Electrifying Vehicles

Insights from the Canadian Plug-in Electric Vehicle Study

Jonn Axsen » Suzanne Goldberg » Joseph Bailey
Sustainable Transportation Research Team
Simon Fraser University

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ELECTRIFYING VEHICLES

The Canadian Plug-in Electric Vehicle Study

Electric-mobility may be a key component in a successful transition toward deep greenhouse reductions. However, widespread uptake and use of plug-in electric vehicles will involve meaningful shifts in social and technical systems. This report considers the potential market for plug-in electric vehicles in Canada's passenger vehicle sector and investi-gates how consumer interests may guide such shifts.

About Us

The Energy and Materials Research Group (EMRG) is a research group directed by Dr. Jonn Axsen and Dr. Mark Jaccard in the School of Resource and Environmental Management (REM) at Simon Fraser University (SFU). EMRG is comprised of faculty, adjunct professors, full-time research associates and graduate students; it collaborates closely with external researchers and consultants. EMRG focuses on the analysis of technologies, strategies, behaviour and policies that lead to a more sustainable flow of energy and materials in society.

Dr. Jonn Axsen leads the EMRG Sustainable Transportation Research Team, which focuses on the transition to lower impact transportation systems. The Team takes a unique interdisciplinary research approach, combining elements of economics, engineering, marketing, policy and psychology into the analysis of sustainable transportation solutions. The Team actively engages stakeholders in the debate around sustainable shifts in our transportation system and provides robust analyses to support sound, evidence-based business and policy decisions.

Report Contributors

Dr. Jonn Axsen

EMRG Director,
Sustainable Transportation
Assistant Professor
Simon Fraser University
jaxsen@sfu.ca

Suzanne Goldberg

Research Director,
Sustainable Transportation
Adjunct Professor
Simon Fraser University
sgoldber@sfu.ca

Joseph Bailey

Doctoral Candidate

George Kamiya

Master's Candidate

Brad Langman

Master's Candidate

Joshua Cairns

Master's Candidate

Michael Wolinetz

EMRG Research Associate
Partner, Navius Research

Amy Miele

Master's Candidate

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Contents

Abstract

Electric-mobility may be a key component in a successful transition toward deep greenhouse-gas (GHG) reductions. 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 or gasoline, and pure battery electric vehicles (BEVs) that are powered solely by electricity. To investigate how consumer interest in PEVs may guide shifts in technology and behaviour, we engage a sample of Canadian new vehicle buyers and British Columbian PEV owners in a mixed-mode survey and interview process. Data collected for this study comes from two distinct surveys: the 2015 Plug-in Electric Vehicle Owners Survey (PEVOS, n = 94) and the 2013 New Vehicle Owners Survey (NVOS, n = 1754).

For both, a multi-method survey and interview process 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.

Through this survey data, we identify three groups of PEV buyers: PEV Pioneers (current PEV owners), the potential Early Mainstream buyers (next PEV buyers) and Later Mainstream buyers (not PEV buyers).

This report summarizes several key results for the potential PEV market in Canada, including:

- PEV Pioneers tend to be of higher income and education and are more engaged in environment- and/or technology-oriented lifestyles, relative to Mainstream respondents.
- Most Mainstream respondents have little familiarity with PEVs, and are particularly confused about the concept of a PHEV.
- Two-thirds of Mainstream respondents already have Level 1 recharge access at home.
- Only 20—33% of Mainstream respondents are aware of public chargers, but awareness does not seem to influence PEV interest.
- About one-third of potential Mainstream respondents want a PEV—the vast majority want a plug-in hybrid (PHEV) rather than a pure electric vehicle (BEV).
- Different PEV models are associated with different symbols; all are associated with being pro-environmental, while the Tesla is more associated with images of style and success.
- Mainstream and Pioneer respondents differ considerably in terms of motivations for PEV interest, e.g. exploring new technology, seeking environmental benefits, or realizing savings.

