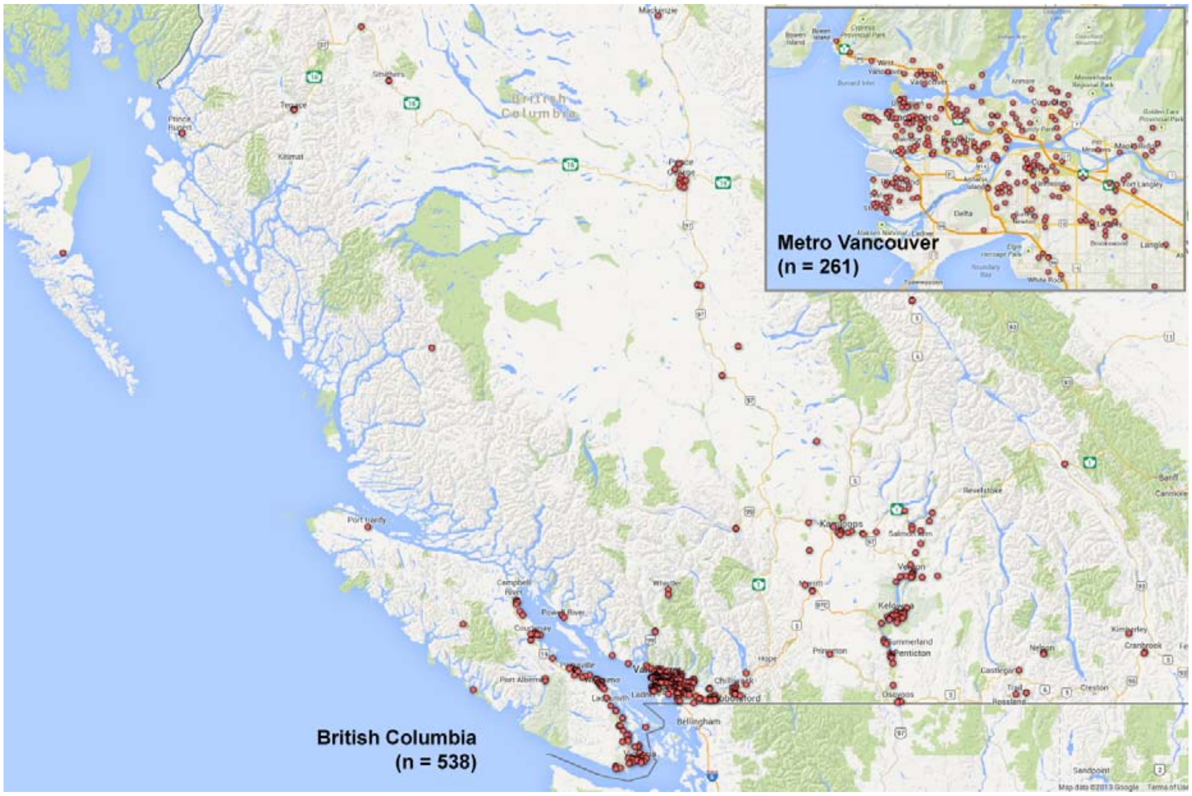

Figure E-2: Geographical representation of BC survey sample by postal code (n = 538)

Results

Through preliminary analysis of CPEVS 2013 data for BC, we have teased out seven initial results presented in this report.

RESULT #1: Many BC consumers have recharge access at home

In Part 2 of CPEVS 2013, respondents conducted a home recharge assessment where they located electrical outlets and panels near their typical parking locations at home. We find that 66% of BC respondents currently have Level 1 access at home (parking within 25 feet or 8 m of an existing 110/120-V outlet), and 19% have Level 2 access at home (parking with 25 feet or 8 m of an existing 220/240-V outlet). Level 1 and Level 2 access vary across respondents based on housing type, and parking space type (Figure E-3). Only about half of the 19% with existing Level 2 access reported that they would regularly use it to charge a PEV. A further 35% also have the potential to install Level 2, where our estimated installation prices would range from $1,000 to $3,500 (depending on household infrastructure).

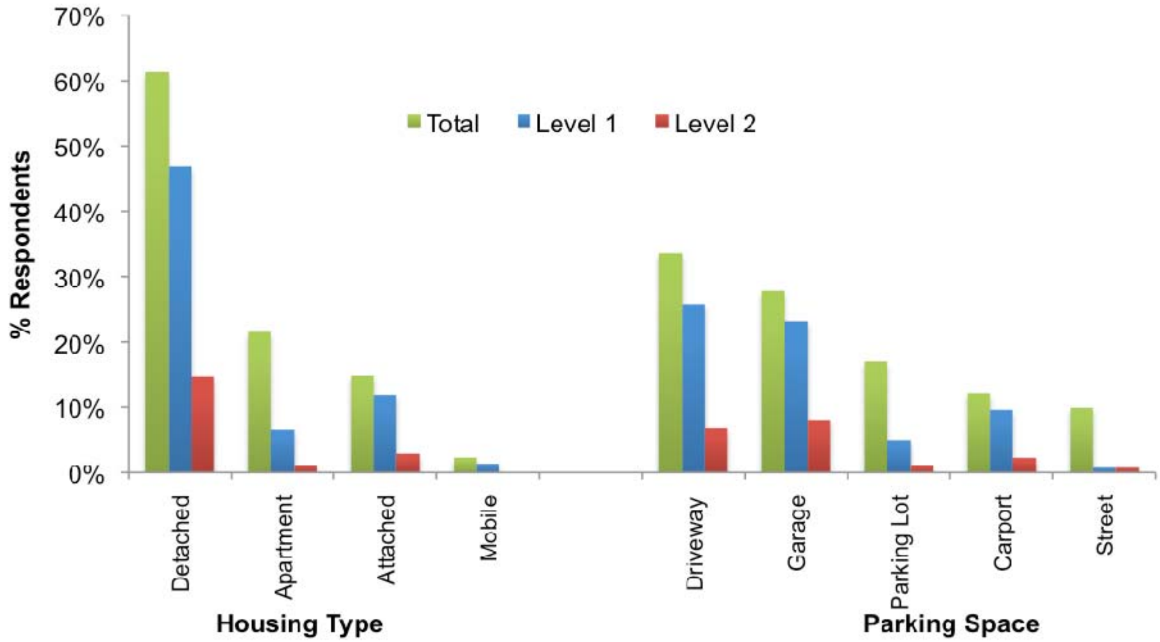

Figure E-3: Respondents' residential Level 1 and 2 access by housing type and parking space (BC only, n = 528)

Figure E-4 depicts BC respondents' driving activity and recharge access by time of day and parking location. Presently, the majority of respondents' charging opportunities are Level 1 outlets at their homes. Very few existing Level 2 PEV charging stations were observed at parking locations during the course of respondents' driving diaries. "Other" parking locations include parking at shopping centres, community centres, and other public parking locations.

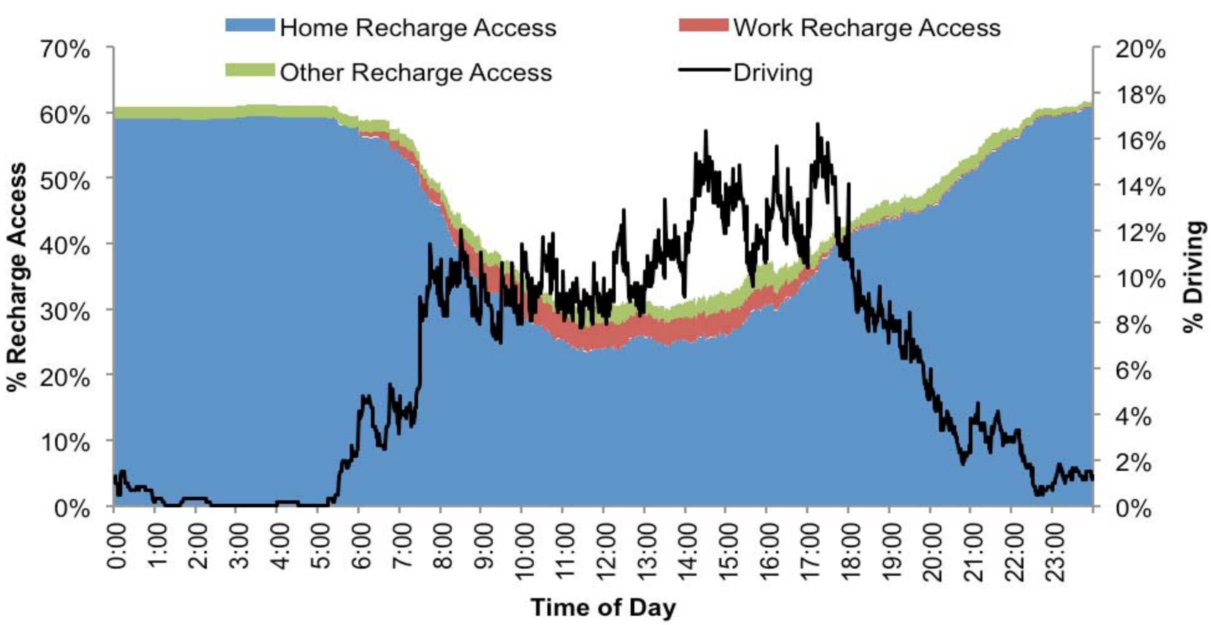

Figure E-4: Recharge access by time of day (BC only, n=528, 3-day driving diary)

RESULT #2: Most BC consumers have little awareness of PEVs

We assess respondents' awareness of PEVs prior to their completion of the PEV "design space" portion of the survey. Respondents first state their familiarity with different vehicle models: a hybrid vehicle (the Toyota Prius), a plug-in hybrid (the Chevrolet Volt), and a pure electric vehicle (the Nissan Leaf). Most respondents are at least somewhat familiar with the Prius (78%), and less familiar with the Chevrolet Volt (55%). The majority are not at all familiar with the Nissan LEAF (63%). We also ask respondents how they think each of these vehicle models can be fueled (Figure E-5): either with gasoline only, electricity only, or both. The majority of respondents are fairly confused about the basic function of each vehicle model. Only 18% successfully answer that the Prius can be fueled only by gasoline, and about a third successfully describe the fueling capabilities of the Volt and Leaf. This lack of prior knowledge and familiarity suggests that consumer perceptions of PEVs are still largely unformed.

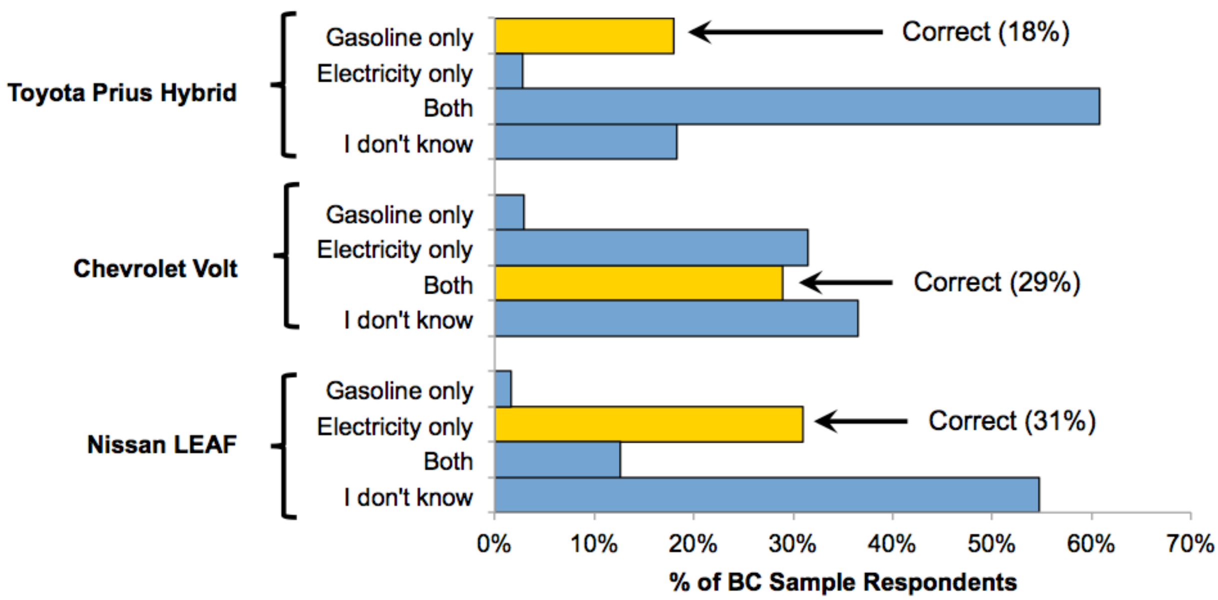

Figure E-5: Vehicle buyer perceptions of three vehicle models and how they are fueled – "How do you think each of the following vehicles can be fueled?" (BC only, n = 538)

RESULT #3: BC consumers are much more likely to want a plug-in hybrid (PHEV) than a "pure" electric vehicle (EV).

In Part 3 of the **CPEVS 2013**, respondents indicate their interest in purchasing various PEV designs. Respondents were first given a basic education in the different types of vehicles available (hybrid, PHEV and EV). Following this education, the "design space" exercise allowed respondents to select a conventional gasoline vehicle as a base, then potentially design and select a hybrid, PHEV or EV version of that base vehicle. Two price scenarios were presented: a higher price scenario (reflecting current prices) and a lower price scenario (reflecting subsidies or lower battery costs).

Figure E-6 portrays the distribution of designs selected by respondents. In both price scenarios, the highest proportion of respondents designed and selected some form of HEV (40 to 38 percent), with minorities selecting a PHEV (28 to 36 percent) or a conventional vehicle (28 to 21 percent). An EV was designed by only two to four percent of survey respondents. This gravitation of respondents to PHEV designs (not EV designs) has been seen in previous surveys of U.S. new vehicle buyers. Respondent interest in PEVs is influenced by price (or subsidies); demand for PHEVs in the lower price scenario is 30% higher relative to the higher price scenario, and interest in EVs doubles (but remains relatively low).

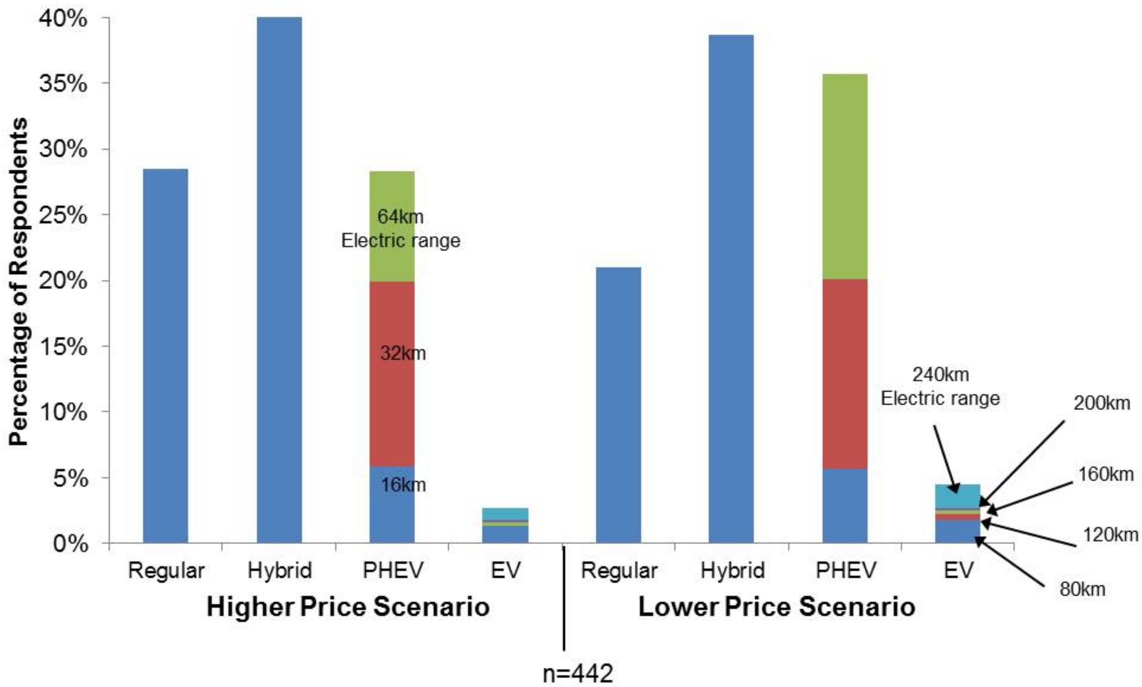

Figure E-6: PEV designs selected by BC respondents (BC only, n = 442, higher and lower price scenarios)

RESULT #4: The potential "early mainstream" PEV buyers are unique in terms of home recharge access, age, household size and lifestyle.

Based on responses to the PEV design space exercises, we identified the potential "early mainstream" PEV market as reflected by those respondents that designed some form of PHEV or EV in the lower price scenario (40% of the total BC sample, or n = 213). We call this the potential "early mainstream" PEV segment. Using logistic regression analysis we find that respondents in the "early mainstream" PEV segment differ from "non-PEV designers" in the following ways:

- **Recharge access:** the "early mainstream" PEV segment is more likely to identify existing Level 1 access at their home, or to identify the potential to install Level 2 at their home.
- **Lifestyle:** the "early mainstream" is more likely to engage in environmental-oriented activities, technology-oriented activities, or spiritual-oriented activities, and less likely to engage in political activities.

- **Demographics:** the “early mainstream” is more likely to be younger, and to have more household members.

Interestingly, we found that a number of other variables do not appear to be statistically related to respondent interest in PEVs. For example, there was no significant association between PEV interest and household income, travel patterns (distance per day of frequency of trips in the driving diary), individual values (e.g. biospheric, altruistic or egoistic values), awareness of a public charger, education level, perceptions of climate change, or region. We also compared the lifestyle engagement of respondents by their selected vehicle design (Figure E-7). Respondents that selected an EV design (only 4% of the total sample) are most likely to engage in technology-oriented lifestyles, and have about the same engagement in environment-oriented lifestyles as respondents that designed a PHEV.

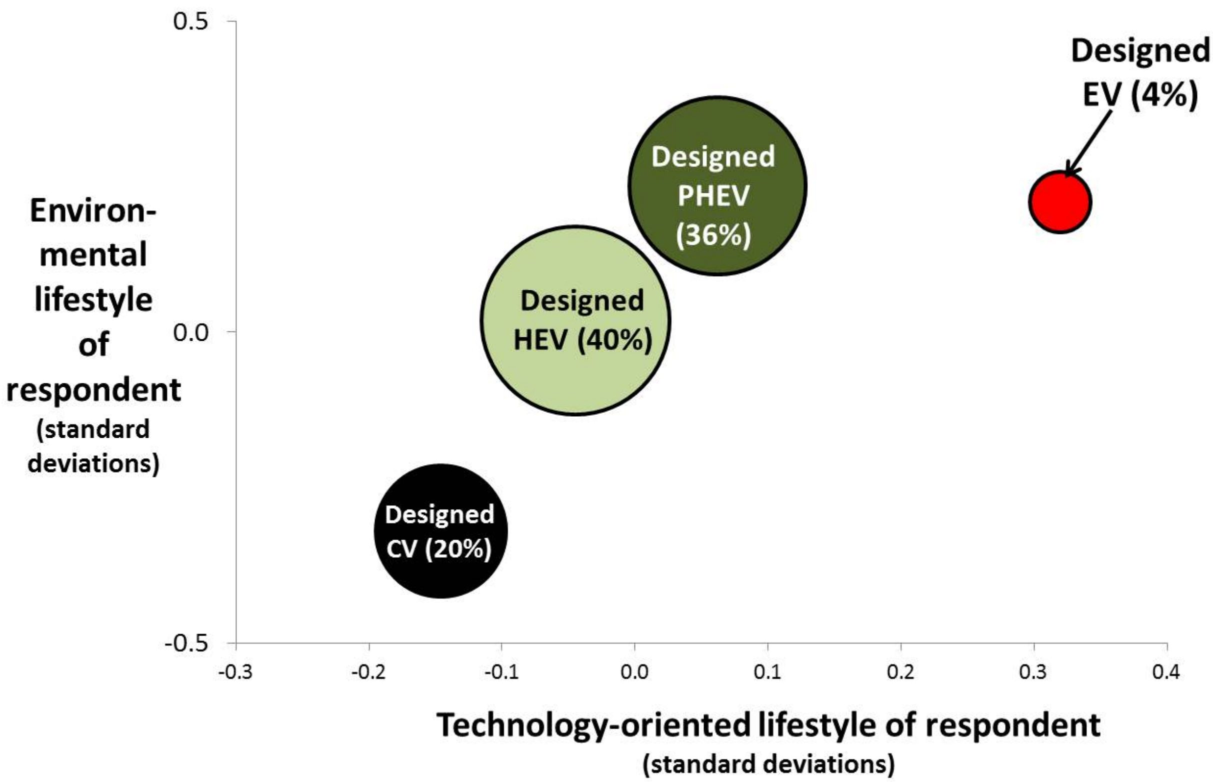

Figure E-7: Comparing respondent designs (conventional, hybrid, plug-in hybrid or electric) by the respondent’s lifestyle (BC only, n = 538)

RESULT #5: There are three different lifestyle segments of potential “early mainstream” PEV buyers in BC.

To provide a more in-depth assessment of the different motives behind potential PEV buyers, we identify different “early mainstream” segments. We conduct a cluster analysis of these respondents based on three lifestyle variables: engagement in technology-oriented and environment-oriented lifestyles, and lifestyle openness (or liminality). Figure E-8 depicts the three identified lifestyle-based segments: **“low-tech environmental,” “active environmental,”** and **“technology-oriented.”**

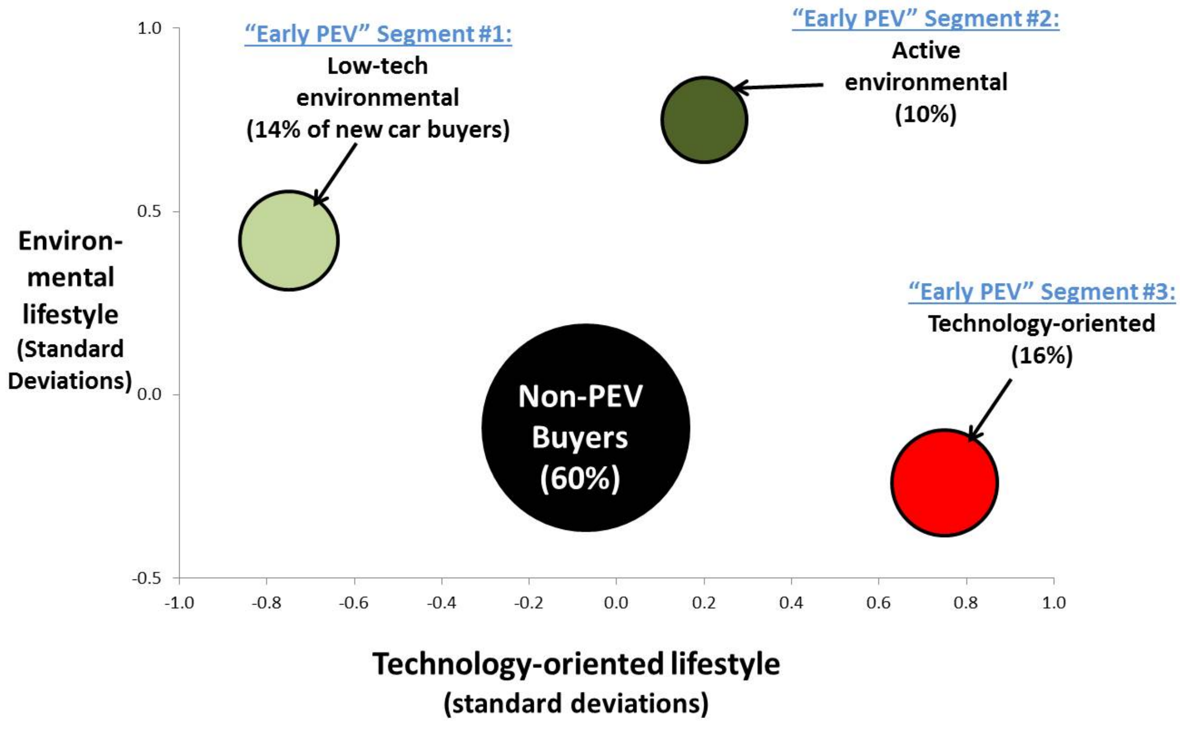

Figure E-8: Comparing "early mainstream" PEV buyer segments by lifestyle (BC only, n = 538)

These three "early mainstream" segments differ according to several other characteristics:

1. Respondents in the "**technology-oriented" cluster**:
    - are least likely to be female (45%);
    - have the highest familiarity with the Toyota Prius, Chevrolet Volt, and Nissan Leaf;
    - are likely to perceive a variety of PEV information sources as important including magazines, news providers, car dealers, TV, research and government; and
    - are the most likely to have "egoistic" values which reflect an interest in wealth and personal gain.
2. Respondents in the **"active environmental" cluster:**
    - are most likely to be female (82%);
    - are most likely to have bachelor's or graduate degrees;
    - have the highest biospheric and altruistic values;
    - are the most likely to engage in recreation activities and to follow politics and news sources;
    - are most likely to see climate change and air pollution as "serious" threats;
    - are most likely to think about the environmental impacts of their electricity use;
    - are most likely to be willing to pay extra to support renewable electricity; and
    - are also likely to see a variety of PEV information sources as important, including news providers, car dealers, research and government.
3. Respondents in the **"low-tech environmental" cluster**:

- tend to have the lowest education level;
- have the lowest level of openness to change (liminality);
- have a slightly higher pro-environmental attitude than the tech-oriented cluster;
- are the least likely to engage in a recreational lifestyle, or to follow news and politics;
- are the least likely to be familiar with the Prius, Volt or Leaf;
- are the least likely to perceive any PEV information sources as important;
- are more likely than the tech cluster to consider air pollution to be serious.