Abstract (cont'd)

- Potential Mainstream usage of PEVs could vary widely by province, where electricity demand could range from 6.8 to 8.7 kWh/day per vehicle. In all provinces, however, uncontrolled demand will peak around 5PM to 6PM.
- With today's electricity grids, usage of PEVs can cut greenhouse gas emissions by 80—98% in British Columbia, around 45% in Alberta, and 58—70% in Ontario.
- With the current supply of PEVs in Canada (7 models), future PEV new market share is not likely to exceed 4—5% by 2030; increasing supply (to 56 models) could increase market share to over 20% by 2030.
- Mainstream and Pioneer PEV respondents are generally open to the idea of enrolling in a "utility controlled charging" program, though some are concerned about privacy and the potential for battery degradation.

Executive Summary
Study Overview

Electric-mobility may be a key component in a successful transition toward deep greenhouse-gas (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 (BEVs) 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 vehicle buyers and British Columbian PEV owners in a mixed-method survey and interview process.

Data collected for this study comes from two distinct study designs: the **2015 Plug-in Electric Vehicle Owners Survey (PEVOS)** and the **2013 New Vehicle Owners Survey (NVOS)**.

This research report addresses several objectives, including:

- Identifying current and potential PEV buyers and assessing their preferences, motivations, behaviour and lifestyles. (Section 5)
- Assessing consumer awareness and understanding of PEV technology (Section 6).
- Assessing awareness of public charging and access to home charging (Section 7).
- Quantifying consumer demand for different PEV designs (Section 8).
- Assessing if charger awareness influences PEV demand (Section 9).
- Identifying different segments of current and potential PEV buyers according to preferences and motivations (Section 8 and Section 10).
- Characterizing driving and charging patterns among current PEV owners, and potential future buyers (Section 11 and Section 12).
- Modeling the potential GHG impacts of PEV usage in different Canadian regions (Section 13).
- Forecasting PEV new vehicle market share under different market and policy conditions (Section 14).
- Assessing consumer acceptance of utility-controlled charging programs that attempt to use PEVs to support renewable energy (Section 15).

Global Policy Context

Canada and British Columbia are not alone in efforts to stimulate PEV development. The issues of global climate change, local air pollution, oil dependence, and energy security have all been drivers of a renewed political push for PEV deployment in many parts of the world. Several national governments have set ambitious targets for PEV deployment, such as the US (Revkin, 2008), China (Wan et al. 2015) and Canada (Natural Resources Canada, 2010).

PEV success requires policy support, and countries and regions will vary in their use of demand-focused policies (e.g. financial and non-financial incentives, and charging infrastructure deployment) and supply-focused policies (e.g. a zero-emissions vehicle standard or low-carbon fuel standard).

Norway represents a particularly strong example, where PEVs represented over 20% of new vehicle market share in early 2015, thanks in large part to aggressive demand-focused policies such as vehicle tax exemptions, as well as other financial incentives. Many other regions (including 3 Canadian provinces: British Columbia, Ontario and Quebec) have also implemented demand-focused policies; however, most are much less stringent than Norway's policies.

On the other hand, some regions have pioneered supply-focused policies such as a low carbon fuel standard (California and British Columbia) or a zero emissions vehicle mandate (California), which put the onus on vehicle or fuel suppliers to develop the market for PEVs and other low- or zero-carbon vehicles. These supply-focused policies may hold particular potential to boost PEV market shares in North American regions, where very strong demand-focused policy (e.g. large taxes on conventional vehicles) are not likely to be politically acceptable.

Our analyses in this paper (particularly Objective #9 and Section 14) suggest that a combination of demand-focused and supply-focused policies is likely required to induce adoption of PEVs significant enough to achieve deep greenhouse reduction targets, as well as other environmental and energy goals.