RESULT #6: Without incentives or policy to control recharge behaviour, PEV electricity demand will likely peak at around 6pm each day.

By matching "early mainstream" respondent's selected PEV design to their three-day driving diary data (temporal driving patterns and recharge potential), we modeled the potential PEV usage patterns of "early mainstream" buyers in BC. Figure E-9 portrays three PEV usage scenarios in terms of kW demanded per PEV across a 24 hour period:

1. **User informed:** representing respondents' selected PEV designs, driving behavior, and present recharge access.
2. **User + Enhanced workplace**: same as scenario #1, but with enhanced workplace recharge access (i.e. assuming Level 2 access is universally available at all workplaces).
3. **EV-240:** using respondents' driving data, but assuming each "early mainstream" respondent is driving an electric vehicle with 240 km of range (EV-240), and that Level 2 recharge access is universally available at all PEV buyers' homes and workplaces.

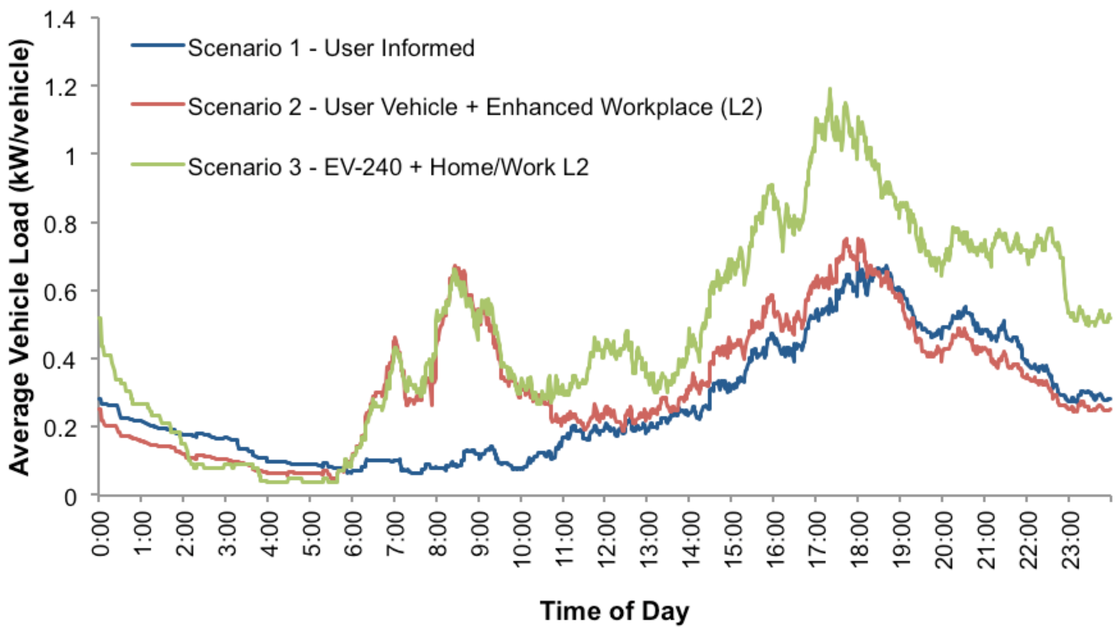

Figure E-9: PEV electricity usage under different scenarios ("early mainstream" PEV buyers in BC, n = 202 respondents, n = 606 diary days, 1-minute intervals)

Scenarios 1 and 2 follow similar electricity demand profiles in the afternoon and evening, while Scenario 3 produces a larger demand spike. Due to enhanced workplace access, Scenarios 2 and 3 have an extra peak in the morning around 8:30am, when many drivers arrive at work and can plug in to recharge. Due to increased charging during the day, more driving is diverted to electric powered driving in Scenario 2, reducing gasoline consumption overall. We did not see any large differences in expected PEV load patterns between weekdays and weekends.

RESULT #7: Early mainstream PEV buyers are generally open to the idea of "utility controlled charging" to support renewables—despite some privacy concern.

The survey also assessed respondent interest in green electricity and PEV charging behaviour through several survey questions and exercises. Regarding electricity sources, respondents are most likely to support solar, wind, geothermal and run-or-river sources (in that order) and least likely to support coal and nuclear sources. The survey also assessed potential consumer acceptance of **utility controlled charging (UCC)**—where the electric utility could control the timing of nightly PEV charging in order to better utilize intermittent renewable electricity sources. After providing a simple explanation of UCC to respondents, we elicited respondent perceptions of UCC (Figure E-10). About two-thirds of respondents believe that UCC could help the environment and just over half believe that UCC should be supported by the government. Respondents are equally split between support and opposition when asked if UCC should be mandatory for PEV drivers, while about one-third perceive UCC as a potential invasion of privacy. We also find that the majority of respondents are willing to sacrifice some PEV charging overnight (resulting in less than a full charge on some mornings) in order to support UCC—either to reduce their electrical bill or to support grid uptake of renewables.

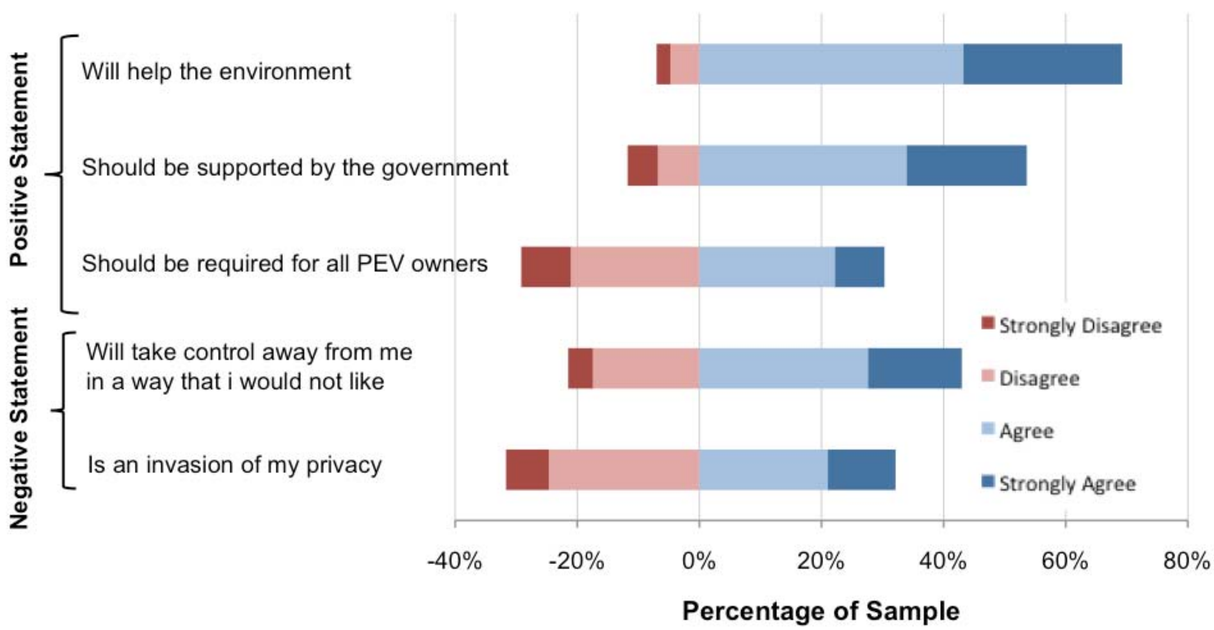

Figure E-10: Perceptions of "utility controlled charging" as indicated by agreement with several statements (BC, n = 442).

Next steps in analysis of CPEVS 2013

Results presented in this report are preliminary, as of October 31, 2013. We will extend much of the present analysis to other Canadian regions, including the Alberta and Ontario samples. Regional comparisons (e.g. BC vs. AB vs. ON) could then be made regarding: travel patterns, residential recharge access, PEV interest, characterizing and segmenting the "early mainstream" PEV buyers, recharge profiles and interest in green electricity and utility controlled charging.

Next steps in analysis using the BC and Canadian data may include:

- Developing more sophisticated discrete choice models of PEV demand. For example, a latent-class approach may be used to identify heterogeneity in consumer valuation of PEVs, fuel savings, recharge access and electric-powered driving range.
- Using insights from "design space" exercises and discrete choice models to construct PEV market share forecasts based on different market conditions (e.g. policy, battery prices, and gasoline and electricity prices).
- Constructing recharge profiles for a variety of PEV usage scenarios, including different assumptions about adoption rates and PEV design preferences, access to recharge infrastructure, time-of-use electricity rates, and implementation of a utility-controlled charging (UCC) scheme to optimize the usage of intermittent renewable sources of electricity for PEVs.
- Using respondent travel diary data to construct spatial models to assess the potential importance and usage of non-home charging infrastructure.

There are several other components to the "consumer research" portion of this broader project sponsored by Natural Resources Canada's ecoEnergy Innovation Initiative (ecoEII). Specifically, Dr. Axsen is leading three more consumer components to this project:

1. **Interviews of BC new vehicle buyers:** From the 538 BC respondents that completed the CPEVS 2013 survey, we are selecting diverse subset of 30 to 40 survey respondents to conduct 2-hour household interviews. Households were selected to provide a diverse subsample in terms of region (within different parts of Metro Vancouver), age, income, education, household size, and lifestyle (e.g. engagement in environmental- or technology-oriented activities). As of October 2013, 18 households have been interviewed.
2. **Survey of BC PEV owners:** The overall CPEVS survey format will be adapted, creating a version for BC households that presently own some type of PEV. Additional questions will assess motives for purchase, and levels of satisfaction with the vehicle. A driving diary will collect data on driving and recharge patterns for the PEV. The survey will likely be launched by the spring of 2014, with the goal of recruiting at least 100 PEV owning households for completion over the following year.
3. **Interviews with BC PEV owners:** To complement the PEV owner survey above, we plan to select a subset of survey respondents to complete household interviews. These interviews will address many of the same topics as the more general "new vehicle buyer" interviews, while also addressing issues more specific to PEV buyers (e.g. experience with residential and non-home charging infrastructure). Interviews will likely be completed by the end of 2014.

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1 Introduction

Electric-mobility may be a key component in a successful societal transition toward deep greenhouse-house (GHG) reductions (Williams et al., 2012). This report considers the potential market for plug-in electric vehicles (PEVs) in the passenger (light-duty) vehicle sector, including plug-in hybrid vehicles (PHEVs) and “pure” electric vehicles (EVs). Widespread uptake and use of passenger PEVs will involve meaningful shifts in social and technical systems (Sovacool and Hirsh, 2009). To investigate how consumer interest in electric-drive vehicles may guide such shifts, we engage a sample of Canadian new car buyers in a mixed-mode survey process. Data were collected via the **Canadian Plug-in Electric Vehicle Survey** (CPEVS 2013).

The survey collected a rich, disaggregated dataset of consumers’ precursor conditions, e.g., current vehicle ownership, access to places to charge a PEV, as well as their beliefs, attitudes, and interests in PEVs. We ascertain their interest through design exercises in which respondents construct a desired vehicle, and also through choice set as is typical of stated or revealed preference choice models (Bunch et al., 1993a; Ewing and Sarigollu, 2000; Hidrue et al., 2011; Train, 1980).

The **CPEVS 2013** survey extends the in-depth survey methods utilized for EVs in the 1990s (Kurani et al., 1994, 1996), and more recently applied to PHEV demand in a 2007 survey of U.S. new-vehicle buyers (Axsen and Kurani, 2009), the linking of PEV demand with green electricity in the U.S. (Axsen and Kurani, 2013a) and assessing PEV interest in San Diego, California (Axsen and Kurani, 2013b). Each of these previous studies utilized what we call “design space” exercises to improve researchers’ understanding of consumers interest in PEV technology under different price and resource conditions. The feasibility and potential cost of home vehicle recharging installation is assessed as part of the questionnaire and reflected back to the respondent during the vehicle design exercise.

This report uses **CPEVS 2013** data to characterize the potential market for passenger PEVs. We presently focus on British Columbia (BC) data, but note that the full survey includes data from other Canadian provinces, including oversamples from Alberta and Ontario. This preliminary research report addresses the following objectives for the BC sample:

1. Characterize new vehicle buyers’ travel patterns and recharge access.
2. Identify the potential “early mainstream” PEV market according to vehicle design interests and demographic and lifestyle characteristics.
3. Anticipate the potential usage patterns (travel and charging) of the “potential early mainstream” PEV market.
4. Assess consumer acceptance of “utility controlled charging” (UCC) as a potential means to power PEVs with intermittent, renewable electricity sources.

2 Context: Plug-in Electric Vehicles and People

2.1 What is electric-drive and why is it important?

Plug-in electric vehicles (PEVs) represent a spectrum of emerging vehicle technologies powered by electricity drawn from the electrical grid. There are two broad categories:

- **Plug-in hybrid vehicles (PHEVs)** can be powered by grid electricity for an initial distance, say 60 km, but are otherwise powered by gasoline until the battery is recharged. Examples include the Chevrolet Volt and the Toyota Prius Plug-in.[1]
- **Electric vehicles (EVs)** are powered solely by electricity for a range of 100 to 300 km, and require regular recharging to operate because they have no gasoline engine. Examples include the Nissan Leaf and the Tesla Model S.

In contrast, **hybrid-electric vehicles (HEVs)** such as the Toyota Prius are powered only by gasoline and are not plugged in to recharge, but can offer improved fuel economy and reductions in air pollution and greenhouse gas (GHG) emissions. In this paper, we compare consumer interest in PHEVs, EVs, and HEVs with interest in **conventional vehicles (CVs)** powered by gasoline or diesel.

Globally, much effort and many resources have been devoted to PEV development since the energy crises of the 1970s (Turrentine and Kurani, 1996). However, in that time, only small markets have developed. Presently, a renewed political push for PEV deployment is linked to climate change abatement and energy security. Several national governments have set ambitious targets for PEV deployment, such as the U.S. (Revkin, 2008) and Canada (Natural Resources Canada, 2010).

The actual societal impacts of PEV deployment are not entirely certain. U.S. based simulations indicate that PEV use could halve petroleum use (Axsen and Kurani, 2010; Gonder et al., 2007) and cut GHG emissions by 15 to 65 percent relative to conventional vehicles (Duvall et al., 2007; Samaras and Meisterling, 2008; Stephan and Sullivan, 2008). Uncertainties in these estimates are both social and technical. The market penetration of PEVs, and thus the magnitude of reductions, will depend on developments in consumer awareness, perceptions, values and preferences. Deployment will be constrained by the ability of PEV technology to meet consumers’ travel, lifestyle and symbolic needs, including driving range and recharge access. Among eventual PEV buyers, GHG reductions will depend on travel patterns and the timing and frequency of charging, as well as the source of electricity. For example, coal-based electricity offers limited benefits relative to today’s conventional vehicles or hybrids (Hadley and Tsvetkova, 2008a; National Academy of Sciences, 2010), natural-gas based electricity could cut emissions by one third (Axsen et al., 2011), and renewable sources such as hydro, solar, or wind could almost eliminate GHG emissions if their generation can be matched to the timing of consumer recharge demand.

[1] Sometimes, discussions of PHEVs will include a separate category for “extended range” EVs. For example, the Chevrolet Volt might be described as an EV that also includes a “backup” gasoline engine for longer trips. We find that this distinction confuses the discussion—PHEVs are any vehicle that can be fueled and powered by both electricity and gasoline (or diesel).

Because a transition to widespread PEV use could require substantial social and technical transitions in Canadian society, there are many important research questions relating to this topic:

- Who will buy PEVs? Under what conditions?
- What will be the effects of different provincial and federal policies on PEV deployment and use? (E.g., rebates and subsidies and vehicle emissions standards?)
- What kind of recharge access is needed to support PEV deployment (e.g. location and recharge speed)?
- How will PEV drivers use their vehicles?
- What will be the GHG impacts of widespread PEV usage?
- How will PEV usage impact a region's electrical grid? How can recharge patterns be "optimized" from a grid management perspective (e.g. time of use rates)?
- What opportunities exist to use PEV charging to complement the intermittent nature of renewable electricity sources (e.g. wind, solar and run-of river hydroelectricity)?

This report touches on each of these questions, addressing some in depth, and pointing the way towards further analysis.

2.2 How will PEVs be recharged in Canada?

The deployment of PEVs is particularly linked to recharge access. PEV drivers could recharge at home, work, or other non-home destinations such as shopping malls. At present in Canada, PEVs can potentially be recharged using three different levels of electrical service:

- **Level 1** uses 110/120V outlets, which is the most prevalent in residences in North America. Level 1 is likely sufficient for many smaller-battery PHEV designs, e.g., those that have blended operation and/or shorter electric powered (or charge-depleting) ranges.
- **Level 2** charging uses 220/240V circuits that are not ubiquitously available in residences in North America, and when they are, there may only be a few for the highest-power appliances. Home access to Level 2 charging requires installation of a specialized residential vehicle charger. At the time of this study, these home chargers can cost several thousand dollars to purchase and install. A Level 2 charger can recharge a battery three to six times faster than a Level 1 charger. Faster charging may be useful for the larger batteries in some PHEVs and may be essential for some EVs.
- **Level 3** chargers (or DC fast chargers) provide much faster charging using a 480V circuit. Charging time varies by charger design and vehicle type; typically a pure EV can be recharged up to an 80% state of charge in 30 minutes. The voltage required for Level 3 is too high for most residential applications, so Level 3 charging is typically only considered for non-home charging.

2.3 PEVs and consumer perceptions

Research on PEV markets varies by perspective—focusing more on technology or consumers. Technology-focused perspectives characterize PEVs as a "technological innovation" (Rogers, 2003) due to physical and functional differences from conventional vehicles (CVs). However, several streams of research indicate that consumer perceptions are more complex and amorphous than a purely technological focus allows. From a consumer perspective, the innovativeness of PEVs can relate to functional, symbolic and societal benefits (Table 1). This two-dimensional conceptualization is further explored by Axsen and Kurani (2012a).

Table 1: Conceptualization of EV benefits (examples)

	Functional	Symbolic
Private benefits	Save money Reliable Fun to drive (experiential)	Expression of self-identity Convey personal status to others Attain group membership
Public benefits	Reduce air pollution Reduce global warming Reduce oil use	Inspire other consumers Send message to automakers, government, oil companies

PEVs are functional innovations because of what they physically do, such as reducing fuel costs or improving driving experience. These are examples of private-functional benefits. In addition, a new product can be a symbolic innovation because it conveys a "different social meaning" than previous products (Hirschman, 1981). Such symbolic values have been found to play a role in vehicle use in general (Steg, 2005; Steg et al., 2001) and electric-drive vehicle purchases in particular.

PEVs may also be societal innovations because they can offer novel benefits to society. Purely private goods benefit only the individual, while public goods such as "clean air" benefit society more generally (Green, 1992). PEVs can be perceived as "mixed goods"—having aspects of both private and public goods (Green, 1992)—because in addition to the private benefits discussed above, they can provide reductions in air pollution, greenhouse gas emissions and oil dependence, or encourage others to care about such issues. We employ the term "societal" as a broad category of collective benefits, including environmental benefits and other regional or national benefits such as decreased oil dependence.

Further, consumer perceptions change over time: functional understandings are altered as more information becomes available; symbolic meanings change and new meanings emerge (Heffner et al., 2007); and pro-societal benefits are negotiated as new perspectives, research, and policies come to light (Calef and Goble, 2007; Gjoen and Hard, 2002; Hess, 2007; Smith, 2005). Thus, a thorough assessment of the potential PEV market needs to recognize the complexity and dynamics of consumer motives and behaviours.

2.4 Approaches to PEV market research

To explain our present research design, we organize this discussion of previous PEV market studies into three different approaches.

First, **constraints analyses** produce forecasts of PEV market penetration based on car buyers' physical, resource, and functional constraints such as home recharge access and driving patterns. Consumers are not directly asked about their interest in PEVs—rather, demand is inferred from driving patterns and/or recharge access. Consumer access to residential recharge infrastructure has been estimated using housing data as proxies, e.g., building type and year of construction. For examples, Nesbitt et al. (1992) estimated the proportion of residences with recharge access to be 28 percent in the U.S. More recently, Williams and Kurani (2006) estimated the proportion to be 15 to 30 percent in California. Other constraints analyses assess the proportion of consumers with present driving patterns that match stipulated PEV range capabilities (Bradley and Quinn, 2010; Gonder et al., 2007; Karplus et al., 2010). Pearre et al. (2011) used driving diary data to conclude that a 160 km range EV (with home charging only) could meet the travel needs of 17 to 32 percent of U.S. drivers, depending on drivers' willingness to change their travel behavior such as redistributing trips among household drivers and vehicles.

Second, **discrete choice models** have been used to forecast PEV market share based on different attribute combinations and consumer preferences. Discrete choice models typically assess demand by representing consumers as self-interested individuals who consciously tradeoff different vehicle attributes to produce the highest utility (following the rational actor model). Attribute values are estimated based on choice sets derived either from hypothetical (stated) consumer data (e.g. Brownstone et al., 2000; Bunch et al., 1993a; Hidrue et al., 2011; Potoglou and Kanaroglou, 2007) or actual (revealed) market data (e.g., Wall, 1996). Choice models tend to focus on functional aspects of PEVs, such as vehicle size, purchase price, operating cost, and performance, in addition to car buyer demographic characteristics (e.g. Train, 1980). Some studies include additional explanatory factors, such as environmental and technology attitudes (Ewing and Sarigollu, 2000), information sharing (van Rijnsoever et al., 2009) and changes in market penetration and acceptance of the new vehicle technology (Axsen et al., 2009). A drawback of this approach is that it tends to focus on consumers' present perceptions and preferences regarding PEV—even though these preferences are often unformed or uncertain.

A third approach to PEV market research seeks to incorporate consumer learning through a **reflexive lifestyle** approach. Researchers examine the effects of consumer learning on the prospects for transitions to PEVs and to address limitations of the constraints studies and choice models noted above. For example, focus groups and interviews conducted at the advent of the period of policy, technology, and market activity regarding EVs in the 1990s reported that most consumers had so little familiarity with EVs that their preferences for novel functional attributes such as battery range were non-existent or unstable (Turrentine et al., 1992). Such findings are consistent with the view that consumers create and develop their preferences with exposure to, experience with, and discussion of novel technology (Bettman et al., 1998). Rather than revealing well-defined and static preferences (as assumed by the rational actor model), stated choice games and even car purchases are opportunities for preference construction, and thus preference change.

The role of travel behavior "games" under these conditions was pioneered by Lee-Gosselin (1990). Building from this, Kurani et al. (1994) and Turrentine and Kurani (1998) attempted to incorporate constructive processes in surveys by designing "interactive stated lifestyle-preference" techniques to simulate decision making grounded in actual household behavior. Their approach allowed for education and learning as part of the survey response process. Since these early studies, ongoing empirical observations show that sufficiently motivated households can adapt their lifestyles to new, limited-range vehicle technologies (Cocron et al., 2011; Pierre et al., 2011; Turrentine et al., 2011; Woodjack et al., 2012). Examples of such adaptations include the careful planning of household trips, reorganization of vehicle use among household members, and learning of recharge behavior at home and publicly.

This third, reflexive lifestyle research approach was recently utilized to assess the early U.S. market potential for PHEVs (Axsen and Kurani, 2008, 2009). A three-stage web-survey was based on insights gained from prior EV research (Kurani et al., 1994) and qualitative interviews of early PHEV drivers (Heffner et al., 2009). The survey was administered to a representative sample of 2,373 new vehicle buying households across the U.S. in 2007. Rather than rely on proxy measures, the survey directly consulted respondents regarding their ability to park a household vehicle where it could be charged: half of respondents reported access to a Level 1 (110/120-V) recharge opportunity at home. A constructive design space exercise assessed consumer interest in PHEV designs and priorities for attributes. Unlike a standard choice model, the design space approach does not limit consumers to selecting from pre-defined vehicle choice sets, and the approach does not assume that consumer valuation of vehicles is necessarily a summation of consumer valuation of the vehicle's attributes. When we presented consumers with this design space, we found that most respondents designed cheaper, lower-range PHEVs than previously assumed by technology and policy experts (Axsen et al., 2010). Overall, one-third of the sample demonstrated both PHEV interest and home recharge access.