Study Design

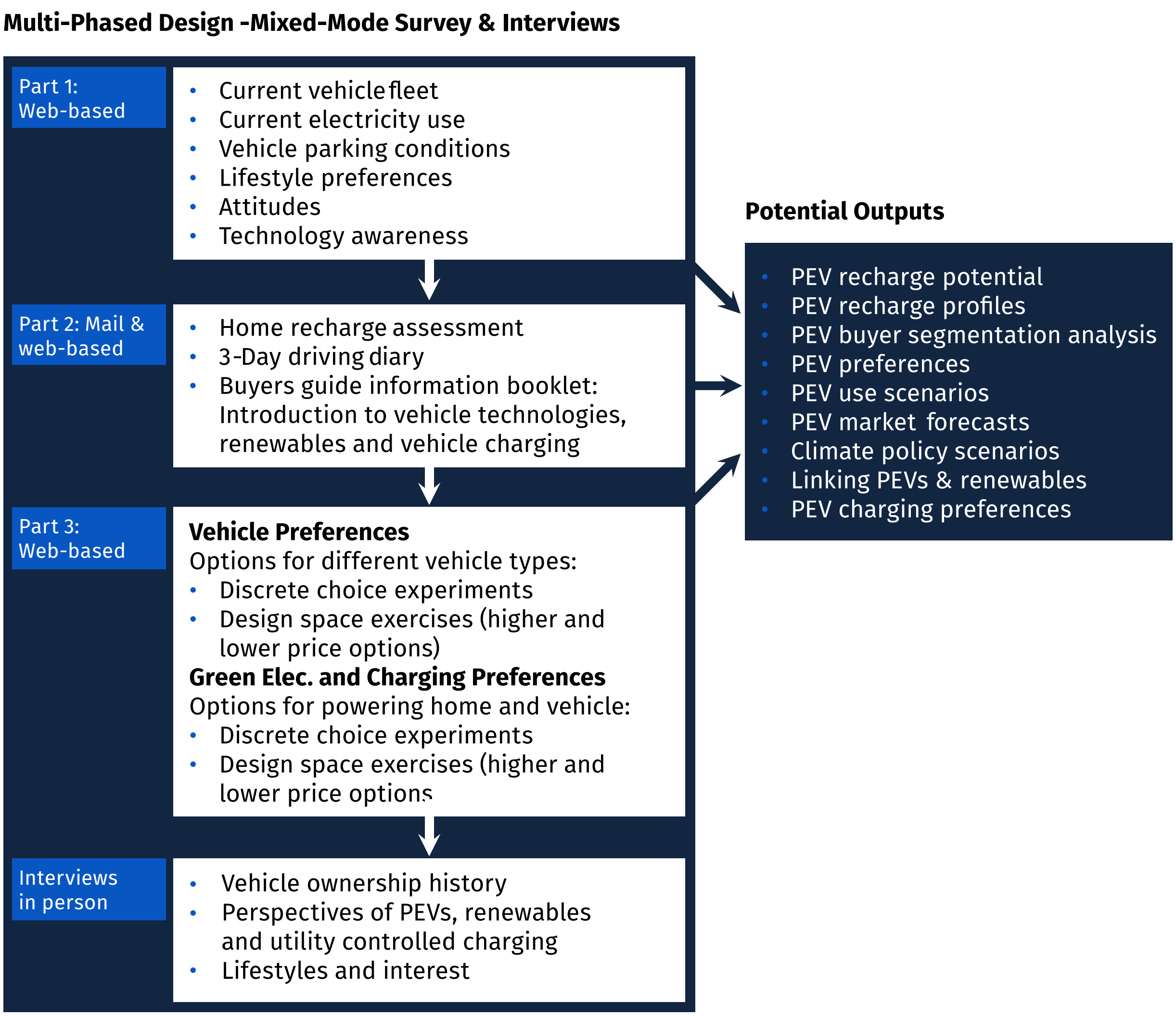
Previous PEV market research can be categorized into three approaches: constraints analyses, rational-actor choice models, and the reflexive lifestyle approach.

The Canadian Plug-in Electric Vehicle Study (CPEVS) 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.

We consider three groups of consumers: PEV Pioneers (current owners of PEVs), the Early Mainstream PEV buyers (the segment most likely to buy PEVs in the next 10—15 years), and the Late Mainstream (the segment not likely to buy PEVs in the next 10—15 years). PEVOS collected data from PEV owners, while NVOS collected data from Mainstream vehicle owners.

The study design for both samples started with a three-part survey that included a driving diary, home recharge assessment, discrete choice experiment and design exercises, and for a subsample of respondents was followed with household interviews (Figure E-1).