Our present study (CPEVS 2013) follows the reflexive lifestyle approach and assumes that consumers construct their interests and preferences as they learn about PEV technology, and that these interests may or may not be constrained by present driving patterns and home recharge access—depending on the motivations of the consumer. Relative to the 2007 U.S. PHEV survey, we extend the vehicle design space games to include a wider range of CV, HEV, PHEV, and EV possibilities. Further refinements were made to better customize the offered vehicle options to each respondent's context and vehicle interests. Further insights to wording and layout of the questionnaire are drawn from more recent interviews with households that participated in a northern California PHEV demonstration project (Axsen and Kurani, 2012a; Caperello and Kurani, 2012; Kurani et al., 2009). Aspects of this survey method have recently been tested with a survey of new vehicle buyers in San Diego, California (Axsen and Kurani, 2012c; Axsen and Kurani, 2013b).

2.5 Our present target: Potential "early mainstream" PEV buyers

Because the **CPEVS 2013** aims to anticipate the potential purchase and use patterns of PEVs in BC and Canada, the survey focuses on new vehicle buying households. In other words, we ignore households that only purchase used vehicles or don't purchase vehicles at all. We assume that only new vehicle buying households will be potential PEV buyers in the shorter term.

For the sake of analysis, it is useful to divide potential PEV buyers into a number of segments. One if the most popular models is Rogers' (2003) "diffusion of innovations" model, which separates potential buyers into innovators, early adopters, early majority, late majority, and finally laggards. This diffusion model focuses on the trait of "innovativeness" as the main determinant of purchase behaviour. However, we find that this model is too limited in its representation of human motives; see Axsen and Kurani (2012b) for a full critique.

Instead, we start with a broader classification, avoiding some of limitations that come with the diffusion of innovations model:

1. **PEV pioneers**: these are the very first buyers of PEVs, and are enthusiasts by nature. These are the types of buyers that already own PEVs in BC and in the rest of Canada. Research shows that such buyers are extreme on many characteristics, including very high income level, pro-technology and pro-environmental values, and overall willingness to explore and experiment (Axsen and Kurani, 2013a). These buyers are a relatively small, specialized group and are generally different from—and thus do not represent—"early mainstream" buyers. Thus, this segment should not be the primary focus the present study.
2. **"Early mainstream" PEV buyers**: this broad segment is the target of the present PEV survey project. This is a much larger segment than the initial pioneers, and generally has characteristics more in line with mainstream values and interests. PEVs must be accepted by this market in order to become a widely accepted technology.
3. **"Later mainstream" PEV buyers (or non-buyers)**: this is the larger market segment of new vehicle buying households that are not presently interested in buying a PEV. It is possible that households in this segment may eventually become buyers, but very important changes will be required, e.g. changes in policy, costs, technology, or cultural norms.

2.6 Conceptual framework: Anticipating "early mainstream" PEV purchase and use behaviour

Figure 1 provides a summary of our present conceptual framework. **CPEVS 2013** collected data from vehicle buyers in BC and Canada to better understand consumer readiness for PEVs (e.g. travel patterns and recharge availability). In addition, CPEVS 2013 collected individual data relating to awareness, perceptions, values and preferences in order to identify and characterize the subset of most likely "early mainstream" PEV buyers. Our analysis focuses on this "early mainstream" segment to simulate the potential electricity and environmental impacts of these early PEV users, and to assess to the opportunities to optimize the environmental impacts of PEV use in BC.

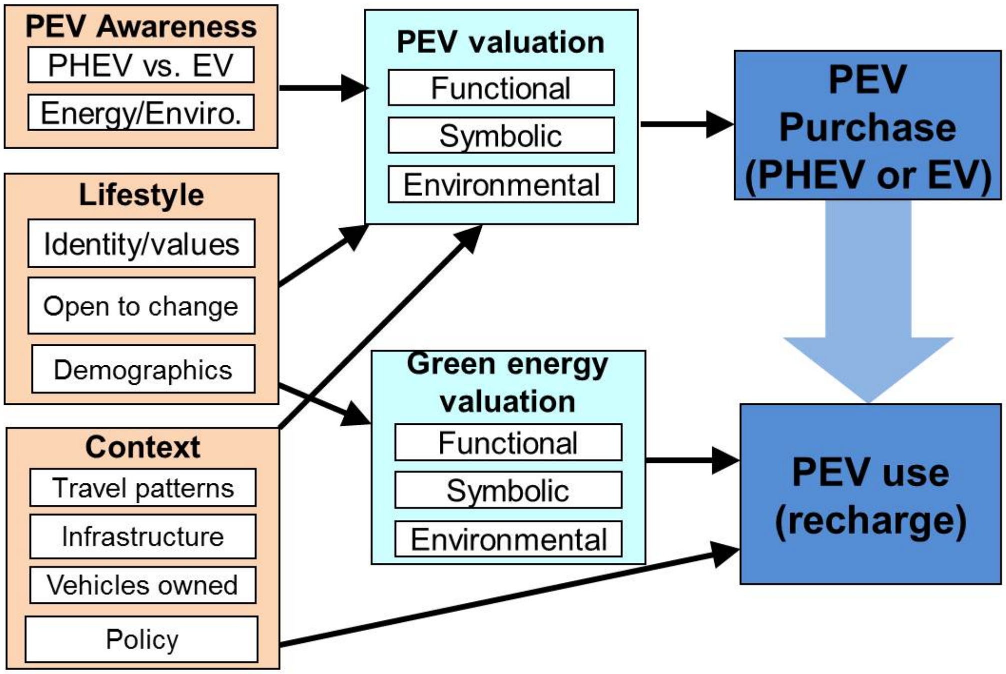

Figure 1: Conceptual framework: Anticipating PEV purchase and use

3 Methods

3.1 Overall study context

CPEVS 2013 and this preliminary analysis are part of an overall research project sponsored by Natural Resources Canada's ecoEnergy Innovation Initiative (ecoEII) under the R&D contribution program, titled: "*Powering Plug-in Electric Vehicles with Renewable Energy Supply in BC*." The principal investigator is Professor Curran Crawford at the University of Victoria, and other academic collaborators include AnnaLisa Meyboom at the University of British Columbia, and Clay Howey at the British Columbia Institute of Technology. The overall project is scheduled to run from 2012 to 2016.

Dr. Jonn Axsen of Simon Fraser University's Energy and Materials Research Group is leading the consumer research portion of this project. This report summarizes one part of the consumer research project: **a Canada-wide survey of new vehicle-buying households (CPEVS 2013),** with a focus on BC. Additional consumer research stages include:

- Interviews of new vehicle buying households in BC (18 of 30 have been completed to date).
- A survey of present owners of plug-in electric vehicles in BC (survey is still being designed).
- Interviews of plug-in electric vehicle owners in BC (not yet started).

The overall NRCan ecoEII project will involve a number of other research stages, including modeling of the electrical grid and interactions with PEV users, and modeling of consumer use of recharge infrastructure. These research stages will be addressed in future reports.

3.2 Regional context: Passenger vehicle buyers in BC and Canada

Our present study includes consumer data from across Canada (minus Quebec), but we presently focus on results for BC. There are several aspects of BC that make it a unique from other provinces and regions in terms of PEV deployment:

- **Low electricity prices:** British Columbians enjoy some of the lowest electricity rates in the world, translating into low fuel costs for PEVs (National Energy Board, 2012). Coupled with relatively high gasoline prices compared to other North American cities, the costs to fuel a PEV is about one-seventh compared to an equivalent conventional vehicle (depending on PEV type and usage patterns).[2]
- **Low-carbon electricity:** Second, BC provides a particular advantage in terms of low-carbon electricity. The vast majority (86%) of electricity is generated from hydroelectric

[2] Based on an electricity price of \$0.083/kWh and a gasoline price of \$1.45/L, comparing per-km fuel costs of a Nissan Versa CV (\$0.0972/km) and Nissan LEAF EV (\$0.0148/km) for an CV:EV cost ratio of 6.6:1, compared to cities such as Calgary (3.4:1), Toronto (3.4:1), Los Angeles (3:1) and New York (1.6:1). Electricity rates are based on household rates with a monthly consumption of 750 kWh in regions with tiered rates, using recent Canadian and US price data from Manitoba Hydro, (2013). and City of Seattle, (2013). We assume the Nissan LEAF has a range of 117 km and usable battery capacity of 21 kWh. We assume fuel efficiency of 6.7 L/100km for the Nissan Versa (US DOE, 2013).

dams, in addition to an increasing amount of generation from renewable sources, such as wind, run-of-river hydro, and biomass (Nyboer and Kniewasser, 2012). BC also has a zero-emissions electricity standard in the *Clean Energy Act s.2(c)* that requires at least 93% of total generation to be met by clean or renewable resources (SBC, 2010). BC's continued reliance on low-carbon electricity promises to increase the potential GHG benefits of electrifying light-duty passenger vehicles.

- **PEV incentives:** Presently, the Government of BC offers point-of-sale rebates of up to $5,000 on the purchase of PEVs through its Clean Energy Vehicle Program. Originally announced in 2011, the program was recently renewed to March 2014 with a $2.5 million budget (LivesmartBC, 2013). BC residents that qualify for the incentive program can also receive rebates of up to $500 for an eligible home recharge station.
- In addition to these incentives for consumers, the Government of BC recently supported the installation of 519 Level 2 public charging stations through its Community Charging Infrastructure Fund. [3]

The market for PEVs has been growing in BC, but very slowly. As of October 2013, over 655 PEVs have been sold in BC, representing about 17% of the total Canadian PEV market (Klippenstein, 2013).[4] Forecasts for further PEV deployment in BC are highly uncertain due to the many complexities discussed in the previous section, such as uncertainties in consumer demand, technological development, energy prices and environmental policy. In their *Electric Load Forecast for 2013-2033*, BC Hydro projects the market share of PEVs to increase to 5% in 2020 and 20% in 2028 (BC Hydro, 2012). The present empirical study may help to improve the basis for making such forecasts.

3.3 Sampling strategy

As noted above, our target population is new vehicle buyers in BC and Canada. We define "new vehicle buyers" as households who have purchased a new vehicle in the past five years and use a vehicle regularly. A market research company (Sentis) was contracted to recruit a representative sample and deploy the survey. Consumer data was collected using a three-part internet-based survey between April and October 2013.

In total, 1,754 respondents completed all three parts of the survey, which included 1,202 respondents representing new vehicle buyers across Canada (excluding Quebec), and oversamples of BC (363) and Alberta (189). Adding together the general Canada sample and BC oversample, 538 BC residents completed all three parts of the survey. We oversampled BC and Alberta to provide a useful regional comparison with contrasting electricity grids and potential differences in vehicle use. Initially, 3179 respondents completed Part 1, with 1823 completing Part 2, of which 1754 finished Part 3 of the survey.

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[3] Details: http://www.livesmartbc.ca/incentives/transportation/CCI_EV_NRs-lists-of-funded-charging-stations.pdf

[4] This estimate does not include the Ford Fusion Energi, C-Max Energi, or Toyota Prius Plug-in, as these models are not categorized separately from the regular hybrid versions in provincial databases. Assuming the BC PEV fleet is similar to that of Canada, these models account for ~8% of total PEV sales, or about 53 vehicles in BC, for a total of 708 PEVs in BC.

We chose a predominantly Internet-based survey because it allows flexibility of survey design (noted below), control over response environment, automation of data entry, and provides a relatively low cost per respondent. In some situations, internet surveys can result recruited sample that is disproportionately younger and of higher socioeconomic status than non-respondents (Couper et al., 2007). However, we do not presently have this concern because our study attempts to characterize potential buyers of new PEVs—a target population that is generally of higher socioeconomic status than the general population anyway. We address the issues of lower response rates of Internet surveys with sufficient completion incentives and believe that because 83% of Canadians now have Internet access, coverage error is not likely to be significant (Internet World Stats, 2013).

3.4 Overview of method

Following the **reflexive lifestyle** approach described in Section 2.4, we designed and implemented an in-depth survey, allowing us to attain rich details from each new vehicle buying household in our sample (Figure 2). Our approach assumes that the vast majority of new vehicle buyers have little prior experience with PEV, and have not previously thought about PEVs much or at all. Our method thus seeks to learn many details about the respondent (Part 1), provides respondents with opportunities to learn about their own interest in PEVs and how the technology may relate to their lifestyle (Part 2), and finally elicits respondent interest in buying a PEV and using it in various ways (Part 3).

The overall flow of the three-part survey is depicted in Figure 2:

- **Part 1 (background information)** investigated the respondent's vehicle fleet, home electricity conditions and also general lifestyle.
- **Part 2 (PEV readiness)** elicited home recharge potential and driving patterns using a home recharge assessment and a three-day driving and parking diary. The home recharge assessment asked respondents to locate and assess electrical outlets around home parking locations. The diary required respondents to record the timing and distance of each trip, parking locations, and the proximity of those locations to an electrical outlet or existing EV charging station. Respondents recorded data in a diary document and then entered their data online. Respondents were also provided with a short booklet to introduce them to vehicle technologies and green electricity and act as a primer for Part 3.
- **Part 3 (PEV interest)** investigated consumer preferences regarding PEVs and the charging of PEVs. The section also combined a series of attitudinal questions with discrete choice exercises and design exercises to investigate the tradeoffs involved in purchasing and charging PEVs.

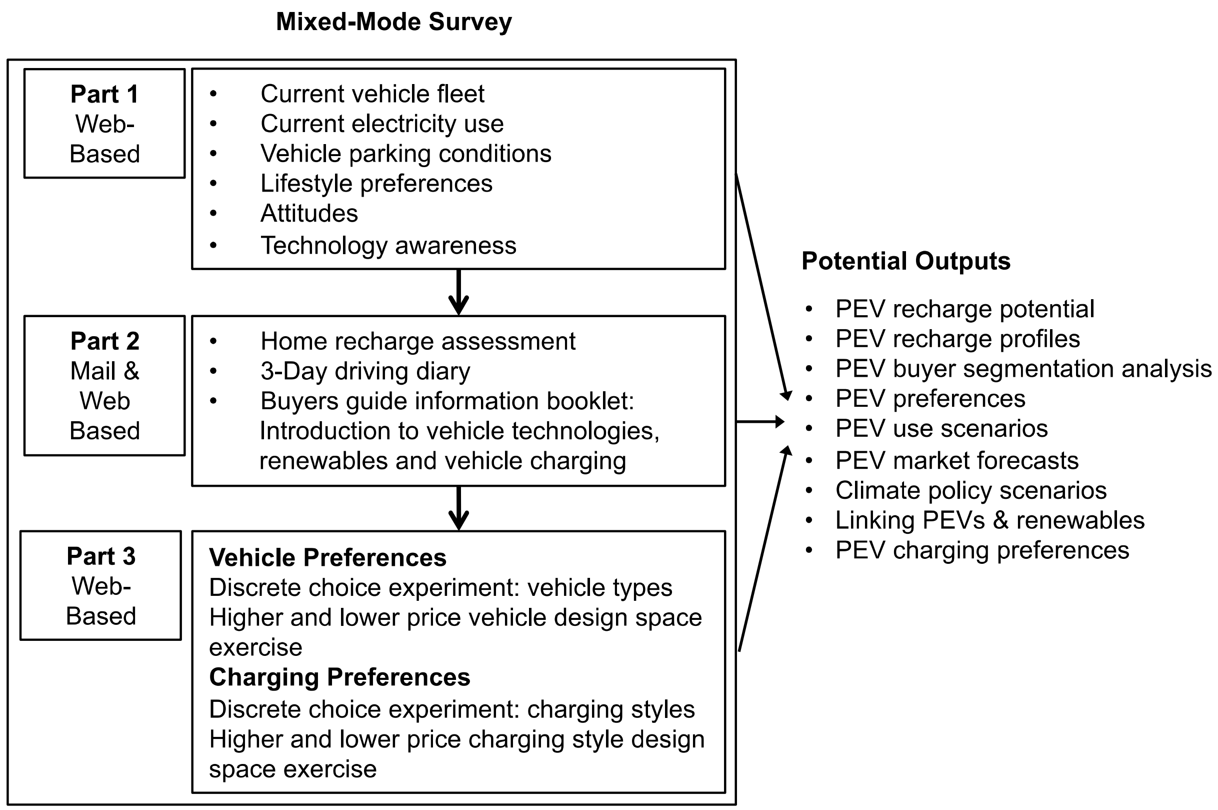


Figure 2: Summary of the Candian Plug-in Electric Vehicle Survey (CPEVS 2013) method

Figure 2 also identifies some of the potential outputs of analysis of this data—only a subset of which are reported in this result. For example, data can be used to identify segments of "early mainstream" PEV buyers, to forecast PEV sales under different market and policy conditions, to construct potential PEV recharge profiles, and to simulate the electricity and greenhouse impacts of PEV usage.

The full survey instrument is available in PDF Form, following the link provided in the Appendix. We provide more general details of these instruments below

3.5 Part 1 of the survey (Background questionnaire)

Part 1 of the survey collected various details about the respondent and their household that may relate to readiness for and interest in PEVs. Sections included:

1. **Vehicle ownership:** included questions on the household's fleet of vehicles (e.g. make/model, use, and purchase history) and fuel costs.
2. **Electricity use:** included questions about sources of electricity and current expenditure on home electricity. In addition we questioned familiarity with renewable sources of electricity and smart meters and willingness to adopt renewables and smart meters.
3. **Vehicle Technologies:** included questions to gauge familiarity and experience with different vehicle technologies/models and PEV charging stations (Axsen and Kurani, 2008).

4. **Values and lifestyle:** included questions on individual values (Stern et al., 1995), the new ecological paradigm (NEP) attitudinal scale (Dunlap et al., 2000), and questions of individual lifestyle that have been shown to relate to interest in pro-environmental technologies (Axsen et al., 2012).
5. **Your Household:** included demographic questions (e.g. education, income, home type).
6. **Preparing for Your Driving Diary:** included questions about the vehicle to be replaced next and basic questions about recharge access at home and work. Responses to these questions were used to customize the Part 2 package that was then mailed out to respondents.

3.6 Part 2 of the survey (Mail-out package on PEV readiness)

For each respondent that completed Part 1 of the survey, a package was mailed to their home, which included a cover letter, home recharge assessment, three-day driving diary, and a PEV "Buyers' Guide".

3.6.1 Home recharge assessment

Previous PEV impact studies (Duvall et al., 2007; Hadley and Tsvetkova, 2008b; Weiller, 2011) have made relatively simple assumptions regarding home recharge access. For example, some studies assume that all vehicle buyers have residential recharge access, or that people living in homes built in a certain year have recharge access.

We provide a more realistic and reliable measure by directly asking consumers about their vehicle's physical access to electrical infrastructure. Based on their responses in Part 1, respondents were sent one of four versions of the Home Recharge Assessment to assess home recharge readiness. Respondents that had a reliable/consistent parking location at home were asked to locate outlets (110/120V and 220/240V) and electrical panels, noting their proximity to their vehicle's typical parking location, as well as any barriers (e.g. walls) that could restrict access. (An example of the home recharge assessment can be attained by following the link provided in the Appendix.)

We have three main purposes for implementing this three-day diary:

1. Following a **reflexive lifestyle** approach, this home recharge assessment helped the survey respondent to better understand their own recharge access.
2. We want to understand what proportions of new vehicle buyers in BC presently have access to Level 1 or Level 2 charging at home, or have the potential install Level 2 charging at home.
3. We provide a "customized" option for Level 2 installation as part of the PEV "design space" exercise (described in Section 3.7.4), and use the home recharge assessment data to estimate the cost of charger installation.

Regarding the third purpose above, we constructed a simple home charge installation cost model. To customize their questionnaires, respondents were first categorized based on three questions:

1. Do they already have a vehicle charging station available at their home?

2. Do they have a reliable home parking space, such as a garage, driveway, carport, or otherwise assigned parking space?
3. If they have a reliable parking space, do they have the authority to install a Level 2 charger or could they obtain permission from the property owner?

Respondents with a reliable space and authority to install a vehicle charger were asked about proximity of existing Level 1 and 2 opportunities, as well as potential to install Level 2. Respondents with a reliable parking space but no authority to install new electrical infrastructure were only asked about existing Level 1 and 2 opportunities. Other respondents (respondents without a reliable parking space or respondents with existing EV charging stations) were not sent any further questions. Respondents that had a reliable parking space were categorized as follows:

- A respondent has **Level 1 access** if they currently have a parking space within 25 feet of an existing 110/120-V outlet.
- A respondent has **Level 2 access** if they currently have a parking space within 25 feet of an existing 220/240-V outlet. We assume that these respondents could install a Level 2 charger for a price of $500.
- A respondent has **Level 2 potential** if they do not have Level 2 access, but can locate an electricity supply panel within proximity of their parking space. We assume that the respondent could install Level 2, but at a price that reflects the amount of work required to install the Level 2 charger. Table 2 summarizes the simple price model, which is based on the distance between the electricity supply panel and parking spot, and the types of obstacles between the panel and parking spot. The price of installation would range from $1000 (< 25 feet and no obstacles) to $3500 (> 50 feet and all three obstacle types). This price model is based off a home recharge assessment method previously tested in a survey of new vehicle buyers in San Diego, California (Axsen and Kurani, 2012c).

Table 2: Price model for Level 2 installation at all (only for respondents that: i) have a reliable parking space, ii) do not already have Level 2 access, iii) have authority to install a vehicle charger)

	Obstacle	Cost
Base cost: distance from parking spot to electricity supply panel	<25 feet	$1000
	26-50 feet	$1500
	> 50 feet	$2000
Additional costs: obstacles	Multiple walls	+$500
	Paved space	+$500
	Building floors	+$500

3.6.2 Three-day driving diary

PEV impact studies have typically used a single day of driving as a representation of driving and parking patterns. The US National Household Travel Survey (NHTS) is a commonly used example (Tate and Savagian, 2009; Weiller, 2011). For the purpose of simulating PEV driving patterns, a key limitation of one-day driving diaries is that they cannot represent driving patterns across multiple, sequential driving days (Davies and Kurani, 2013).

To provide a richer data set, we implemented a three-day driving diary, starting with a day of the week assigned at random to stratify participants across the week. (An example of the diary can be attained by following the link provided in the Appendix.) If the respondent did not drive on the assigned day of the week, we asked them to begin the diary on the next day that they used their vehicle. As a result, the diary data may slightly overestimate the amount of travel but not to the extent of the NHTS, which omits zero-trip days (Davies and Kurani, 2013).

Using the vehicle they intended to replace next, respondents recorded detailed trip data for each trip taken: start and end times, distance traveled, trip purpose. At each destination, parking data was recorded, including the type of parking (e.g. garage, street) and any availability of existing electrical outlets or PEV charging stations. For data verification purposes, respondents also recorded the total number of trips taken on each day, as well as the total distance traveled on each diary day.

We have two main purposes for implementing this three-day diary:

1. Following a **reflexive lifestyle** approach, this diary helped the survey respondent to better understand their own driving patterns, and recharge access. This “reflection” helps respondents to better think about their own lifestyle and mobility needs and opportunities, and thus can improve the quality and reliability of preferences we elicit from them.
2. We use the diary data itself to help us build models that simulate how early mainstream PEV buyers may drive and recharge the PEV that they desire—and how that usage may impact, and potentially interact with, the electrical grid.

Regarding the latter purpose, we implicitly assume that current driving patterns (in conventional vehicles) accurately reflect the driving patterns of the same respondents if they were to buy a PEV. It is not clear how driving behaviours may actually differ between drivers of conventional vehicles and PEVs. One theory is that the cheaper cost of operating a PEV could result in a “rebound effect,” where drivers actually increase the total distance they drive. However a study of new Toyota Prius HEV buyers in Switzerland found no evidence of rebound effects (De Haan et al., 2006). Another idea is that with range-limited or low-carbon vehicles, drivers may be prompted to reduce total driving distance and/or improve driving efficiency, reducing overall energy consumption and GHG emissions. For example, some drivers in a PHEV trial reported altering their driving habits (e.g. acceleration rate) to improve fuel economy, viewing driving a PHEV as a “game” with objectives like maximizing electric-powered range (Caperello and Kurani, 2011). For the purposes of this report, we ignore the potential for rebound effects or behavioural efficiency improvements, and instead assume that future PEV driving patterns will match present conventional driving patterns.

3.7 Part 3 of the survey (PEV and recharge interest)

Part 3 of the survey included the following sections:

- **Driving Patterns:** Questions to re-familiarize respondents with our survey and to remind them to consider their recent driving diary experience.
- **Next Vehicle:** Understanding the next vehicle purchase of the respondent. Identifying reasons for purchase and potential expenditure on this next vehicle. This vehicle model is used to frame future exercises eliciting PEV purchase interest (Axsen and Kurani, 2009).

- **Vehicle Preferences:** Eliciting vehicle preferences via vehicle design exercises (Axsen and Kurani, 2009) and choice experiments (Bunch et al., 1993b).
- **Charging Preferences:** Using the same design exercises and choice experiment methods as previously but changing the subject to charging a PEV.
- **Overall reaction to the survey:** This section included questions that can only be asked once the respondent is familiar with the concepts that we introduced throughout the survey. This section is an opportunity to obtain respondent feedback and also to garner information about respondent understanding of the subject matter (Dillman and Groves, 2011).
- **The future:** To further support the reflexive nature of the survey we seek to interview respondents after their survey experience. In person qualitative interviews can further our understanding of respondent preferences.

3.7.1 PEV "design space" exercise

The vehicle and electricity program design data used in this analysis were collected with design exercises. The design exercises allow the respondent to personalize a vehicle or charge style to match their exact preferences. The constructive designs used in this study are consistent with theories of constructed preferences that view consumer preferences as outcomes of, not inputs to, decision contexts and processes (Bettman et al., 1998). The idea is that we provide the respondent with a "space" or design envelope—a series of design options that the respondent can select in order to create their preferred design in a particular context. Figure 3 provides a screenshot of the PEV design space game.

Following the **reflexive lifestyle** approach explained in Section 2.4 we assume that most survey respondents have little or no experience with PEVs prior to completing the survey. Part 2 of the survey included exercises that helped the respondent think through their potential usage of a PEV, including the home recharge assessment and driving diary. We also included a "PEV Buyers' Guide document, which explained how the different vehicle technologies that we discuss in section 2.1 function. After introducing vehicle technologies, the guide discusses vehicle charging and also provides an introduction to different kinds of renewable energies that one might charge with. This document is based off a previously successful Buyers' Guide (Axsen and Kurani, 2008).

To begin the design space exercise, the questionnaire first elicited information about the anticipated price, make and model of the next new conventional (gasoline) vehicle the respondent's household would buy (if they could only select from conventional gasoline models). The respondent then completed two PEV purchase exercises, each comparing their anticipated conventional vehicle with hybrid (HEV), plug-in hybrid (PHEV) and pure electric (EV) versions of the same vehicle. Both the HEV and PHEV were described as having 33% improved fuel efficiency, when gasoline was being used (in charge-sustaining operation). The different configurations of these vehicles are in Table 3. Respondents were presented with "higher" price and "lower" price conditions, where prices in both cases also depended on the body size of their next anticipated vehicle purchase (based on Axsen and Kurani, 2013b). The higher price condition was designed to approximate modern day costs of these vehicles. The lower price condition was designed to represent the potential price after subsidies or cheaper batteries.

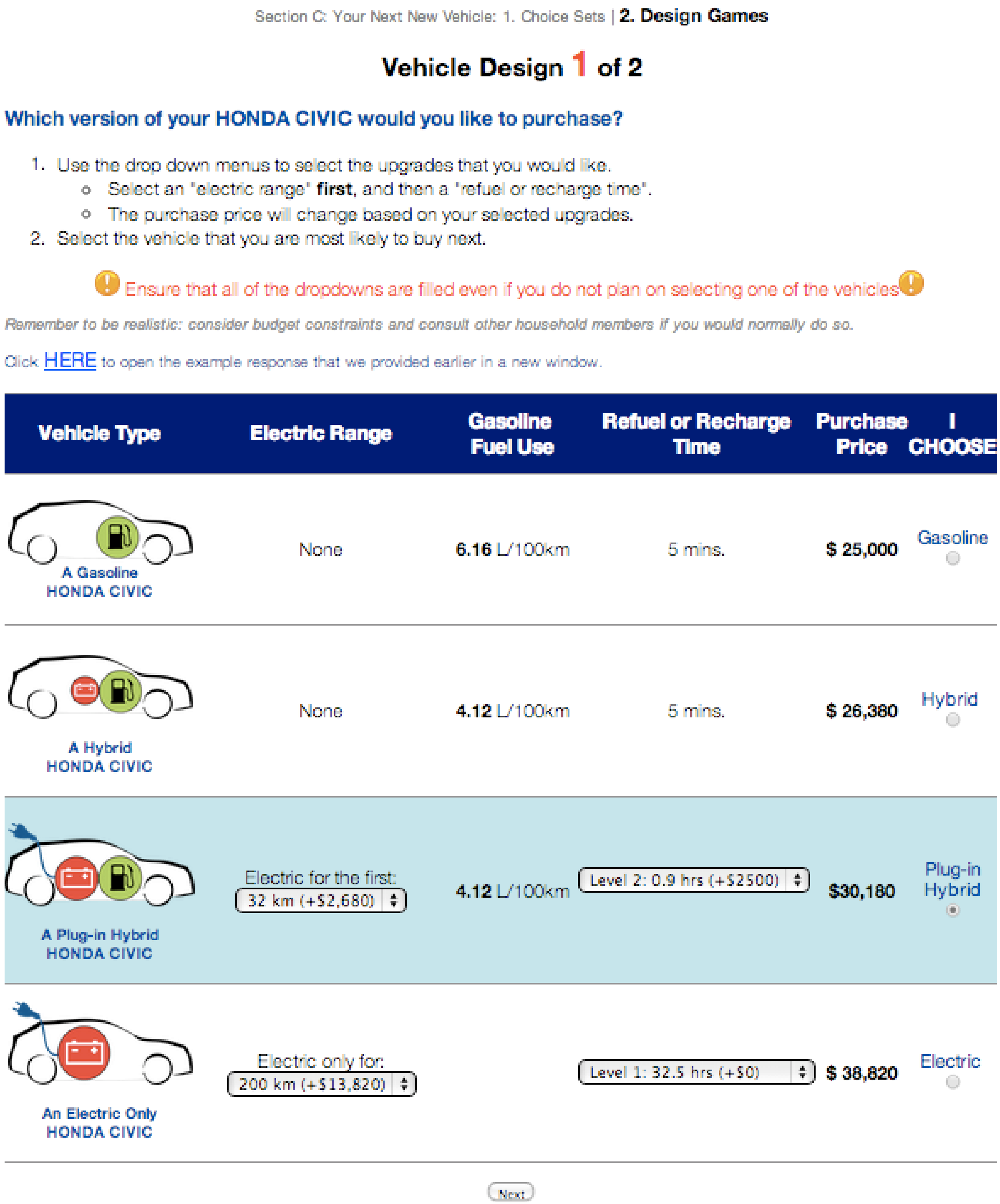


Figure 3: Screenshot of PEV "design space" exercise

Table 3: PEV "Design space" exercise options and prices (prices incremental to respondents' next anticipated conventional vehicle).

Vehicle type and battery range (km)	Higher price				Lower price			
	Compact	Sedan	Mid-SUV	Full-SUV	Compact	Sedan	Mid-SUV	Full-SUV
HEV	$1380	$1740	$2050	$2470	$930	$1070	$1200	$1370
PHEV-16	$2230	$2720	$3130	$3690	$1690	$1910	$2100	$2360
PHEV-32	$2680	$3230	$3810	$4500	$1910	$2170	$2440	$2770
PHEV-64	$3560	$4260	$5190	$6120	$2350	$2680	$3130	$3580
EV-80	$6500	$7880	$10150	$12150	$3220	$3620	$4600	$5300
EV-120	$8940	$10690	$13930	$16600	$4440	$5030	$6490	$7520
EV-160	$11380	$13500	$17710	$21050	$5660	$6440	$8380	$9750
EV-200	$13820	$16310	$21490	$25500	$6880	$7840	$10270	$11970
EV-240	$16260	$19130	$25260	$29940	$8100	$9250	$12160	$14200

In the vehicle design, there were three attributes respondents could manipulate and or choose from: vehicle type (CV, HEV, PHEV or EV), kilometers of electric range and if available, speed of home recharge (Level 1 or Level 2). Respondents were given opportunities to improve each attribute under the different price conditions depicted in Table 3 until they had a vehicle that they believed best represented their next vehicle purchase. The prices in Table 3 are largely hypothetical, where "higher" and "lower" scenarios cover a range of conditions comparable to previous near-term and later-term price estimates (Kalhammer et al., 2007; Kromer and Heywood, 2007; Markel et al., 2006). These Incremental prices include the cost of the battery as well as changes to the engine, motor, exhaust and wiring. Further, we assumed a more power dense battery is more expensive (per kWh) than a more energy dense battery (Santini et al 2011). Two previous PEV "design space" surveys have used similar incremental prices with samples in San Diego, California (Axsen and Kurani, 2013b), and the U.S. (Axsen and Kurani, 2013a). Of course, any estimates of future battery and PEV costs are highly speculative and uncertain. Our overall research question does not substantially rely on using "correct" battery costs.

In addition to vehicle size and range, we personalized the cost of installing a Level 2 charger (6 kW) at home for those respondents that have the potential to do so (i.e. respondents that have a reliable parking spot at home, and would have authority to install a vehicle charge).[5] Using the charger installation pricing model explained in Section 3.6.1 (Table 2), the design space exercise allowed respondents to "pay" to install Level 2 charging at home if they designed some type of PEV, either PHEV or EV (installation prices ranged from $500 to $3500). If respondents had no access to home recharging or if they had a vehicle recharger already available at home, then this charger installation was not included in their design space exercise in the survey.

3.7.2 PEV discrete choice experiment

To complement the design space exercise, we also asked respondents to complete two different choice experiments, which we use to create models of consumer preferences. These are also

[5] 6 kW corresponds to the charge input from a common heavy-duty household circuit (220-240V @ 40A) derated by 20% and an assumed charge efficiency of 83-90% (EPRI, 2009; Lemoine et al., 2008; Parks et al., 2007; Weiller, 2011). We assume a charge input of 1 kW for Level 1 (110-120V @ 15-20A).

known as discrete choice models. Discrete choice models quantify consumer trade-offs among product attributes (Train, 1986). Discrete choice experiments are frequently utilized in transportation, including the modeling of consumer demand for alternative-fuel vehicles (Bunch et al., 1993a; Ewing and Sarigollu, 2000; Hidrue et al., 2011) and in the renewable energy literature for the modeling of demand for renewable electricity (for a review see Menegaki 2008). The discrete choice method is based on rational choice theory, which is critiqued as oversimplifying consumer behaviour. However, we use this method to provide a simple, easily quantified complement to the descriptive statistical data from the survey questions and as a comparison to the design exercises.

Discrete choice models can be estimated using multinomial logit (MNL). MNL is based on random utility theory, assuming that a portion of the utility, or satisfaction, derived by an individual is unobservable. The observable portion of utility is represented by a vector of coefficients weighted to the specified attributes of the product in question, such as purchase price and fuel costs. The alternative specific constant (ASC) represents the observable utility of each choice not captured by attributes specified in the model. The unobservable utility is specified by a random parameter with a mean of zero, following a Weibull distribution. This distribution simplifies the model, allowing estimation without simulation.

Respondents completed a vehicle choice experiment in which they faced a series of six choice sets. Table 4 summarizes the attributes and attribute levels used to construct this experiment. To create the experiment we developed a fractional factorial design, which represents a subset of all possible combinations of attributes and levels. By using a fractional factorial design we are able to exploit the "sparsity-of-effects" principle to expose information about the most important features of preferences (Wu and Hamada, 2011). Fractional factorial designs are often used to reduce the computing and respondent effort required relative to a full factorial design (Hensher et al., 2005).

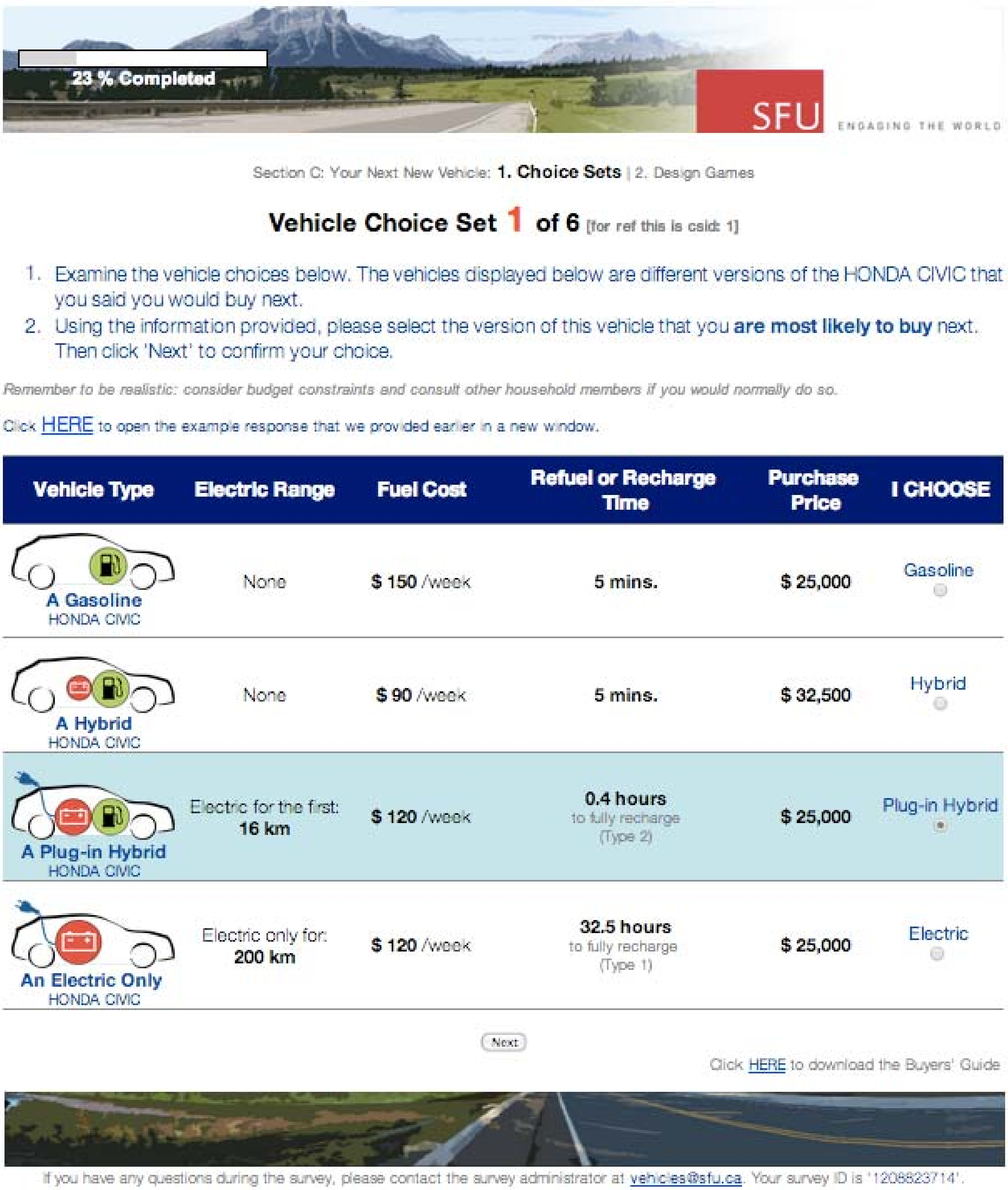
Each choice set presented the respondent with their anticipated "next" conventional vehicle (as explained for the design space exercise) along with hybrid (HEV), plug-in hybrid (PHEV) and electric vehicles (EV) with different combinations of attributes. Aside from the drivetrain and the attributes depicted in Table 4, respondents were informed that all vehicles were identical (e.g. in terms of appearance, power and performance). In each choice set, respondents were asked to choose the vehicle that they would most likely buy. Figure 4 depicts how the vehicle choice set appeared to the consumer.

An important strength of choice models is that estimated coefficients can be utilized to estimate a quantitative measure of respondents' valuation of PEVs: willingness-to-pay (WTP). The ratio of any of the model estimated coefficients to the price coefficient will represent the average trade-off that the sample is willing to make between a dollar of purchase price and an extra unit of that variable, e.g. an extra mile of range. The WTP of the PHEV or EV constant will represent consumers' valuation of PHEV or EV relative to conventional vehicles, holding the other variables equal between the alternatives.

Although the vehicle experiment was intended to specify some of the major attributes that differentiate a conventional vehicle from HEV, PHEV and EVs, many important attributes are likely missing. Implicitly, these missing attributes are captured by a constant (or ASC) in estimated MNL models that represents each alternative type. Also known as “lurking variables,” these missing attributes may include consumer perceptions of greenhouse gas and air quality impacts, electricity costs, and uncertainties about PEV technology. Nevertheless, we feel that these experiments serve as one useful assessment of consumer preferences—which can also be compared with design space results, and household interviews.

Table 4: PEV choice model experimental design

Attributes	Levels
Purchase Price: A scalar relative to the respondents; anticipated next conventional vehicle.	Same price 10% More 20% More 40% More
Fuel Cost: A scalar relative to the amount they expect to spend on fuel (per month) for their “next conventional vehicle.”	80% Less 60% Less 40% Less 20% Less
Charger type (Level 1 & Level 2): The speed at which the vehicle recharges. To reduce cognitive burden we also showed the respondent the time required for a full charge. This time was estimated as a function of the vehicle range, vehicle type and the charger type.	Level 1 – 1 kWh Level 2 – 6 kWh
PHEV Electric Range: Range in km that the vehicle can travel in charge depletion mode.	16 km 32 km 64 km
EV Electric Range: Total range the vehicle can travel.	120 km 160 km 200 km 240 km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Section C: Your Next New Vehicle: **1. Choice Sets** | 2. Design Games

Vehicle Choice Set 1 of 6 [for ref this is csid: 1]

1. Examine the vehicle choices below. The vehicles displayed below are different versions of the HONDA CIVIC that you said you would buy next.
2. Using the information provided, please select the version of this vehicle that you **are most likely to buy** next. Then click 'Next' to confirm your choice.

Remember to be realistic: consider budget constraints and consult other household members if you would normally do so.

Click HERE to open the example response that we provided earlier in a new window.

Vehicle Type	Electric Range	Fuel Cost	Refuel or Recharge Time	Purchase Price	I CHOOSE
A Gasoline HONDA CIVIC	None	$ 150 /week	5 mins.	$ 25,000	Gasoline
A Hybrid HONDA CIVIC	None	$ 90 /week	5 mins.	$ 32,500	Hybrid
A Plug-in Hybrid HONDA CIVIC	Electric for the first: 16 km	$ 120 /week	0.4 hours to fully recharge (Type 2)	$ 25,000	Plug-in Hybrid
An Electric Only HONDA CIVIC	Electric only for: 200 km	$ 120 /week	32.5 hours to fully recharge (Type 1)	$ 25,000	Electric

Next

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If you have any questions during the survey, please contact the survey administrator at vehicles@sfu.ca. Your survey ID is '1208823714'.

Figure 4: Illustrative PEV choice set (screenshot from survey)

3.7.3 Green electricity "design space" exercise

Another objective of Part 3 was to assess respondent interest in "green electricity" and how that might relate to recharging of a PEV. As with PEV demand, green electricity and charging interest was assessed through a design space exercise and a discrete choice experiment. Here, we define "green electricity" as electricity produced by zero-carbon sources such as wind, solar, geothermal, run-of-river hydroelectricity and tidal generation. Our present of definition of "green" excludes large hydroelectric dams, which closely aligns with the approach taken by the California renewable energy program. [6]

The green electricity design space exercise asked respondents to design a "green" electricity program that could be directed to their home or their vehicle. This design space exercise is based off of a more complex version previously implemented with a sample of U.S. new vehicle buyers (Axsen and Kurani, 2013a). The design space was customized to each respondent, based on their report of their current electricity bill (Figure 5). We estimated the monthly kWh consumption of each respondent by using their current bill and the average price of electricity in their province. If the respondent designed a PEV in the lower price PEV design space, the respondent's home electricity bill was increased by an amount that approximated the likely usage of the PEV. If the respondent did not design a PEV then they did not have the option to direct electricity to a vehicle. Consequently, their home electricity bill did not reflect the cost of charging a PEV.

Respondents could design and select some version of the program, or select no program at all. There were two price scenarios; the higher price scenario charged $0.03/kWh for using green electricity, while the lower price scenario charged $0.015/kWh. The design space options are summarized in Table 5. When designing a green electricity program, respondents could select the percentage of their home electricity that would be provided from "green" sources (25% to 100%). For the green electricity design selected by the respondent, the respondent's monthly bill would increase by the proportion of the electricity consumption that would be green, multiplied by the cost per kWh or the green electricity. The respondent could also select a particular source of green electricity, and, if they designed a PEV in the lower price design exercise, whether that green electricity would be directed towards their home or PEV.

[6] For more information see the Overall Program Guidebook at: http://www.energy.ca.gov/2012publications/CEC-300-2012-003/CEC-300-2012-003-CMF.pdf.

Table 5: Green electricity design space options (for designing a home electricity and vehicle recharge program)

Attributes	Attribute levels
Amount of Green Electricity	25% 50% 75% 100%
Green Electricity Source	Wind Small Hydro Solar Mixed
Green Electricity Priority	I don't mind My Household My Vehicle

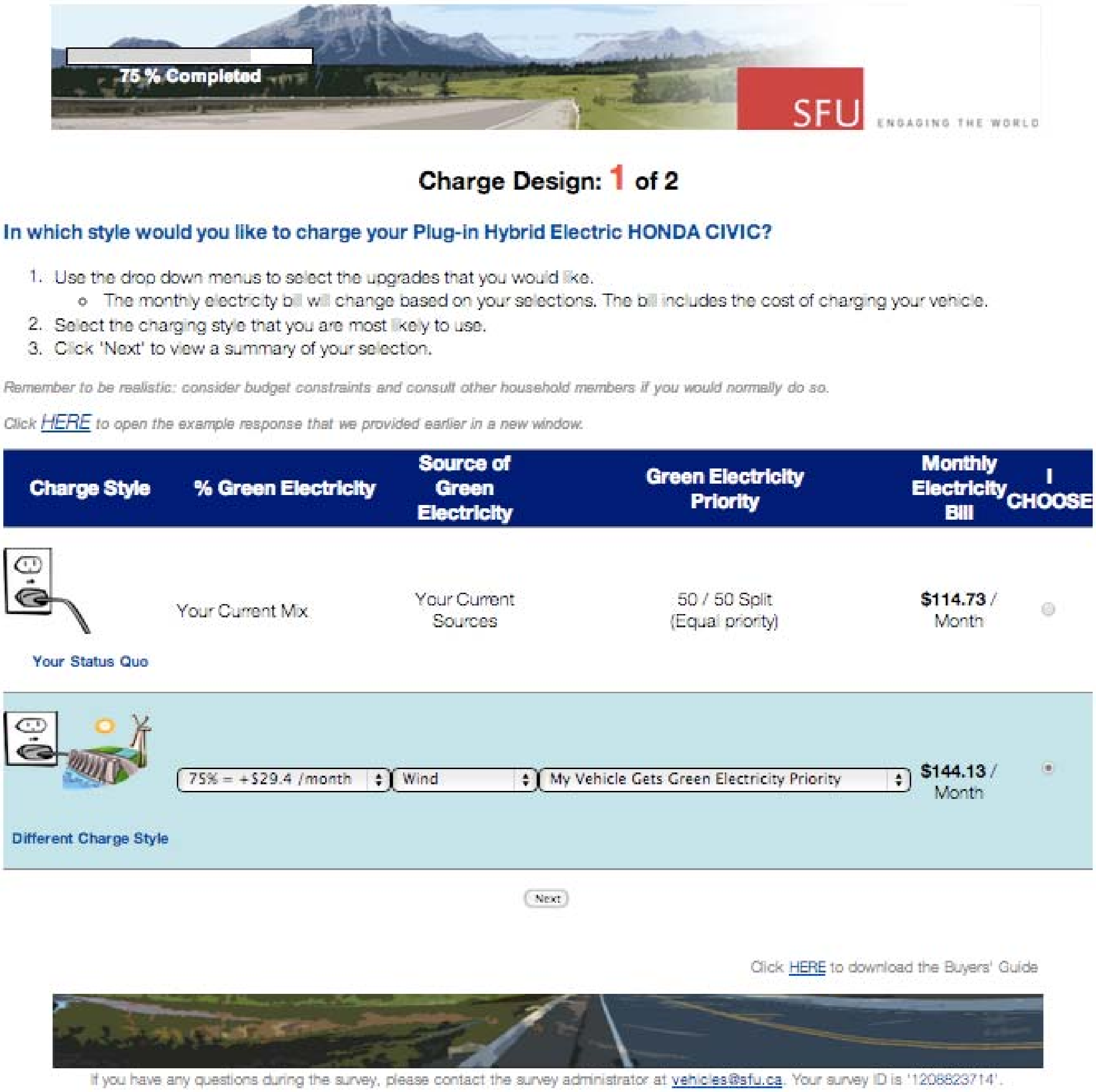


Figure 5: Illustrative green electricity design space (screenshot from survey)

3.7.4 Discrete choice experiment for utility controlled charging

We also assessed respondent interest in green electricity and PEV charging behaviour through a second discrete choice experiment. Here we specifically explored consumer acceptance to the idea of **utility controlled charging (UCC).** The idea is that the electric utility (e.g. BC Hydro) or a third party could have direct control over the timing of PEV charging. The purpose of this control would be to: 1) improve the efficiency of the electrical grid (reduce costs), and/or 2) increase the uptake of intermittent, renewable sources of electricity by matching PEV charging to the timing of when renewable sources are available. This might work by allowing the electric utility to have remote control of when the vehicle begins to charge, at what rate it charges and also when the vehicle stops charging. Consumer acceptance of and preferences for UCC would have implications for the potential of PEVs to help with grid system management and the integration of non-dispatchable renewable energy.