Figure E-1: Overview of multi-method survey and interview process



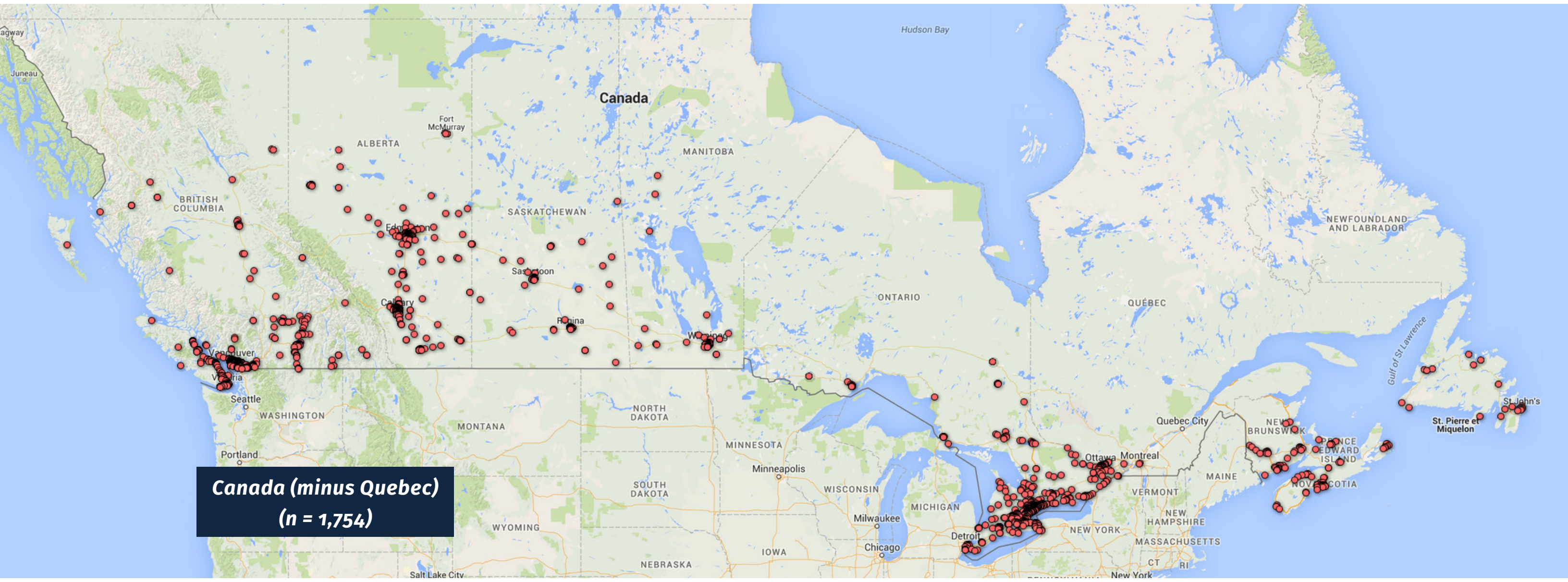
Data Collection

The sample of Mainstream vehicle buyers (NVOS respondents) was recruited by Sentis Market Research in 2013. 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. A diverse subsample of 22 of these households was recruited for semi-structured interviews.

The sample of 94 PEV Pioneer (PEVOS) respondents was recruited from the British Columbia Government's Clean Energy Vehicle Program, the Vancouver Electric Vehicle Association (VEVA) and Emotive BC.

Survey data were collected between June 2014 and February 2015. A diverse subsample of 12 of these households was recruited for semi-structured interviews.

Figure E-2: Geographical representation of the Canadian NVOS sample by postal code (n = 1754)



Results

This report summarizes the key findings from the 10 primary research objectives listed in the Study Overview, drawing from analysis of Mainstream (NVOS) and PEV Pioneer (PEVOS) respondent data. This executive summary provides key highlights for each objective.

Objective #1: Compare PEV Pioneers and Mainstream Buyers

PEV Pioneers (PEVOS respondents) tend to have higher engagement in technology- or environment-oriented lifestyles, and express higher levels of environmental concern than Mainstream buyers (NVOS respondents). PEV Pioneers also have higher education and income; they are more likely to have a graduate degree (30% vs. 11%) and an annual household income greater than $90,000 (67% vs. 33%). Moreover, PEV Pioneers are more likely to be male and to own their own home compared to both Mainstream new vehicle owners and the Canadian Census.

Most of our PEV Pioneer respondents own either the Nissan Leaf (46%), Chevrolet Volt (24%), or Tesla Model S (10%). Tesla owners, in particular, report the highest income and education levels.