The discrete choice experiment presented six choice sets to each respondent. Each choice set presented the respondent's current home electricity situation and two other alternatives that represented UCC scenarios. As a starting point, the respondent had to imagine using a particular PEV design. We provided up to two PEV scenarios:

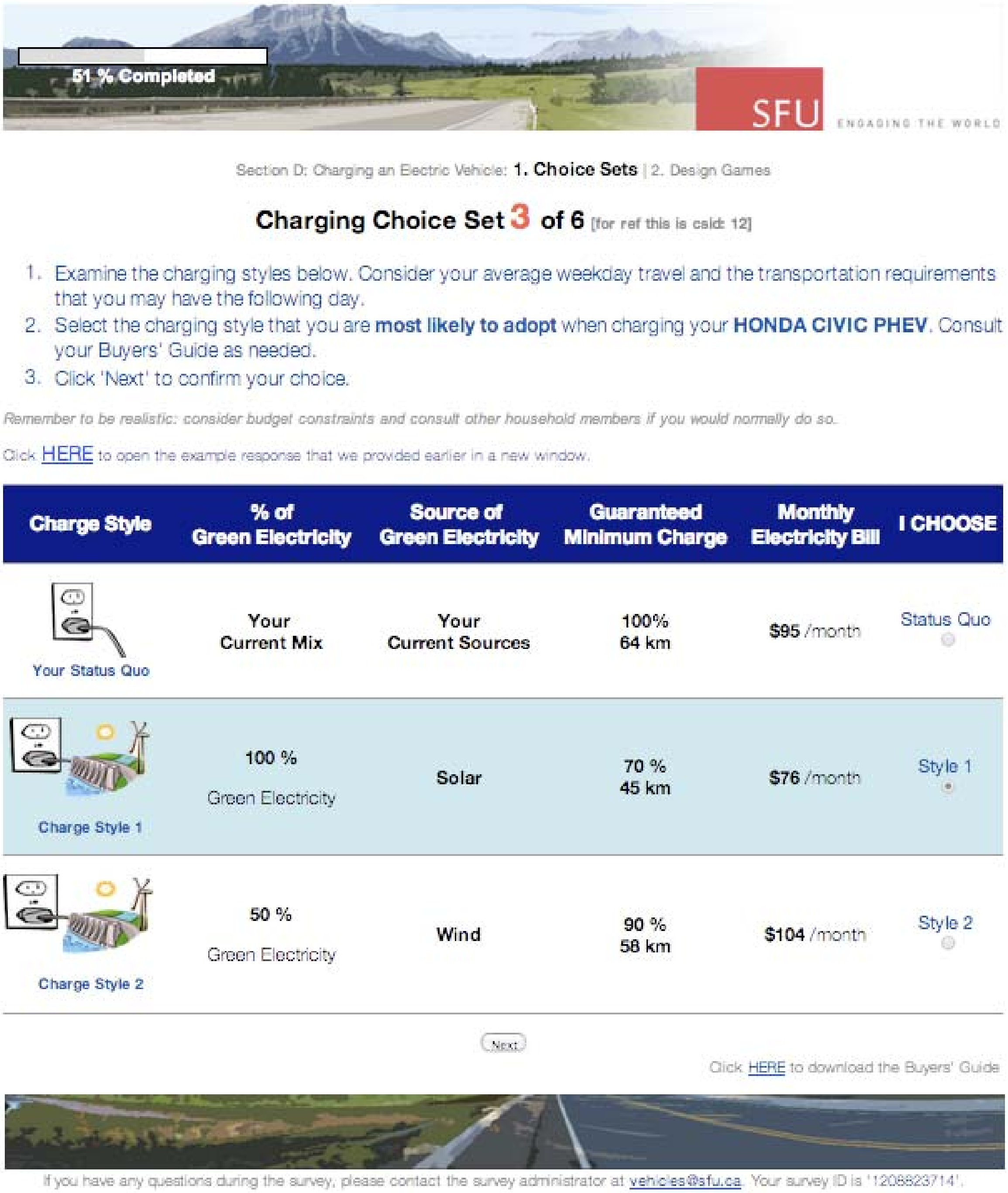
- All respondents completed the choice set while thinking of a 240km range EV vehicle (as a version of their anticipated next conventional vehicle), which we refer to as an EV-240.
- Respondents that selected some type of PEV (PHEV or EV) in the "lower price scenario" of the PEV design space game repeated the choice experiment (all six choice sets) while imagining the particular PEV design that they selected. If the respondent did not design a PEV, they did not complete this second scenario.

The intention of the second PEV scenario is to better estimate the charging preferences of the "early mainstream" PEV buyers given a likely mix of vehicles that they presently want to buy.

The attributes of the UCC plans varied between alternatives and are depicted along with the choice set in Table 6 and Figure 6 respectively. Like the green electricity design space exercise, the UCC choice model was customized for each respondent based on their monthly electricity bill, and also based on their particular vehicle (EV-240 and for some, their customized PEV design). We used SAS's choice mktEx macro function (Kuhfeld, 2005) to generate the experimental design. This macro attempts to optimize D-efficiency, which is a standard measure of the goodness of the experimental design. As D-efficiency increases, standard errors of parameter estimates in the model decrease—see Rose et al. (2008) for details. The attributes and levels were selected with the assistance of pretesting (to ensure respondent familiarity and understanding) and also on previous literature (Brownstone et al., 2000; Bunch et al., 1993a; Hidrue et al., 2011; Potoglou and Kanaroglou, 2007).

Table 6: Utility controlled charging choice model experimental design

Attributes	Levels
Percentage of Green Electricity: To supply the respondents' home and vehicle.	25% of current electricity 50% of current electricity 75% of current electricity 100% of current electricity
Source of Green Electricity: The source of the green electricity to supply the respondents' home and vehicle.	Wind Solar Small Hydro Mixed
Guaranteed Minimum Charge: A scalar that determines the amount of charge that the vehicle would have 'the next morning'. This was displayed to the respondent as both percentage charge and electric range in km.	25% Charged in the morning 50% Charged in the morning 75 % Charged in the morning 100% Charged in the morning
Monthly Electricity Bill: A scalar multiplied by the sum of the user's current electric bill and the expected cost of charging a vehicle.	25% of current bill 50% of current bill 75% of current bill 100% of current bill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Section D: Charging an Electric Vehicle: **1. Choice Sets** | 2. Design Games

Charging Choice Set 3 of 6 [for ref this is csid: 12]

1. Examine the charging styles below. Consider your average weekday travel and the transportation requirements that you may have the following day.
2. Select the charging style that you are **most likely to adopt** when charging your **HONDA CIVIC PHEV**. Consult your Buyers' Guide as needed.
3. Click 'Next' to confirm your choice.

Remember to be realistic: consider budget constraints and consult other household members if you would normally do so.

Click HERE to open the example response that we provided earlier in a new window.

Charge Style	% of Green Electricity	Source of Green Electricity	Guaranteed Minimum Charge	Monthly Electricity Bill	I CHOOSE
Your Status Quo	Your Current Mix	Your Current Sources	100% 64 km	$95 /month	Status Quo
Charge Style 1	100 % Green Electricity	Solar	70 % 45 km	$76 /month	Style 1
Charge Style 2	50 % Green Electricity	Wind	90 % 58 km	$104 /month	Style 2

Next

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If you have any questions during the survey, please contact the survey administrator at vehicles@sfu.ca. Your survey ID is '1208823714'.

Figure 6: Illustrative UCC choice set (screenshot from survey)

3.8 Excel-based models of PEV driving, recharging and electricity impacts

Data on driving, parking patterns and recharge potential collected from Part 2 were analyzed using Microsoft Excel to create 72-hour driving and parking profiles for each respondent indicating:

1. Whether the respondent was driving or parked;
2. Details about their driving (e.g. distance traveled) and parking (e.g. location);
3. The recharge potential of the parking location.

These 72-hour logs for each respondent were linked to three vehicle design and recharge access scenarios outlined in Table 7. Scenario 1 represents a "base case", while Scenarios 2 and 3 represent higher levels of vehicle electrification and/or recharge access:

- Scenario 1 is informed by data collected from the respondents:
    - For recharge availability, we use the Home Recharge Assessment (which limits the available recharge levels/options) to inform available recharge options and costs (based on Table 2) from which the respondent selects a preferred level of recharge access during the vehicle design exercises. Data from the driving diary informs recharge access at work and "other" locations (Figure 12).
    - Vehicle preferences are elicited through the vehicle design exercises. Distributions of preferred PEV designs are shown in Figure 15.
- Scenario 2 also considers the vehicles designed by the respondent but with enhanced workplace recharge access (i.e. allowing for Level 2 access at all work places).
- Scenario 3 models an extreme scenario where all vehicles are EV-240km and recharge access is available at Level 2 at all homes and workplaces.

We model each respondent's recharge profile by pairing their driving patterns to their specified vehicle designs and recharge access, from which we calculated aggregated electricity and gasoline use. We also model theoretical scenarios of higher recharge access (e.g. access to Level 2 charging at work) and different vehicle designs (e.g. EV-240km).

Table 7: PEV usage modeling Scenarios

Scenario	Vehicle Design	Recharge Availability		
		Home	Work	Other
1: Base	User designed[a]	Home recharge assessment + User designed[a]	Driving diary[b]	Driving diary[b]
2: Enhanced Workplace Charging	User designed[a]	Home recharge assessment + User designed[a]	Universal Level 2	Driving diary[b]
3: EV Maximum	EV-240km	Universal Level 2	Universal Level 2	Driving diary[b]

[a] "User designed" data is from the "lower price" scenario of the design exercises.
[b] In the driving diary, respondents were asked to locate outlets within 25 ft. (~8 m) of their parking space at each location, or whether they could have parked at a existing EV Charging Station in the area.

In our models, we also assume the following:

- Level 1 charge rate of 1 kW; Level 2 charge rate of 6 kW.
- Usable battery capacities in Table 8.
- Battery (DC) electricity consumption (fuel efficiency) in Table 9.

Table 8: Usable battery capacity (kWh) for a range of PEV designs and vehicle classes (Adapted from Axsen and Kurani, 2013b)

	Usable Battery Capacity (kWh)			
	Compact	**Sedan**	**Mid-SUV**	**Full-SUV**
PHEV-16	2.6	3.0	4.0	4.7
PHEV-32	5.2	6.0	8.1	9.5
PHEV-64	10.4	12.0	16.1	19.0
EV-80	13.0	15.0	20.2	23.7
EV-120	19.5	22.5	30.2	35.6
EV-160	26.0	30.0	40.3	47.4
EV-200	32.5	37.5	50.4	59.3
EV-240	39.0	45.0	60.5	71.2

Table 9: Electricity consumption (kWh/km) by vehicle class (Adapted from Axsen and Kurani, 2013b)

Class	**Consumption (kWh/km)**
Compact	0.163
Sedan	0.188
Mid-SUV	0.252
Full-SUV	0.297

4 Results

4.1 The recruited sample

Sentis Market Research was hired to recruit survey respondents. Screener data was collected to ensure that the realized sample would match the target population (new vehicle buying households) in terms of basic demographic information (e.g. age and gender). In total, 1754 respondents completed all three part of the survey, with 538 respondents from BC (Figure 7). The full Canadian sample includes all provinces except for Quebec. Because some collected data was missing or inappropriate in some survey sections, some parts of this analysis draws from different subsets of the total sample (as will be noted in the text).

Table 10 compares the realized BC and Canada sample distributions to the corresponding Census data distributions. Demographic data on the target population (new vehicle buyers in Canada) is not accessible, so we expect our realized sample to differ substantially from the general population. Compared to the overall Canada sample, the BC sample was generally older, with fewer high-income earners.

Comparing the BC sample to the corresponding Census data, we find that the recruited sample is generally representative of new car buyers, specifically:

- **Age:** our sample is generally older than the Census, which aligns with previous studies and data on new car buyers in the US (Axsen and Kurani, 2010; Harris-Decima, 2013).
- **Education:** our respondents are more likely to have a higher education than the general population, which is characteristic of new car buyers (Busse et al., 2013).
- **Income:** our sample has generally higher income than the Census, which is typical of new car buyers (Busse et al., 2013).
- **Home ownership:** our respondents are more likely to own a home, and more likely to live in detached (single family) homes and high-rise apartments than the general population.

Overall, we are confident that the realized sample is representative of new-vehicle buying households in BC and in English-speaking Canada (i.e. minus Quebec).

Table 10: Sample representativeness: comparing the sample demographics to the Census

Region	British Columbia		Canada	
	Survey (n = 538)	**Census** (BC)	**Survey** [a] (n = 1754)	**Census** (Canada)
Sample Size	538	4,400,057	1,754	33,476,688
Household Size				
1	15.1%	28.3%	13.1%	27.6%
2	42.2%	34.8%	40.0%	34.1%
3	18.8%	15.0%	20.8%	15.6%
4+	24.0%	22.0%	26.2%	22.7%
Sex (of person filling out the survey)				
Female	60.8%	51.0%	58.4%	51.0%
Male	39.2%	49.0%	41.6%	49.0%
Age (of person filling out the survey)				
15-24	7.1%	12.6%	7.0%	13.0%
25-34	18.8%	12.8%	23.0%	12.9%
35-44	18.8%	13.5%	18.2%	13.4%
45-54	20.4%	16.0%	19.5%	15.9%
55-64	19.5%	14.0%	19.2%	13.1%
65+	15.4%	15.7%	13.1%	14.8%
Work Status (of person filling out the survey)				
Employed	59.1%		60.9%	62.3%
Retired	23.0%		21.0%	33.1% [b]
Student	3.7%		4.0%	
Family caregiver	7.1%		6.8%	0.2%
Presently unemployed	5.9%		5.6%	4.4%
Not applicable	1.1%		1.8%	0.0%
Highest level of education completed (of person filling out the survey)				
Less than high school	2.6%	19.9%	1.8%	23.8%
High school certificate or equivalent	16.7%	27.9%	16.6%	25.5%
Apprenticeship, trades certificate or diploma	9.8%	10.9%	6.2%	10.9%
College, CEGEP, or other non-univ. diploma	21.6%	16.7%	24.3%	17.3%
Some university	12.4%	5.4%	12.5%	4.4%
University degree (Bachelor)	26.5%	14.2%	26.2%	13.5%
Graduate or professional degree	10.5%	5.1%	12.4%	4.6%
Household income (pre-tax)				
Less than $40,000	16.5%	25.8%	14.8%	24.9%
$40,000 to $59,999	21.9%	19.0%	20.5%	19.3%
$60,000 to $89,999	28.8%	24.2%	27.8%	24.3%
$90,000 to $124,999	23.5%	16.8%	24.6%	16.8%
Greater than $125,000	9.4%	14.2%	12.2%	14.7%
Residence ownership				
Own	75.8%		77.9%	68.7%
Rent	24.2%		22.1%	31.3%
Residence type				
Detached House	61.7%	53.8%	66.7%	61.9%
Attached House (e.g. townhouse, duplex, triplex, etc.)	14.8%	23.2%	15.3%	17.0%
Apartment – “low-rise” (<5 story’s/levels)	14.6%	15.1%	10.0%	13.2%
Apartment – “high-rise” (≥5 story’s/levels)	6.6%	5.7%	6.4%	6.8%
Mobile Home	2.3%	2.1%	1.6%	1.2%

Note: Data on household size, sex, age, and residence type are from the 2011 Canada Census. Data on work status, education, and income are from the 2006 Canada Census. Data on home ownership are from the Canadian Mortgage and Housing Corporation: http://www.cmhcschl.gc.ca/odpub/esub/64693/64693_2013_A01.pdf?fr=1374042362378

[a] Overall Canada sample is unweighted. Survey data includes only English-speaking Canada – Quebec was excluded due to language translation costs. Census data includes Quebec.

[b] Students and retirees grouped as “not in labour force”.

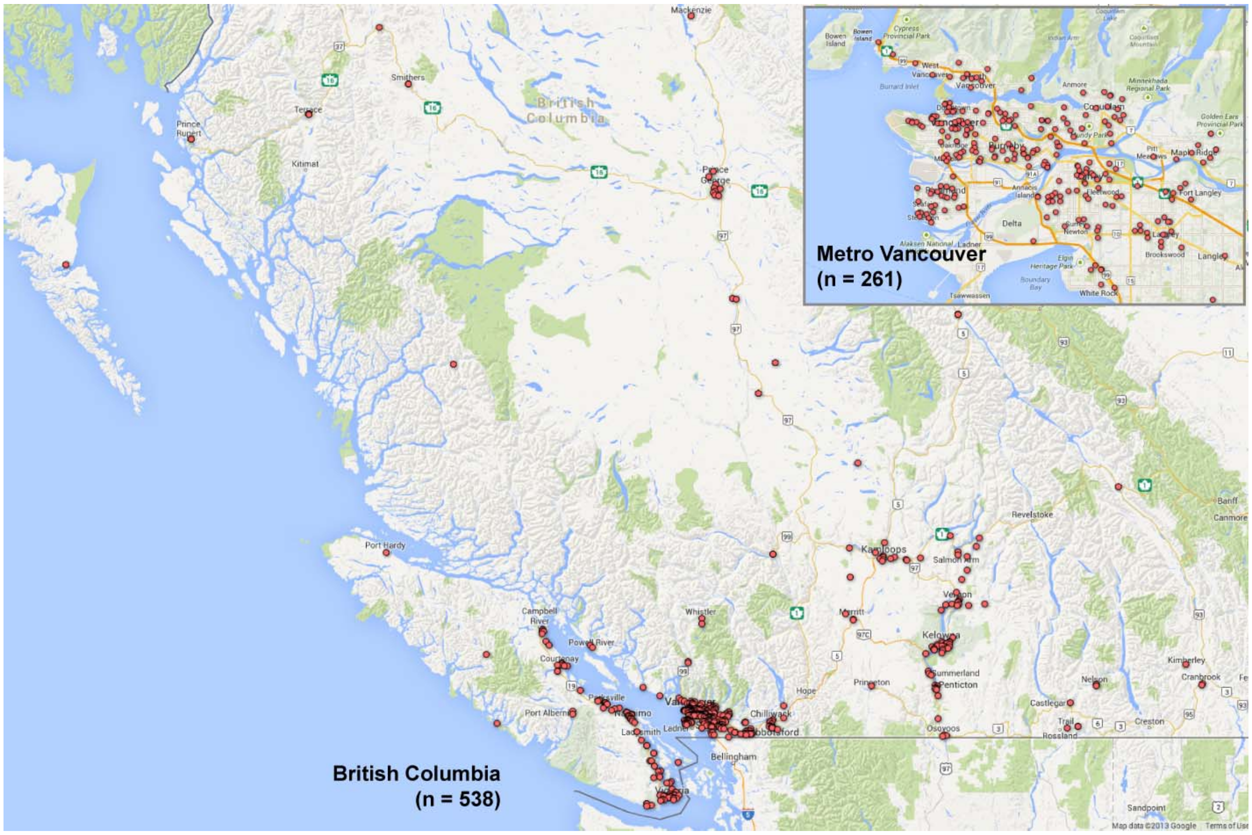

Figure 7: Geographical representation of the BC survey sample by postal code (n = 538, full map: http://goo.gl/sDdQa3)

4.2 Driving patterns

Respondent driving data was collected in Part 2 of the survey instrument. Prior to analyzing the three-day driving diary data, we filtered and analyzed the data to detect errors in data entry or poor quality data. Missing or inappropriate values were imputed where possible, e.g. AM/PM mistakes, typos in data entry, and odometer decimal errors. Through this data cleaning process, the sample size for BC decreased from 538 to 528. In Part 3, respondents are shown a summary of their driving data from the driving diary and are asked if their driving patterns during their three-day diary are representative of their typical driving patterns. 81% felt that their diary data was typical, while 13% felt they drove significantly less and 5.8% felt they drove significantly more than is typical for them.

Trip length and distance traveled per day could be important determinants of PEV design choice and the proportion of travel powered by electricity. Excluding zero-trip days, average daily driving distance was 54 km while the median was 36 km. Including zero-trip days, average daily driving distance was 49 km, which would equate to about 17,900 km per year.

The distribution of daily distances driven (excluding non-driving days) is shown in Figure 8. We exclude non-driving days here in order to compare our data to the US National Household Travel

Survey (NHTS), which does not include non-driving days. We find that 63% of diary days were below 50 km and followed a distribution similar to the 2001 US NHTS data (Jaramillo et al., 2009). When comparing driving to currently available PEVs, we find that on 72% of diary days, respondents drive less distance than the electric range of the Chevrolet Volt and 90% drive less than the electric range of the Nissan LEAF (Figure 8).

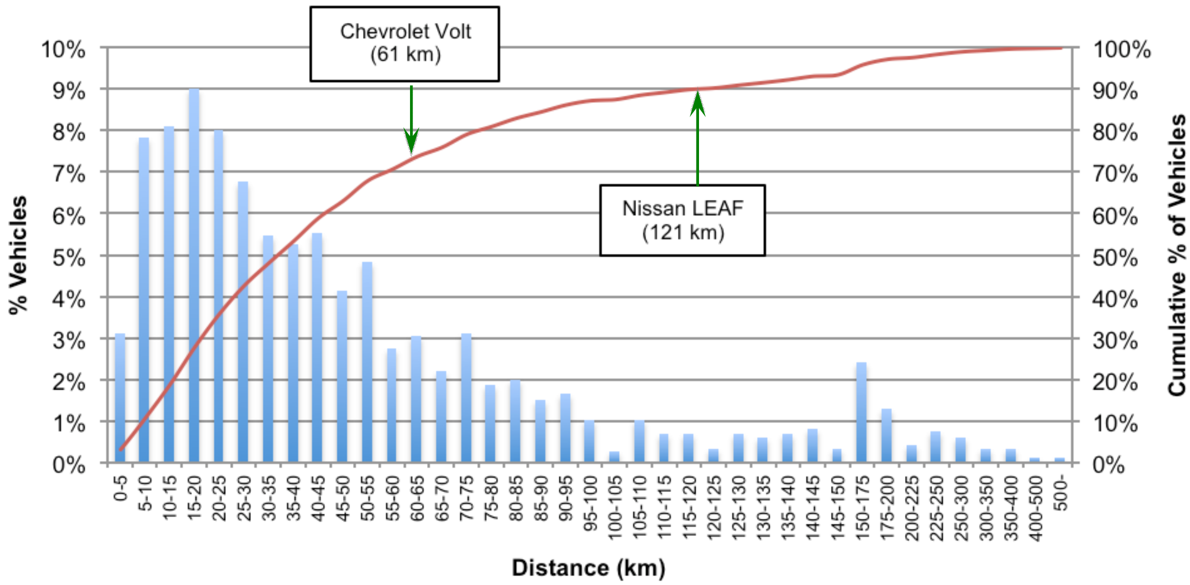

Figure 8: Distribution of daily distance traveled (BC only, n = 528, excluding non-driving days to compare with NHTS data)

The driving patterns of Metro Vancouver respondents are similar to respondents from the rest of BC or Canada (not shown). For example, non-Metro BC respondents have a slightly higher proportion of daily distances below 25 km (45%) compared to Metro Vancouver (40%) or the rest of Canada (39%). However, these differences are only slight and are not statistically significant (at a 95% confidence level). We find greater differences in travel patterns between urban and rural respondents (Figure 9), where urban residents travel shorter distances per day relative to rural residents.[7] For example, 69% of diary days for urban residents were below 50 km compared to 61% for rural residents.

[7] For this report, we equate "urban" with the Census definition of a "population centre" (area with a population of at least 1,000 and a density of 400 people/km^2). All other residents are considered "rural".

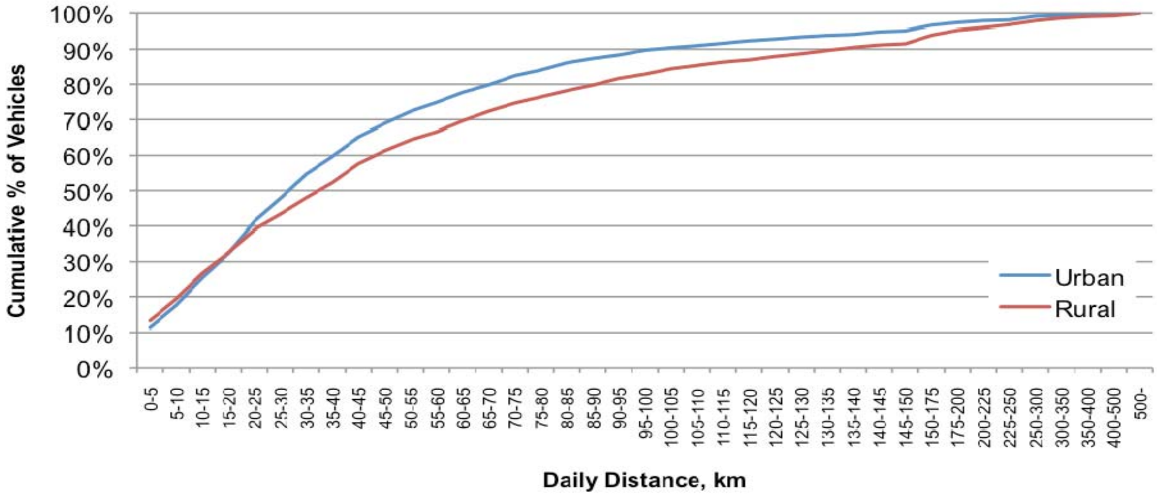

Figure 9: Distribution of daily distance traveled, including zero-trip days (Canada sample, Urban n = 981; Rural n = 693)

Final home arrival times (Figure 10) could have important electricity load implications, as it generally predicts peak load if charging is unconstrained. We find that peak arrival time is around 5 PM. About 15% of respondents arrive between 5-6PM, and 76% of respondents are home by 8PM, both of which are quite close to analyses conducted with 2001 US NHTS data (Tate and Savagian, 2009; Weiller, 2011).

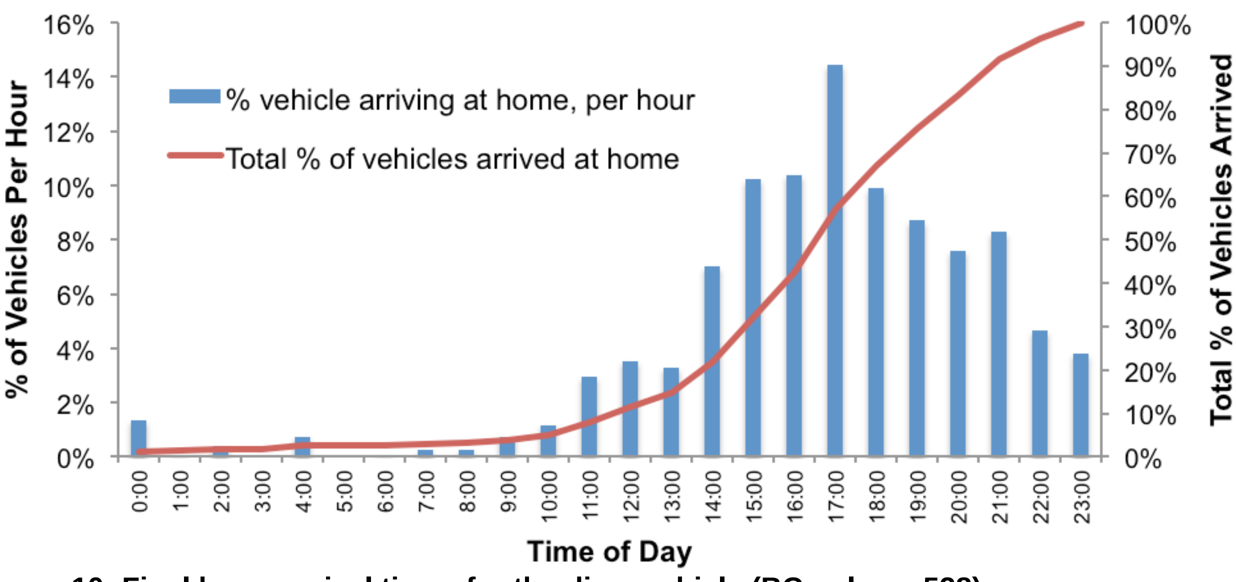

Figure 10: Final home arrival times for the diary vehicle (BC only, n=528).

4.3 BC Sample home recharge access (Level 1 and Level 2)

To assess potential recharge access, we analyzed data collected from the Home Recharge Assessment (Part 2). Respondents with a reliable parking space were asked about their vehicle's proximity to existing Level 1 and 2 opportunities (i.e. 110/120-V and 220/240-V outlets respectively). Following Axsen & Kurani (2012), we consider a respondent to have home "access" to Level 1 or Level 2 charging if they have an existing outlet (110/120V for Level 1 and 220/240V for Level 2) within 25 ft. (~8m) of their typical parking location.

Overall, 66% of BC respondents currently have Level 1 access at home, and 19% have Level 2 access at home. Figure 11 shows Levels 1 and 2 access for the BC sample by housing type and type of parking space. Recharge access is proportionally higher among respondents living in detached and attached homes compared to apartments, and those parking their vehicle in a garage, driveway, or carport. These results are similar to results observed using a similar survey instrument in San Diego, California (Axsen & Kurani, 2012). Compared to the rest of Canada, the BC sample has slightly lower Level 1 and Level 2 recharge access, which may be dictated by the higher proportion of respondents living in apartments (which tend to have a lower probability of recharge access).

Only about half of the 19% with existing Level 2 access reported that they would regularly use it to charge a PEV. In addition to these respondents (9.9%) with existing Level 2 access, a further 35% also have the potential to install Level 2, based on our methodology explained in Section 3.6.1. A total of 44% of these respondents state that they would be interested in paying for the Level 2 installation if they could purchase the PEV that they want in the design space exercise.

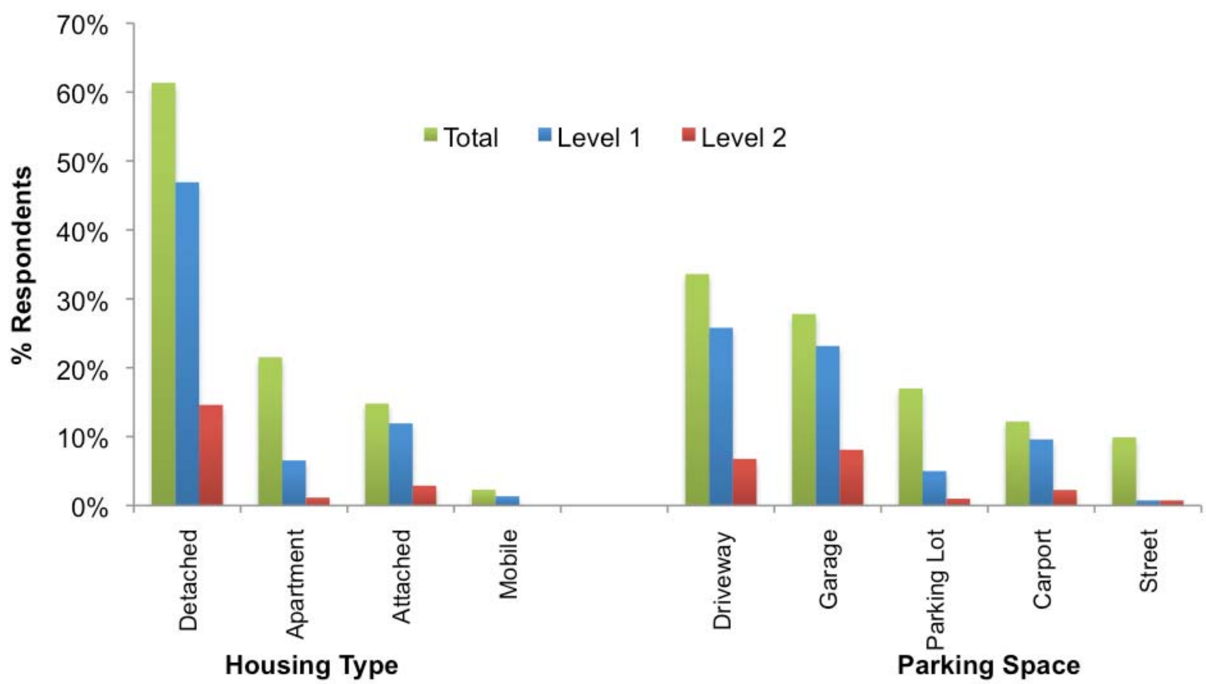

Figure 11: Respondents' residential Level 1 and 2 access by housing type and parking space (BC only, n = 528)

Table 11: Charging upgrade breakdowns by Level 2 installation costs and interest (BC only, n = 526)

	Install Cost	Total	% of sample	% Wanting PEV [b]	% Wanting PEV and wanting to install Level 2
No Level 2	Can't install	289	54.9%	31.1%	0%
Existing Level 2	$500	52	9.9%[c]	50.0%	25.5%
Can Install Level 2	$1,000	52	9.9%	50.0%	25.0%
	$1,500	31	5.9%	38.7%	6.5%
	$2,000	38	7.2%	34.2%	18.4%
	$2,500	36	6.8%	30.6%	2.8%
	$3,000	19	3.6%	36.8%	36.8%
	$3,500	9	1.7%	44.4%	22.2%
Total [a]		526	100%	36.3%	10.0%

[a] We removed the five respondents that already had a Level 2 vehicle charger.
[b] PEV "interest" is indicated by selection of a PEV in the "lower price" PEV design exercise.
[c] Here we use a second definition for Level 1 and Level 2 access and asked those respondents who identified Level 2 access if they would regularly use it to charge a PEV.

Figure 12 depicts respondents' driving activity and recharge access by time of day and parking location. Presently, the majority of respondents' charging opportunities are Level 1 outlets at their homes. Very few existing PEV charging stations were observed at parking locations during the course of respondents' driving diaries. "Other" parking locations include parking at shopping centres, community centres, and other public parking locations.

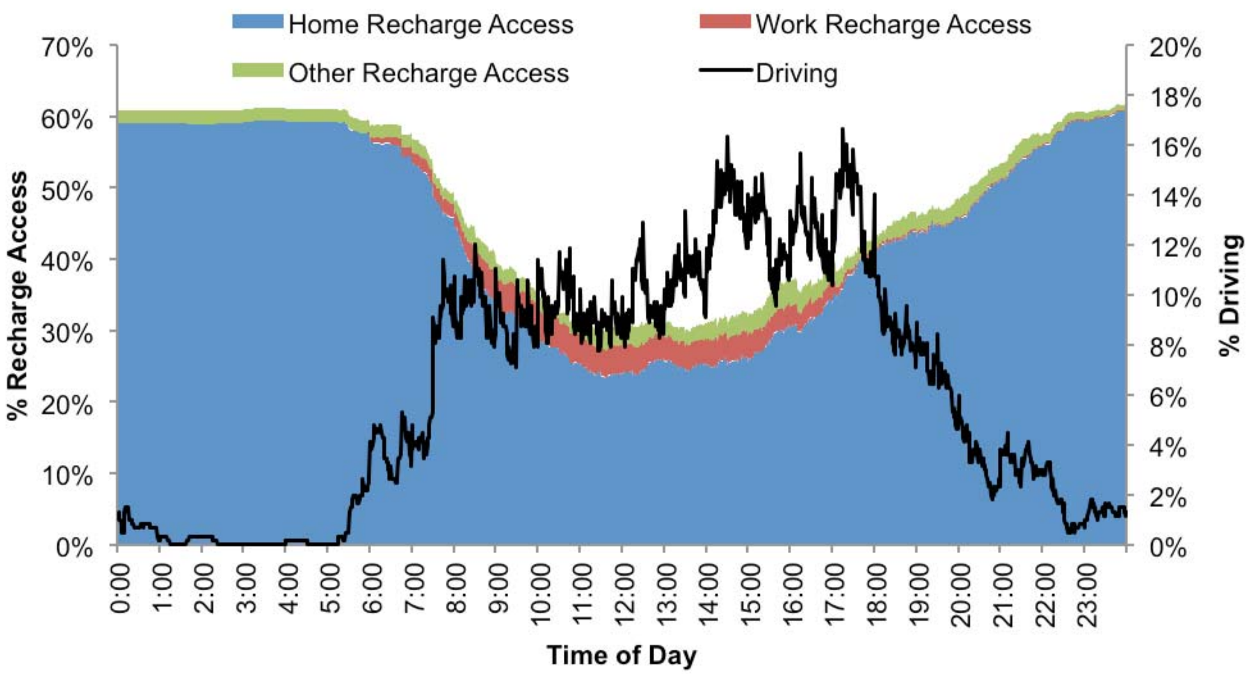

Figure 12: Recharge access by time of day (BC only, n=528)

4.4 Consumer awareness of PEVs

To begin our analysis of the potential BC market for PEVs, we start by assessing the sample's awareness of PEVs prior to completing our survey. Figure 13 depicts respondents' stated familiarity with different vehicle models: a hybrid vehicle (the Toyota Prius), a plug-in hybrid (the Chevrolet Volt), and a pure electric vehicle (the Nissan Leaf). Most respondents are at least somewhat familiar with the Prius (78%), and less so with the Chevrolet Volt (55%). The majority are not at all familiar with the Nissan Leaf (63%).

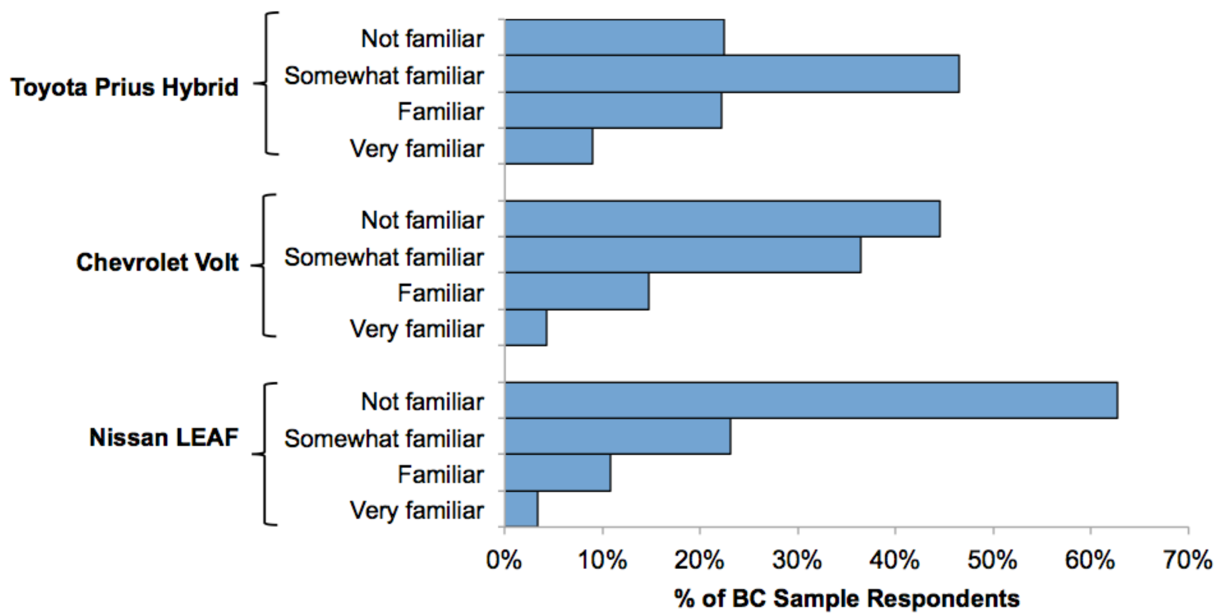

Figure 13: Vehicle buyer familiarity with three vehicle models (BC only, n = 538)

We further explore respondent familiarity by asking how they think each of these vehicle types can be fueled (Figure 14): either with gasoline only, electricity only, or both. The majority of respondents are fairly confused about the basic function of each vehicle model. Only 18% successfully answer that the Prius can be fueled only by gasoline, and about a third successfully describe the Volt and Leaf. This clear lack of prior knowledge or familiarity with PEV technology supports our present methodology—where respondents were first educated about PEV design options before their interests and preferences were elicited.

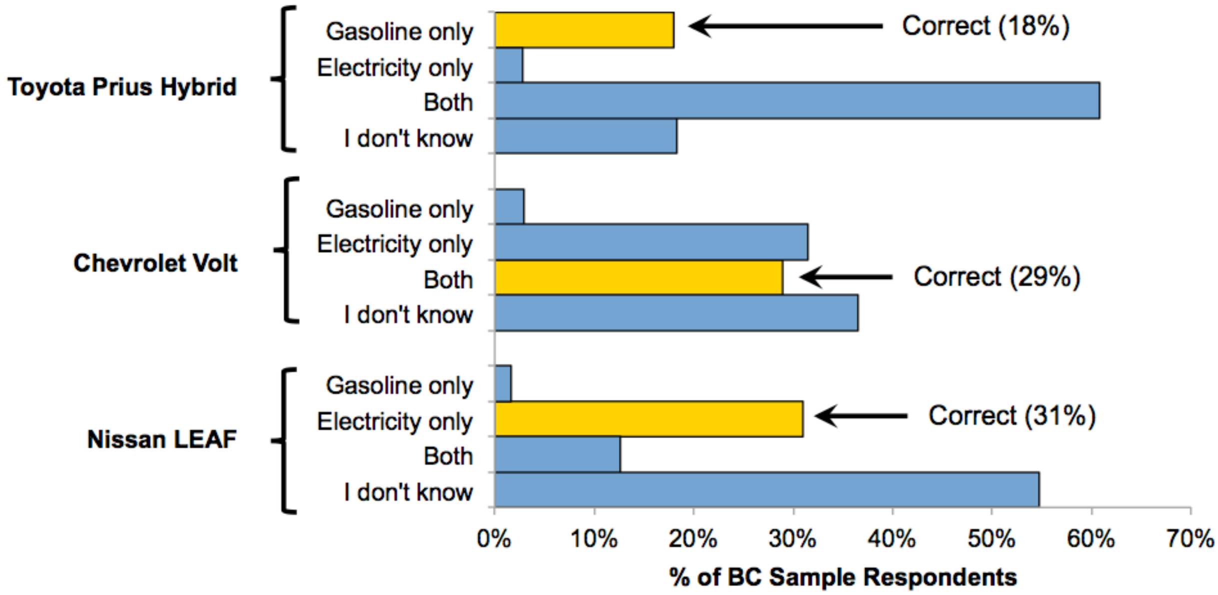

Figure 14: Vehicle buyer perceptions of three vehicle models and how they are fueled – "How do you think each of the following vehicles can be fueled?" (BC only, n = 538)

4.5 Consumer interest in PEV designs

After respondents completed Part 2 of the survey (home recharge assessment, three-day driving diary, and "PEV Buyers' Guide"), they indicated their interest in various PEV designs in Part 3 of the survey (detailed in Section 3.7). These data give us a sense of which respondents want to buy a PEV, and which type of PEV they would want—after the respondent has received some basic education in the options that are available (e.g. PHEV versus EV).

The "design space" exercises included higher and lower price scenarios (Table 3). We provide the higher and lower price scenarios to represent current price and potential price after subsidies (or cheaper batteries) respectively. For example, in the higher price scenario it would cost about $9000 to "upgrade" a conventional compact car to an EV-120km compact car (like the Nissan LEAF). In our lower price scenario, this incremental price drops to around $4500. This reduction of ~$4500 is similar to the current $5000 dollar incentive in BC provided by LivesmartBC (2013).

Figure 15 portrays the distribution of designs selected by respondents. In both price scenarios, the highest proportion of respondents designed and selected some form of HEV (40 to 38 percent), with minorities selecting a PHEV (28 to 36 percent) or a conventional vehicle (28 to 21 percent). An EV was designed by only two to four percent of survey respondents. This gravitation of respondents to PHEV designs (not EV designs) has been seen in previous surveys of new vehicle buyers in San Diego, California (Axsen and Kurani, 2013b), and across the use U.S (Axsen and Kurani, 2013a).

Clearly, respondent interest in PEVs is influenced by price (or subsidies). In the lower price scenario, demand for PHEVs increases by 30% relative to the higher price scenario. Notably, this increased demand is concentrated towards PHEVs with a range of 64km (similar to a Chevrolet Volt) where the rebate almost doubles the percentage of respondents that design this vehicle. Similarly, respondent interest in EV designs doubles in the lower price scenario—although EVs still only represent around five percent of the total market.

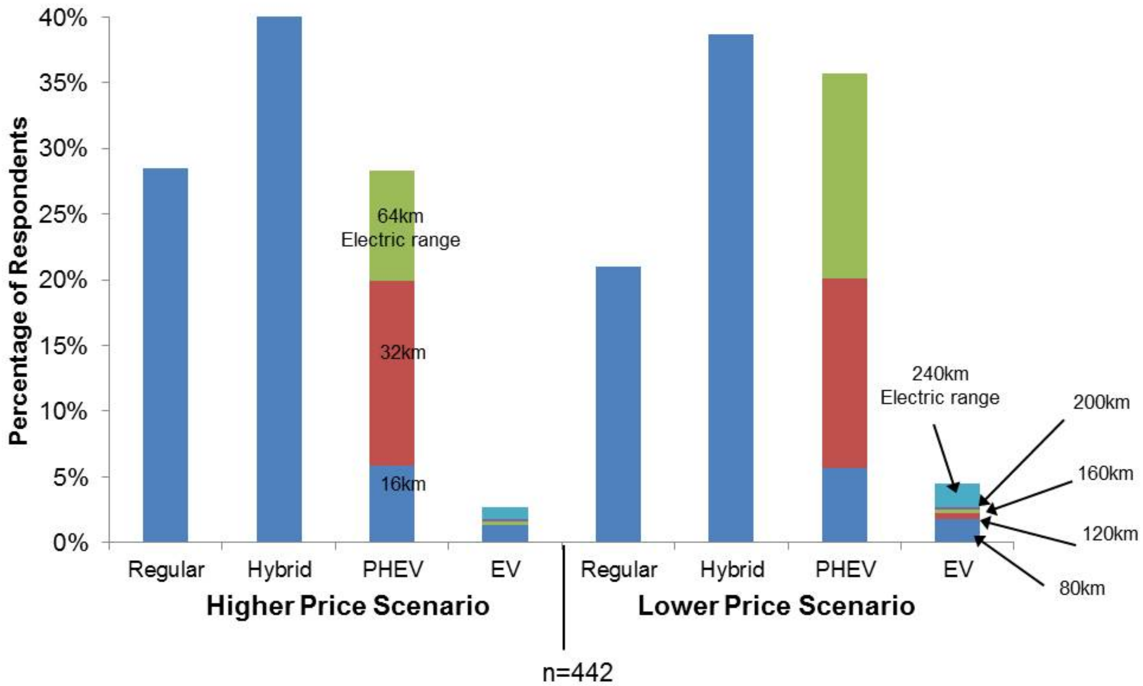

Figure 15: PEV designs selected by BC respondents (BC only, n = 442, higher and lower price scenarios)

4.6 PEV discrete choice experiment (DCE) results

In addition to the "design space" exercise, Part 3 of the survey method also included a discrete choice experiment (DCE). Rather than ask the respondent to select their ideal vehicle design, the DCE collects consumer choices over a variety of attribute combinations (price, fuel cost, range, etc.), then quantifies the relative value that respondents place on each vehicle attribute.

Table 12 portrays a simple, preliminary choice model estimated from this data. The coefficients in the model are of the correct sign—where positive coefficients indicate that respondents want more of that attribute, and negative coefficients represent undesirable attributes. For example, purchase price and fuel price have negative coefficients, indicating that respondents want to pay less money to buy and operate the vehicle. Similarly, respondents value having more electric range, and they see access to Level 2 charging at home as positive. However, only some of these attribute estimates are significant at a 90% confidence level or higher. Notably, the electric range coefficients for PHEVs and EVs are not statistically significant, which needs to be explored with further modeling (perhaps to better represent respondent heterogeneity). Some of these vehicle attributes are interacted with the vehicle types (PHEV or EV). For example, the existence of

Level 2 charging has a greater effect in increasing demand for EVs than for PHEVs, as indicated by the magnitude of the coefficient estimate.