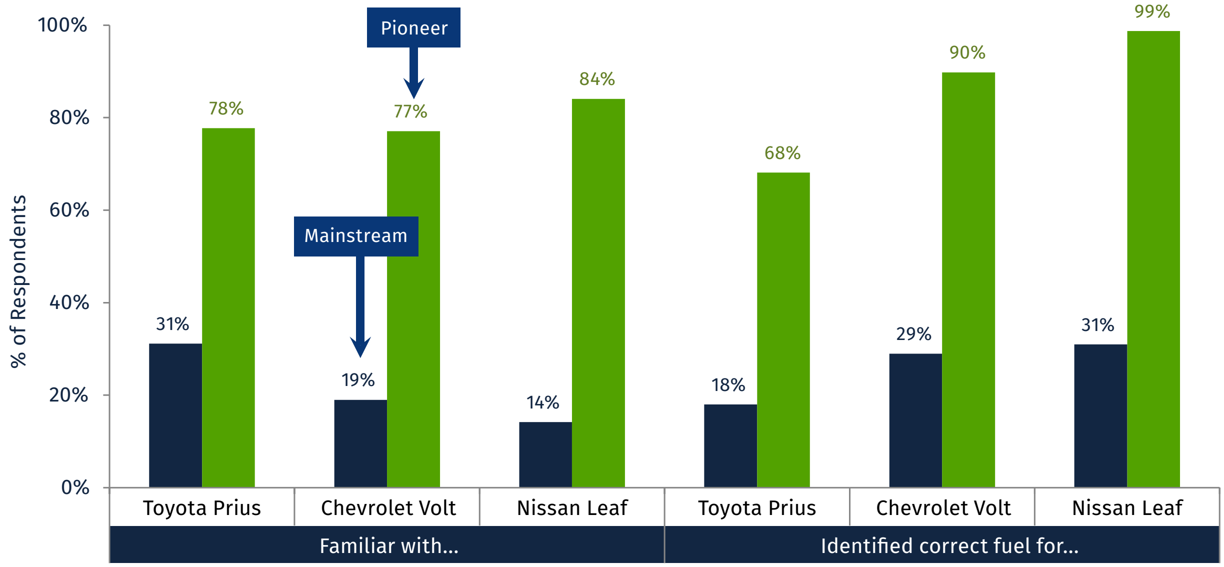
Objective #2: Assess Awareness and Understanding of PEV Technologies

According to the reflexive theory, consumers develop preferences as they learn about new products and technologies. We thus assess the initial awareness of Mainstream and PEV Pioneer respondents to compare each sample's understanding of (or confusion with) PEV technologies.

Through this comparison, we see significant differences in the level of technological awareness between the two samples (Figure E-3). While PEV Pioneers demonstrate considerably high familiarity with major PEV models (77—84%), only a minority of Mainstream respondents were familiar with PEVs (14—31%) and were able to correctly identify how to fuel the Toyota Prius (18%), the Chevrolet Volt (29%), and the Nissan Leaf (31%). Mainstream respondents demonstrated a particular confusion about the idea of PHEVs.

For example, in an interview, Mrs. Park (pseudonym) expressed some confusion with PHEVs, saying "so just to clarify… let's say I didn't have time to charge it and I still had to drive it, it would still drive because it would just default to gas?"

Figure E-3: Comparison of PEV familiarity and refueling between Mainstream (NVOS, n = 538, blue bars) and PEV Pioneer respondents (PEVOS, n = 157, green bars) in British Columbia



Objective #3: Identify Home Charging Awareness and Public Charging Access

PEV charging infrastructure is an important aspect of PEV deployment; however, it is unclear what kind of charging infrastructure is needed to best support PEVs. As a first step, we explore potential access and use of home charging and public charging among the Mainstream and PEV Pioneer samples, highlighting key differences in charging availability.