The model also tests for the effects of respondent demographics and lifestyle on their relative interest in hybrid (HEVs), plug-in hybrid (PHEVs), and electric vehicles (EVs). For example, EVs are more desirable (all else held constant) to respondents of age 55 or older, with higher education, or with an environmental- or technology-oriented lifestyle. PHEVs follow a similar pattern, but appear to be desired more by people under the age of 55. We also link this discrete choice experiment to the work of Kurani et al. (1996) by introducing the concept of a "potential hybrid household". "Potential hybrid households" are households that own two or more vehicles; buy new vehicles and have at least 1 vehicle that is not a full sized sedan, van, sport-utility vehicle or pick-up truck. Based on the research of Kurani et al. (1996), we hypothesized that potential hybrid households are more likely to prefer PEVs since the composition of their current vehicle fleet would not be significantly changed through the replacement of a vehicle by a PEV. In the case of PHEVs and EVs we find this to be the case.

In this particular model, the alternative specific constants for HEVs, PHEVs and EVs are statistically significant and negative. These constants account for all the "lurking" variables that the rest of the model does not cover, such as the intangible benefits or drawbacks of each vehicle type. Examples might include safety concerns, symbolic values, or perceived inconvenience. The "base" vehicle here is a conventional vehicle, indicating that all else held constant (e.g. price, fuel cost, range, and charger access), the HEV is less desirable than the conventional vehicle, the PHEV even less so, and the EV is least desired.

In addition to determining the demographics and lifestyles of those more likely to adopt PEVs we can also estimate that average "willingness to pay" for certain attributes in the experiment. As exhibited in Table 12 we have determined that the average Canadian new car buyer (which we know to be similar to the average BC new car buyer) is willing to pay $1264 to upgrade to a level 2 charger if they were to own a PHEV. This value increases to $3483 in the event of a respondent owning an EV. This is understandable given the pure electric nature and larger ranges available for EVs.

Table 12: PEV discrete choice model (Canada sample, n = 1469)

Attribute	Unit	Coefficient	Sig.	WTP
Alternative Specific Constants				
HEV		-0.415	***	
PHEV		-1.701	***	
EV		-4.538	***	
Base = Conventional Vehicle				
Attributes				
Purchase Price	(CAD)	-0.0002	***	
Fuel cost per month	(CAD)	-0.008	***	
Level 2 Home Charger x PHEV	1 if true 0 if else	0.235	***	$1,264
Level 2 Home Charger x EV	1 if true 0 if else	0.648	***	$3,483
Range x PHEV	(km)	0.0003		
Range x EV	(km)	0.0012		
Demographics				
Older than 55 x HEV	1 if true 0 if else	-0.572	***	
Older than 55 x PHEV	1 if true 0 if else	0.345	***	
Older than 55 x EV	1 if true 0 if else	-1.130	***	
Bachelor's Degree or Higher x HEV	1 if true 0 if else	0.176	***	
Bachelor's Degree or Higher x PHEV	1 if true 0 if else	0.363	***	
Bachelor's Degree or Higher x EV	1 if true 0 if else	0.336	***	
Household Income > 80k x HEV	1 if true 0 if else	0.024		
Household Income > 80k x PHEV	1 if true 0 if else	0.060		
Household Income > 80k x EV	1 if true 0 if else	0.048		
# of Persons in Household x HEV	Continuous number	-0.008		
# of Persons in Household x PHEV	Continuous number	0.109	***	
# of Persons in Household x EV	Continuous number	0.075	*	
"Potential Hybrid household[a]" x HEV	1 if true 0 if else	-0.009		
"Potential Hybrid household[a]" x PHEV	1 if true 0 if else	0.172	***	
"Potential Hybrid household[a]" x EV	1 if true 0 if else	0.449	***	
Lifestyle Scales (Factor Scores[b])				
Environmental lifestyle x HEV	Continuous factor score	0.079	***	
Environmental lifestyle x PHEV	Continuous factor score	0.120	***	
Environmental lifestyle x EV	Continuous factor score	0.133	***	
Tech-oriented lifestyle x HEV	Continuous factor score	0.018		
Tech-oriented lifestyle x PHEV	Continuous factor score	0.015	***	
Tech-oriented lifestyle x EV	Continuous factor score	0.075	***	
Model Summary				
Sample		1469		
Pseudo R^2		0.18		

[a] "Potential Hybrid household[a]" is discussed by Kurani as a household that owns two or more vehicles; buys new vehicles and has at least 1 vehicle that is not a full sized sedan, van, sport-utility vehicle or pick-up truck (Kurani et al., 1996).

[b] A factor score is a numerical value that indicates a person's relative spacing or standing on a latent factor. In this case, these are standardized scores, where 1 is one standard deviation above the mean.

*Significant at 90% confidence level

**Significant at 95% confidence level

***Significant at 99% confidence level

4.7 Characterizing the potential "early mainstream" PEV buyers

Based on responses to the "lower price" version of the PEV design exercise, we identified an overall potentially "early mainstream" PEV market sample—consisting of respondents that designed some form of PHEV or EV (39.5% of the total BC sample, or n = 213). We call this the "early mainstream" sample, which we can compare to the "non-PEV designers" based on demographics, lifestyle, values, beliefs, driving patterns and recharge access. Table 13 below summarizes a logistic regression, which teases out the particular characteristics that are statistically related to the respondents' selecting a PEV design. Specifically:

- **Recharge access:** the early mainstream PEV sample is more likely to identify existing Level 1 access at their home, or to identify the potential to install Level 2 at their home.
- **Lifestyle:** survey respondents indicated their frequency of participation in 45 different activities. We performed a factor analysis technique (principal axis-factoring using SPSS), to identify 10 "lifestyle factors" (groupings of related activities). We included all 10 lifestyle factors in the regression, and found four that are statistically significant predictors. The early mainstream PEV sample is more likely to engage in environmental-oriented activities, technology-oriented activities, or spiritual-oriented activities, and less likely to engage in political activities.
- **Demographics:** the early mainstream PEV sample is more likely to be younger, and to have more household members.
- **Prior knowledge of EVs:** we found only a slight association (at a 90% confidence level) between the respondent having previously researched the Nissan Leaf and selecting a PEV design. We comment on this relationship further in the next section when we divided early PEV buyers into sub-segments.

Interestingly, we found that a number of other variables do not appear to be statistically related to respondent interest in PEVs. For example:

- **Household income** was not associated with PEV interest (continuous or categorical)
- **Travel patterns** were not associated with PEV interest, including distance travelled per day or frequency of trips (from the 3-day driving diary) or ownership of multiple vehicles.
- **Respondent values** (e.g. biospheric or egoistic) were not associated with PEV interest when controlling for other measures of motivation (e.g. lifestyle).
- **Awareness of at least one public charger** was not a significant predictor of PEV interest.
- **Education** was not a significant predictor.
- **Perceptions of the seriousness of climate change or air pollution** were not significant predictors.
- **Region** was not a significant predictor, including GVRD versus rest of BC, and urban versus suburban/rural.

Table 13: Binary logistic regression explaining selection of PEV (PHEV or EV) among BC respondents (n = 539)

		Full model	Reduced model
PEV readiness			
	Level 1 access at home	**0.50****	**0.51****
	Level 2 access at home	0.48	**0.49****
	Have researched the Prius	0.15	
	Have researched the Volt	0.13	
	Have researched the Leaf	0.59	**0.77***
Travel patterns			
	Trips per day	0.08	
	Distance per day	0.00	
	Own 2 or more vehicles	0.15	
	Have seen public charger	0.15	
Values and attitudes			
	Traditional values	-0.08	**-0.11***
	Biospheric values	0.02	
	Altruistic values	-0.02	
	Egoistic values	-0.01	
	Liminality (openness to change)	-0.02	
	New Environmental Paradigm	0.03	
	"Medium" or "Dark" Green	-0.22	
	Climate change is a serious problem	0.04	
	Air pollution is a serious problem	0.11	
Demographics			
	# in household	**0.26****	**0.27****
	Age	**-0.02****	**-0.01****
	Bachelor's degree	0.20	
	Grad Degree	0.46	
Lifestyle			
	Technology	**0.25****	**0.22****
	Spiritual	**0.29****	**0.26****
	Career	-0.11	
	Environmental	**0.41*****	**0.47*****
	Home	0.05	
	Indoor	-0.03	
	Recreation	-0.09	
	Family	-0.10	
	Environmental Politics	-0.25	**-0.27****
	Politics/news	0.06	
Constant term		-0.45	0.15
Model summary	Observations	539	539
	-2 log likelihood	647.54	659.136
	Cox & Snell R-square	0.135	0.116

*Significant at 90% confidence level
**Significant at 95% confidence level
***Significant at 99% confidence level

In addition to comparing PEV buyers with non-PEV buyers more broadly, we can also compare respondents that designed a conventional vehicle (CV), hybrid vehicle (HEV), plug-in hybrid vehicle (PHEV), and pure electric vehicle (EV). Using chi-square tests of association, we find the following differences:

- CV designers are more likely to live outside the General Vancouver Regional District **(GVRD) region** (95% confidence level).
- EV designers are most likely to have a **pro-environmental attitude** (NEP scale), followed by PHEV buyers (95% confidence level).
- The **average age** of descends from CV designers (52 years), to HEV designers (47 years), to PHEV buyers (46 years), to EV designers (42 years) (99% confidence level).
- PHEV designers are most likely to have 3 or more household members (95% confidence level).
- CV designers are least likely to be familiar with the Toyota Prius Hybrid (95% confidence level).
- EV designers are most likely to be familiar with the Nissan Leaf (90% confidence level), and to researched the Leaf (95% confidence level)

We also compared the lifestyle engagement of respondents by their vehicle design (Figure 16). EV designers are most likely to engage in technology-oriented lifestyles, and have about the same engagement in environment-oriented lifestyles as PHEV designers. We also compared the "image" that each respondent associates with the vehicle that they design (not shown). PHEV and EV designers are most likely to associate their vehicle with the image of "supporting the environment" and being "responsible" and "intelligent." There was no association between vehicle design and perceived images of being attractive, exotic, feminine, masculine, powerful, sporty, or successful.

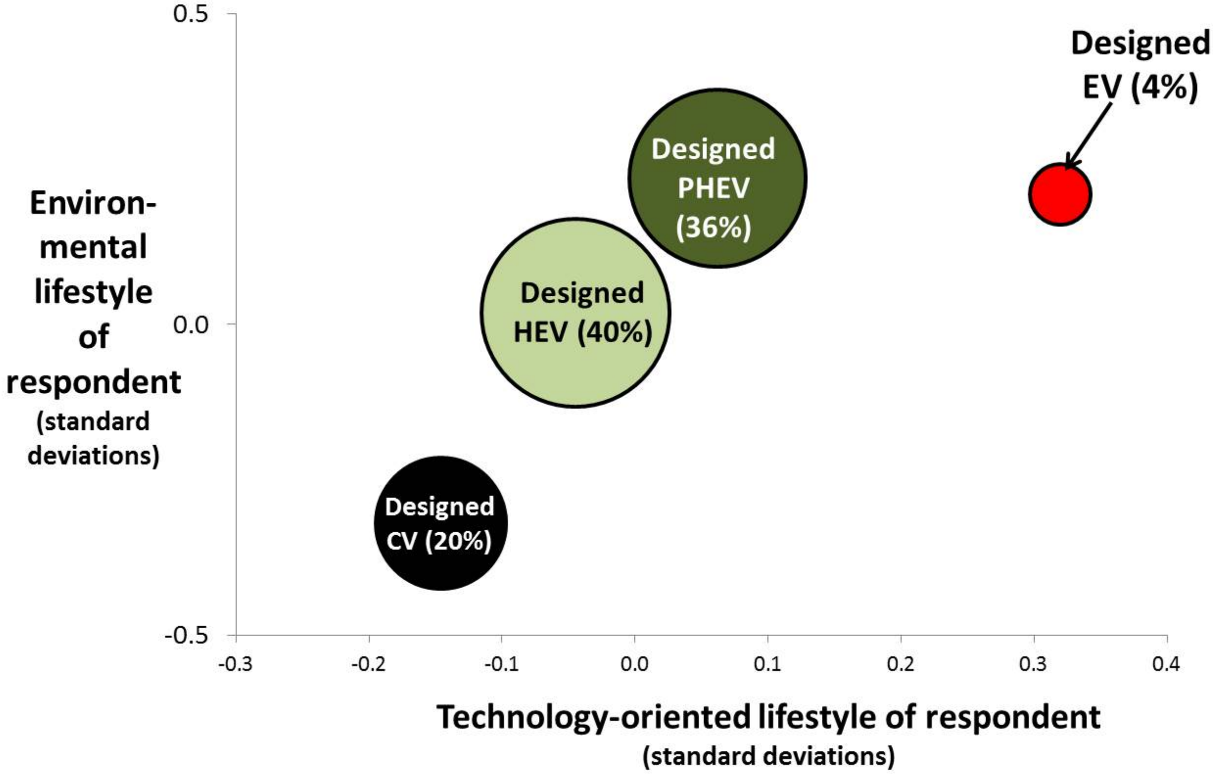

Figure 16: Comparing respondent designs (conventional, hybrid, plug-in hybrid or electric) by the respondent's lifestyle (BC only, n = 538)

4.8 Segmentation of potential "early mainstream" PEV buyers

To provide a more meaningful assessment of the different motives behind potential PEV buyers, we conduct a segmentation analysis. Focusing only on the "early mainstream" PEV respondents, we conduct a cluster analysis based on three lifestyle variables: engagement in technology-oriented and environment-oriented lifestyles, and lifestyle openness (or liminality). Table 14 depicts the three identified clusters:

1. **The "low-tech environmental" cluster**: high on environmental lifestyle (34% of early PEV sample, or 14% of the total sample).
2. **The "active environmental" cluster**: high on environmental lifestyle and openness to change (26% of early PEV sample, or 10% of the total sample). We also call this the "liminal" cluster, as this is a more precise term to describe respondents as being in a state of transition or flexibility in their lifestyles.
3. **The "technology-oriented" cluster:** respondents that are strongly engaged in a technology-oriented lifestyle, but not an environmental lifestyle (40% of early PEV sample, or 16% of the total sample).

Figure 17 below provides a visual comparison of the three clusters based on lifestyle.

Table 14: PEV lifestyle-cluster descriptions and center values (BC Early Mainstream only, n = 213)

Variable	Final cluster centers 1. Low-tech environmental	 2. Active environmental	 3. Technology-oriented
Technology-oriented lifestyle	-0.758	0.201	**0.746**
Environment-oriented lifestyle	**0.417**	**0.741**	-0.240
Liminality (openness to change)	-0.625	**1.184**	-0.220
Sample size	74	55	86
% of PEV designing sample	34%	26%	40%

Note: Cluster analysis used the k-means clustering procedure in SPSS software. Clusters are constructed using standardized variables, so the depicted cluster centers are also standardized.

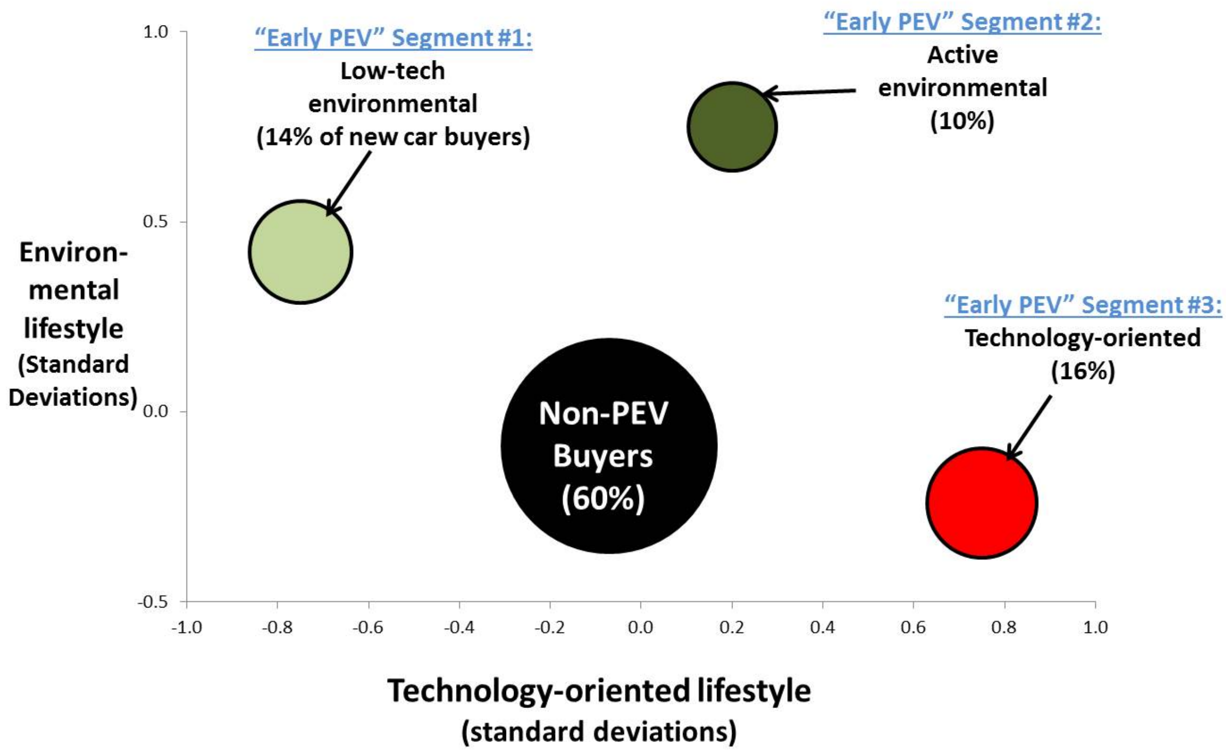

Figure 17: Comparing "early mainstream" PEV buyer segments by lifestyle (BC only, n = 538)

Table 15 provides a more detailed description of each early PEV cluster according to a number of characteristics.

4. Respondents in the "**technology-oriented" cluster**:
    - are least likely to be female (45%);
    - have the highest familiarity with the Toyota Prius, Chevrolet Volt, and Nissan Leaf;

- are likely to see a variety of PEV information sources as important including magazines, news providers, car dealers, TV, research and government; and
- are the most likely to have “egoistic” values which reflect an interest in wealth and personal gain.

5. Respondents in the **“active environmental” cluster:**
    - are the most likely to be female (82%);
    - are the most likely to have bachelor’s or graduate degrees;
    - have the highest biospheric and altruistic values;
    - are the most likely to engage in recreation activities and to follow politics and news sources;
    - are the most likely to see climate change and air pollution as “serious” threats;
    - are the most likely to think about the environmental impacts of their electricity use;
    - are the most likely to be willing to pay extra on their electrical bill to support renewable or low-carbon electricity sources; and
    - are also likely to see a variety of PEV information sources as important, including news providers, car dealers, research and government.
6. Respondents in the **“low-tech environmental” cluster**:
    - tend to have the lowest education level;
    - have the lowest level of openness to change (liminality);
    - have a slightly higher pro-environmental attitude than the tech-oriented cluster;
    - are the least likely to engage in a recreational lifestyle, or to follow news and politics;
    - are the least likely to be familiar with the Prius, Volt or Leaf;
    - are the least likely to perceive any PEV information sources as important;
    - are more likely than the tech cluster to consider air pollution to be serious.

Table 15: Comparing potential early PEV buyer segments by various characteristics (BC "early mainstream only," n = 213)

PEV lifestyle cluster	Low-tech enviro.	Active enviro.	Tech-oriented
Sample	**74**	**55**	**86**
Designed vehicle (in "lower price" design exercise)			
Designed a PHEV	93.2%	92.7%	83.7%
Designed an EV	6.8%	7.3%	16.3%
Demographics			
Female* **	71.62%	81.82%	**45.35%**
Income: 100-149k	19.4%	22.0%	13.3%
Income: 150k+	3.0%	0.0%	10.7%
Education: Bachelors	20.6%	**36.4%**	**34.1%**
Education: Grad	6.8%	**18.2%**	11.8%
3 or more in Household	58.1%	38.2%	54.7%
Own 2 or more vehicles	58.1%	54.6%	59.3%
Live in detached home	52.2%	70.6%	68.5%
Values (score)			
Biospheric* **	9.2	10.4	9
Altruistic* **	9.9	**10.8**	9.9
Egoistic* **	6.3	6.8	**7.4**
Traditional	10.2	10.4	10.2
New Environmental Paradigm (NEP) score* **	6.4	**8.7**	5.2
Liminality (openness)* **	-1.77	**6.4**	0.058
Lifestyle factor (standardized score)			
Technology-oriented* **	-0.8	0.2	**0.8**
Environmental* **	0.4	**0.75**	-0.2
Indoor **	-0.2	**0.15**	0.06
Recreation* **	-0.2	**0.31**	0.03
News/Politics* **	-0.3	**0.22**	0.06
Beliefs (% agreeing)			
Global warming is "serious" **	31%	**55%**	34%
Air pollution is "serious"* **	**49%**	**65%**	30%
Think about electricity impacts "frequently"* **	28%	**49%**	19%
Would pay extra 5% or more for green electricity **	34%	**58%**	44%
Importance of PEV information source (1 = "not important", 4 = "very important")			
Magazines* **	1.3	1.7	**1.9**
News* **	2.2	**2.7**	**2.7**
Dealers* **	1.6	**2.4**	2.2
TV **	2.0	2.3	**2.4**
Friends	2.3	2.7	2.6
Research* **	2.1	**3.0**	**2.9**
Government* **	1.4	**2.0**	**2.1**
PEV research			
Familiarity: **Prius*** **	2.0	2.3	**2.5**
Familiarity: **Volt*** **	1.5	**1.9**	**2.1**
Familiarity: **Leaf*** **	1.4	1.5	**1.9**
Research (%): Researched Prius	10.8%	**18.2%**	**23.3%**
Research (%): **Research Volt*** **	0.0%	**16.4%**	**17.4%**
Research (%): **Researched Leaf** **	1.4%	**7.3%**	**11.6%**

*Significant association at 90% confidence level
**Significant association at 95% confidence level
***Significant association at 99% confidence level

4.9 Potential PEV use patterns

Of the 213 BC early mainstream analyzed above, 202 were deemed to have entered quality diary data. The analysis in this section considers these respondents only, representing a total of 606 diary days. The diary days were stratified across the week, and include 461 weekdays and 145 weekend days (6.4:2), a ratio modestly higher than the ideal 5:2 ratio.

Figure 18 shows the average vehicle load (kW/vehicle) of this sample under three scenarios (previously outlined in Section 3.8 and Table 7):

1. **User informed:** using by PEV designs, driving behavior, and recharge access as collected from the respondents.
2. **User + Enhanced workplace**: using respondents' PEV designs and driving behavior, but with enhanced workplace recharge access (i.e. assuming Level 2 access is universally available at all work places).
3. **EV-240:** using respondents' driving data, but assuming each early mainstream respondent is driving an electric vehicle with 240 km of range (EV-240), and that Level 2 recharge access is universally available at all homes and workplaces.

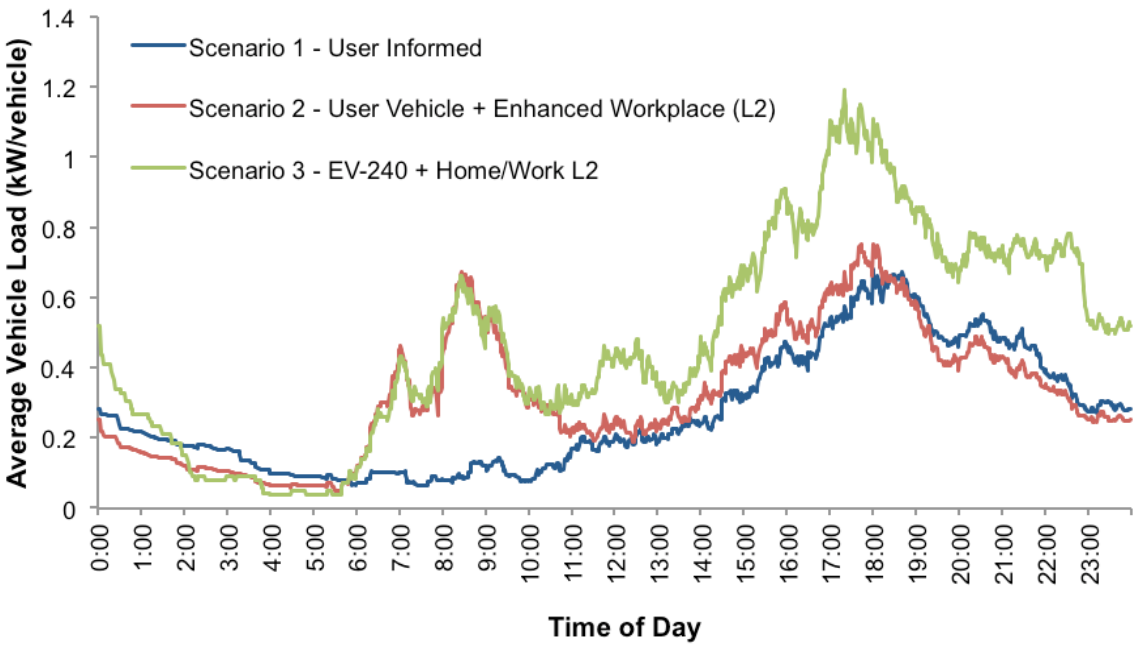

Figure 18: PEV electricity usage under different vehicle and recharge scenarios ("early mainstream" PEV buyers in BC, n = 202 respondents, n = 606 diary days, 1-minute intervals)

Scenarios 1 and 2 follow similar electricity demand profiles in the afternoon, but due to enhanced workplace access, there is a second peak in the morning at around 8:30AM. Due to increased charging during the day, more driving is diverted to electric drive in Scenario 2, reducing gasoline consumption overall (from 1.04 L/vehicle/day in Scenario 1 to 0.80 L/vehicle/day in Scenario 2). Modeling weekday vs. weekend electricity impacts did not reveal any large differences in load distribution.

4.10 UCC market acceptance

As explained in Sections 3.7.3 and 3.7.4, we also assessed respondent interest in green electricity and PEV charging behaviour through several questions, including a design space exercise and a discrete choice experiment. As a starting point, we elicited respondent perceptions (object or support) of different sources of electricity (Figure 19).[8] Solar is the most popular source of electricity with 93% supporting (70% strongly supporting) this as a source. Following solar, wind, geothermal and run-of-river sources respectively are most frequently supported by respondents. In terms of opposition, 54% BC respondents object to nuclear power (30% strongly) and 65% object to coal-based electricity (35% strongly). We also see a smaller segment of respondents that objects to large-scale hydroelectricity (17%).

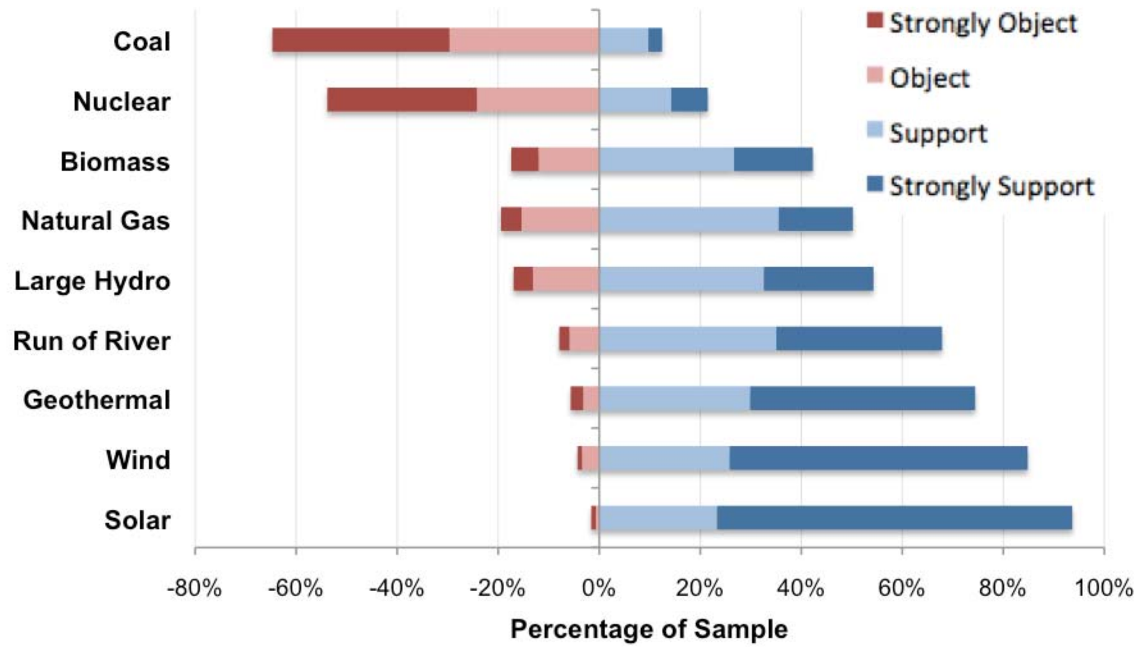

Figure 19: Respondent support for various sources of electricity (BC only, n = 442)[9].

Part 3 of the survey also specifically explored consumer acceptance to the idea of **utility controlled charging (UCC).** The idea is that the electric utility (e.g. BC Hydro) or a third party could have direct control over the timing of PEV charging. The purpose of this control would be to: 1) improve the efficiency of the electrical grid (reduce costs), and/or 2) increase the uptake of intermittent, renewable sources of electricity by matching PEV charging to the timing of when renewable sources are available.

In Part 3 of CPEVS 2013, we explained the basic concept of UCC to respondents, and then elicited perceptions of the idea. Figure 20 summarizes general perceptions of UCC among all BC respondents. When looking at the positive statements, we see that 69% of respondents believe

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[9] The data used in the UCC analysis represent a smaller sample number than previous figures and tables. This is because this sample was collected slightly earlier than those used for the other analyses.

that UCC could help the environment and that 54% believe that UCC should be supported by the government. Respondents are equally split in support and opposition when asked if UCC should be mandatory for PEV drivers. Looking at the negative statements, 43% of the sample believes that UCC will take control away from them “in a way that they would not like,” and 31% see UCC as a potential invasion of privacy.

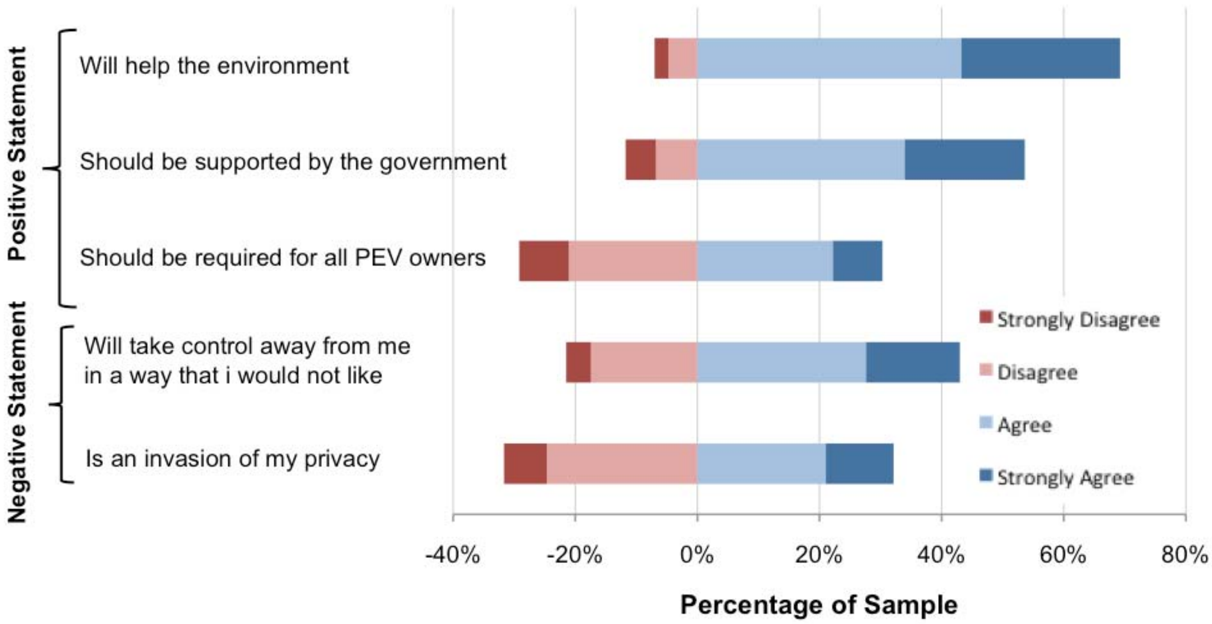

Figure 20: Perceptions of “utility controlled charging” as indicated by agreement with several statements (BC, n = 442).

Part 3 of the survey also explained specific UCC scenarios to assess respondent openness to having a PEV that is not fully charged in the morning. Figure 21 depicts responses to one scenario: where the respondent imagines that they own “pure” EV with a 240 km electric range (EV-240). Around 90% of respondents in BC would be open to 10% UCC-based battery depletion in the morning on at least 20% (1 out of 5) of mornings). About 60% of respondents will permit a 50% depletion of the vehicle battery on at least 20% of mornings. As the level of battery depletion (on the following morning) increases, acceptance for UCC decreases. At least 7% of respondents say they would never allow a10% battery depletion, and 38% say they would never allow a 50% battery depletion.

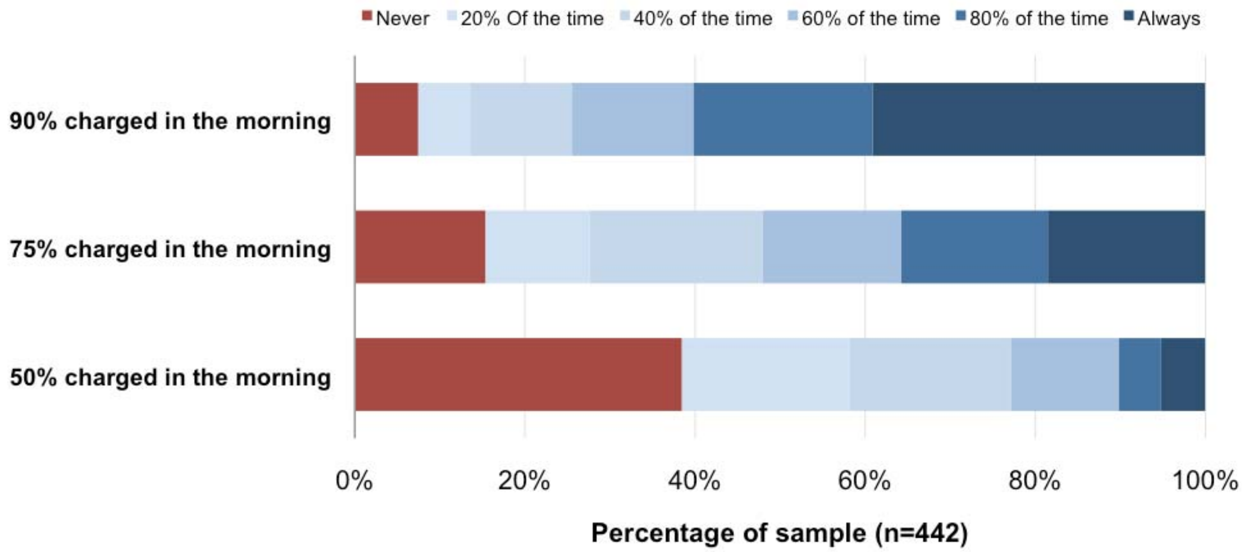

Figure 21: Respondent willingness to have reduced PEV charge on some mornings, for a 240km EV (BC only, n = 442, question: "if there was a chance that your battery would only be 50%, 75%, or 90% charged in the morning, how often would you be okay with this?")

For the UCC discrete choice experiment, we focus these results on the "early mainstream" PEV (40% of our sample) because this segment is most likely to purchase a PEV in the short run, and are thus more relevant to questions about UCC. Table 16 depicts a preliminary discrete choice model, predicting respondent interest in UCC depending on the attributes of the program (e.g. savings on electricity bill, and % of renewable energy that is used), and characteristics of the respondent (e.g. demographics, values and lifestyle).

As would be expected, respondents are more likely to enroll in a UCC program if the program provides more financial savings (reduced electricity bill), and provides a higher percentage of renewable energy to the vehicle (wind, solar, small hydro or a mix). Put into a dollar value, on average respondents are willing to pay about \$2/year for an additional percentage of renewable electricity to supply their home and vehicles. Also, respondents are more likely to enroll if the program provides a higher "minimum state of charge" for the PEV each morning—for example, if the PEV is guaranteed to be 95% charged rather than 70% state of charge. In monetary terms, respondents are willing to pay on average about \$8/year for a 1% increase in guaranteed minimum charge in the morning. Another way to frame this tradeoff is that respondents see an increase in renewable electricity of 4 percentage points just as favourably as a 1 percent increase in minimum state of charge.

UCC interest also varies by respondent characteristics. As demonstrated in Table 16, UCC is more likely to be adopted by those that are: younger, more educated, residing in detached homes, and with more environmental- and technology-oriented lifestyles. Recall that engagement in these two lifestyles also predicts PEV interest. Household income is not strongly associated with consumer preferences for UCC (income also did not predict PEV interest). With regard to energy sources, respondents are less likely to subscribe to a UCC program if it is based only on wind, whereas solar, small hydro, or a mix are all slightly preferred to wind.

Table 16: Utility-controlled charging (UCC) discrete choice model results (BC "Early Mainstream" PEV buyers, n=178)

Attribute	Units	Coefficient		Annual WTP
Alternative specific constant				
UCC program	n/a	-2.219	***	
DCE Attributes				
Guaranteed minimum charge (GMC)	Percentage	0.022	***	$8.05
Renewable Energy	Percentage	0.006	***	$2.09
Electric Bill	Incremental Cost $	-0.033	***	
Source = Wind	1 if Source is wind 0 if else.	-0.435	***	
Source = Small Hydro	1 if Source is small hydro 0 if else.	0.194		
Source = Solar	1 if Source is solar 0 if else.	0.122		
Source excluded category = Mixed	Source excluded category = Mixed			
Demographic Variables				
Age	Years	-0.028	***	
High Income	1 if income > 80k/yr. 0 if else	-0.138		
Sex	1 if male 0 if female	-0.168		
Education	1 if Bachelors or Higher 0 if else	0.913	***	
Detached Home	1 if detached home 0 if else	0.389	**	
Hybrid Household	1 If hybrid household 0 if else	-0.082		
Attitudinal Variables				
NEP Scale	Scale	-0.017		
Environmental oriented lifestyle scale	Scale	0.061	**	
Technology oriented lifestyle	Scale	0.053	***	
Altruistic values	Scale	0.068		
Traditional values	Scale	0.060		
Smart meters are an invasion of privacy[2]	Scale	0.069	**	
Travel Variables				
High Driving Distance[3]	1 if drive >60km/day (average) 0 if else	0.058		
Model Summary				
Sample size	178			
Pseudo R-square	0.17			

*Significant at 90% confidence level
**Significant at 95% confidence level
***Significant at 99% confidence level

5 Summary of key preliminary results

RESULT #1: Many BC consumers have recharge access at home

In Part 2 of CPEVS 2013, respondents conducted a home recharge assessment where they located electrical outlets and panels near their typical parking locations at home. We find that 66% of BC respondents currently have Level 1 access at home (parking within 25 feet or 8 m of an existing 110/120-V outlet), and 19% have Level 2 access at home (parking with 25 feet or 8 m of an existing 220/240-V outlet). Level 1 and Level 2 access vary across respondents based on housing type, and parking space type. Only about half of the 19% with existing Level 2 access reported that they would regularly use it to charge a PEV. A further 35% also have the potential to install Level 2, where our estimated installation prices would range from $1,000 to $3,500 (depending on household infrastructure).

RESULT #2: Most BC consumers have little awareness of PEVs

We assess respondents' awareness of PEVs prior to completing the PEV design portion of the survey. Respondents first state their familiarity with different vehicle models: a hybrid vehicle (the Toyota Prius), a plug-in hybrid (the Chevrolet Volt), and a pure electric vehicle (the Nissan Leaf). Most respondents are at least somewhat familiar with the Prius (78%), and less familiar with the Chevrolet Volt (55%). The majority are not at all familiar with the Nissan Leaf (63%). We also ask respondents how they think each of these vehicle models can be fueled: either with gasoline only, electricity only, or both. The majority of respondents are fairly confused about the basic function of each vehicle model. Only 18% successfully answer that the Prius can be fueled only by gasoline, and about a third successfully describe the Volt and Leaf. This lack of prior knowledge and familiarity suggests that consumer perceptions of PEVs are still largely unformed.

RESULT #3: BC consumers are much more likely to want a plug-in hybrid (PHEV) than a "pure" electric vehicle (EV).

In Part 3 of the CPEVS 2013, respondents indicate their interest in purchasing various PEV designs. Respondents were first given a basic education in the different types of vehicles available (hybrid, PHEV and EV). The "design space" exercise then allowed respondents to select a conventional gasoline vehicle as a base, then potentially upgrade it to a hybrid, PHEV or EV version. Two price scenarios were presented: a higher price scenario (reflecting current prices) and a lower price scenario (reflecting subsidies or lower battery costs). In both price scenarios, the highest proportion of respondents designed and selected some form of HEV (40 to 38 percent), with minorities selecting a PHEV (28 to 36 percent) or a conventional vehicle (28 to 21 percent). An EV was designed by only two to four percent of survey respondents. This gravitation of respondents to PHEV designs (not EV designs) has been seen in previous surveys of U.S. new vehicle buyers. Respondent interest in PEVs is influenced by price (or subsidies); demand for PHEVs in the lower price scenario is 30% higher relative to the higher price scenario, and interest in EVs doubles (but remains relatively low).

RESULT #4: The potential “early mainstream” PEV buyers are unique in terms of home recharge access, age, household size and lifestyle.

Based on responses to the PEV design space exercises, we identified a potential “early mainstream” PEV market as reflected by those respondents that designed some form of PHEV or EV in the lower price scenario (40% of the total BC sample, or n = 213). We call this the “early mainstream” PEV segment. Using logistic regression analysis we find that respondents in the “early mainstream” PEV segment differ from “non-PEV designers” in terms of recharge access, lifestyle, age and household size. Interestingly, there was no significant association between PEV interest and household income, travel patterns (distance per day of frequency of trips in the driving diary), individual values (e.g. biospheric, altruistic or egoistic values), awareness of a public charger, education level, perceptions of climate change, or region.

RESULT #5: There are three different lifestyle segments of potential “early mainstream” PEV buyers in BC.

To provide a more in-depth assessment of the different motives behind potential PEV buyers, we conduct a segmentation analysis. Focusing only on the “early mainstream” PEV respondents, we conduct a cluster analysis based on three lifestyle variables: engagement in technology-oriented and environment-oriented lifestyles, and lifestyle openness (or liminality). Figure E-8 depicts the three identified lifestyle-based segments: “low-tech environmental,” “active environmental,” and “technology-oriented.”

RESULT #6: Without incentives or policy to control recharge behaviour, PEV electricity demand will likely peak at around 6pm each day.

By matching “early mainstream” respondent’s selected PEV design to their three-day driving diary data (temporal driving patterns and recharge potential), we modeled the potential PEV usage patterns of “early mainstream” buyers in BC. Three PEV usage scenarios were modeled:

1. **User informed:** representing respondents’ selected PEV designs, driving behavior, and present recharge access.
2. **User + Enhanced workplace**: same as scenario #1, but with enhanced workplace recharge access (i.e. assuming Level 2 access is universally available at all workplaces).
3. **EV-240:** using respondents’ driving data, but assuming each “early mainstream” respondent is driving an electric vehicle with 240 km of range (EV-24), and that Level 2 recharge access is universally available at all homes and workplaces.

Scenarios 1 and 2 follow similar electricity demand profiles in the afternoon and evening, while Scenario 3 produces a larger demand spike. Due to enhanced workplace access, Scenarios 2 and 3 have a second peak in the morning around 8:30am. Due to increased charging during the day, more driving is diverted to electric drive in Scenario 2, reducing gasoline consumption overall. Modeling weekday vs. weekend electricity impacts did not reveal any large differences in load distribution.

RESULT #7: Early mainstream PEV buyers are generally open to the idea of "utility controlled charging" to support renewables—despite some privacy concern.

The survey also assessed respondent interest in green electricity and PEV charging behaviour through several survey questions and exercises. Regarding electricity sources, respondents are most likely to support solar, wind, geothermal and run-or-river sources (in that order) and least likely to support coal and nuclear sources. The survey also assessed potential consumer acceptance of **utility controlled charging (UCC)**—where the electric utility could control the timing of nightly PEV charging in order to better utilize intermittent renewable electricity sources. After providing a simple explanation of UCC, we elicited respondent perceptions of the idea. About two-thirds of respondents believe that UCC could help the environment and just over half believe that UCC should be supported by the government. Respondents are equally split between support and opposition when asked if UCC should be mandatory for PEV drivers, while about one-third perceive UCC as a potential invasion of privacy. We also find that the vast majority of respondents are willing to allow some PEV battery depletion (having less than a full charge on some mornings) in order to support UCC.

6 Next Steps

This report presents preliminary results from the **2013 Canadian PEV Survey (CPEVS 2013)**. Next steps in this research process are summarized below.

6.1 Next steps with CPEVS 2013 data

We will extend much of the present analysis to rest of Canada, including the Alberta and Ontario sample. Regional comparisons (e.g. BC vs. AB vs. ON) could then be made regarding:

- Travel patterns
- Residential recharge access
- PEV interest
- Characterizing and segmenting the "early mainstream" PEV buyers
- Recharge profiles
- Interest in green electricity and utility controlled charging (UCC)

Next steps in analysis using the BC and Canadian data may include:

- Developing more sophisticated discrete choice models of for PEV demand. For example, a latent-class approach may be used to identify heterogeneity in consumer valuation of PEVs, fuel savings, recharge access and electric-powered range.
- Use insights from "design space" exercises and discrete choice model to construct PEV market share forecasts based on different market conditions (e.g. policy, battery prices, and gasoline and electricity prices).
- Construct recharge profiles for a variety of PEV usage scenarios, including different assumptions about adoption rates and PEV design preferences, access to recharge infrastructure, time-of-use electricity rates, and implementation of a utility-controlled charging (UCC) scheme to optimize the usage of intermittent renewable sources of electricity for PEVs.
- Use driving diary data to construct spatial models regarding the potential importance and usage of non-home charging infrastructure.

6.2 Next steps with PEV consumer research in BC

As noted in Section 3.1 there are several other components to the "consumer research" portion of this broader project sponsored by Natural Resources Canada's ecoEnergy Innovation Initiative (ecoEII). Specifically, Dr. Axsen is leading three more components to this project:

4. **Interviews of BC new vehicle buyers:** From the 538 BC respondents that completed the CPEVS 2013 survey, we are selecting diverse subset of 30 to 40 survey respondents to perform household interviews. Two researchers visit the household to conduct a two hour interview to assess the participants' experience, perceptions and valuation of PEVs, and openness to utility controlled charging. Households were selected provide a divers subsample in terms of region (within different parts of Metro Vancouver), age, income, education, household size, and lifestyle (e.g. engagement in environmental- or

technology-oriented activities). As of October 2013, 18 households have been interviewed.

5. **Survey of BC PEV owners:** The overall CPEVS survey format will be adapted, creating a version for BC households that presently own some type of PEV. Additional questions will assess motives for purchase, and levels of satisfaction with the vehicle. A driving diary will collect data on driving and recharge patterns for the PEV. The survey will likely be launched by the Spring of 2014, with the goal of recruiting at least 100 PEV owning households for completion.
6. **Interviews with BC PEV owners:** To complement the PEV owner survey above, we plan to select a subset of survey respondents to complete household interviews. These interviews will address many of the same topics as the more general "new vehicle buyer" interviews, while also addressing issues more specific to PEV buyers (e.g. experience with residential and non-home charging infrastructure). Interviews will likely be completed by the end of 2014.

6.3 Next steps in the overall NRCan ecoEII project

The overall NRCan ecoEII project ("*Powering Plug-in Electric Vehicles with Renewable Energy Supply in BC*," 2012-2016) is led by Prof. Curran Crawford at the University of Victoria, and includes collaborators at the University of British Columbia (AnnaLisa Meyboom) and the British Columbia Institute of Technology (Clay Howey). This project has several broad research objectives:

1. Use CPEVS survey data to construct behaviourally realistic model of PEV utilization.
2. Develop temporally-explicit model of potential renewable electricity supply.
3. Construct scenarios of placement, design, operation of at-home and public charging infrastructure.
4. Integrate demand and supply models to quantify the greenhouse gas and economic impacts of to match renewables and PEVs in BC.
5. Adapt PEV-renewable model to apply to other Canadian regions.

The results discussed in this report directly feed into objective #1 above, are related to objective #3, and will also facilitate objectives #4 and #5.

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Appendix: Survey instrument

Our entire survey method has been posted to the following website:
http://www.rem.sfu.ca/people/faculty/jaxsen/CPEVS-2013-documents

The following documents are posted for the Canadian Plug-in Electric Vehicle Survey (CPEVS 2013):

1. Part 1: web-based background questionnaire (PDF)
2. Part 2: mail-out package:
    - Cover letter (PDF)
    - Home recharge assignment (PDF)
    - Three-day driving diary (PDF)
    - PEV "buyers' guide" document (PDF)
3. Part 3: web-based PEV interest questionnaire (PDF)