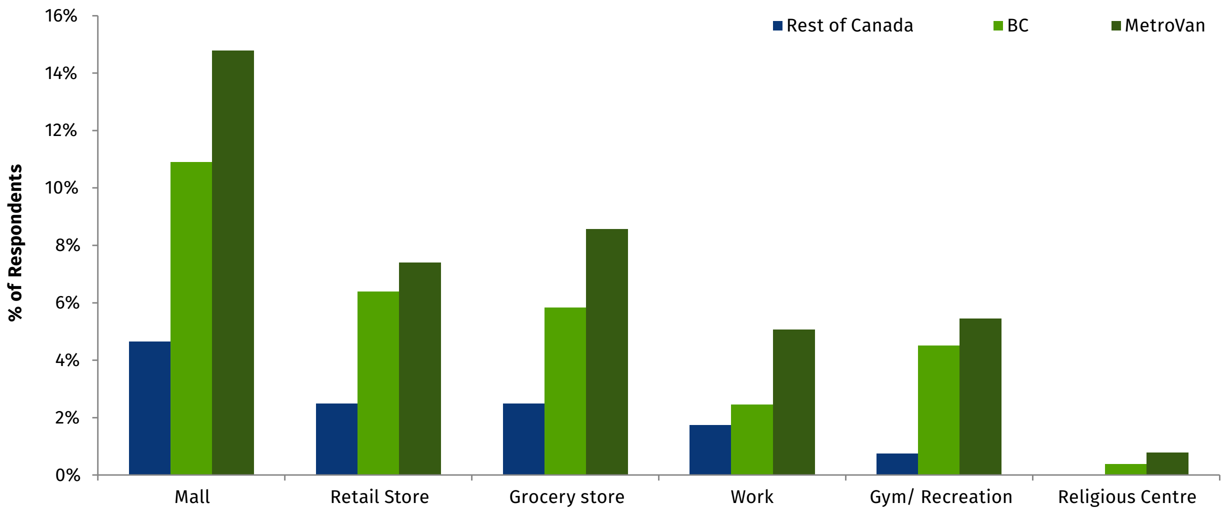
Among Mainstream (NVOS) respondents, two-thirds presently have Level 1 charging access at home, and 35% have the potential to install Level 2 charging (Figure E-4). One-third of Mainstream respondents in British Columbia have seen at least one public (non-home) charger, compared to only 18% in the rest of Canada (Figure E-5). Higher awareness in British Columbia is likely due to recent efforts to install several hundred public chargers and charger signage.

In contrast, nearly all PEV Pioneers (PEVOS) have access to home charging, with 75% having installed a Level 2 charger. PEV Pioneers were also more likely to be aware of at least one public charger when they purchased their vehicle (86%), though their reported usage of any specific public charger tended to be infrequent (once per month or year).

In interviews, several PEV Pioneers explain that after a brief learning period they discovered that they have little need to use public charging infrastructure.

Figure E-4: Mainstream respondents' residential Level 1 and 2 access by housing type and parking space (British Columbia only, n = 528)

Figure E-5: Mainstream respondents' public charger awareness by location categories; rest of Canada (n = 1207); British Columbia (n = 536) and Metro Vancouver (n = 257); Source: Bailey et al., 2015.



Objective #4: Identify PEV Demand and Dssess Dttribute Valuation

Interest in PEVs and valuation of PEV attributes may help us understand the motivations of PEV pioneers and potentially identify the next likely segment of PEV buyers, the Early Mainstream. We find interesting differences between these two samples in terms of PEV interest, valuations and motivations.

About one-third of Mainstream respondents expressed interest in buying some form of PEV (Figure E-6), and most selected a PHEV over a BEV design (89—93%); we define this sub-sample as the “Early Mainstream.” Motivations for PEV interest included driving flexibility (for PHEVs), fuel savings, and pollution reduction. Resistance to PEVs included range limitations (especially for BEVs), reliability concerns, and aesthetic concerns (i.e. PEVs look “strange”).

Among PEV Pioneer respondents, almost all would buy another PEV (96—100%). Most (50—70%) selected a BEV over a PHEV design. PEV Pioneers expressed very high valuation of PHEVs and BEVs, as well as PEV attributes including fuel savings, driving range, and Level 2 charging at home. About half of the PEV Pioneer sample reported that their vehicle purchase was strongly influenced by the BC Government’s CEVforBC™ rebate.

Motivations for BEV interest (over interest in PHEVs) included improved driving experience, environmental benefits, independence from oil companies, and technological superiority. The number and type of symbols and images that PEV Pioneer respondents associated with their vehicles varied significantly between owners of different PEV models; all models are associated with environmental symbols, but the Tesla Model S is much more likely to represent sportiness or being successful, powerful or exotic (Figure E-7).

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

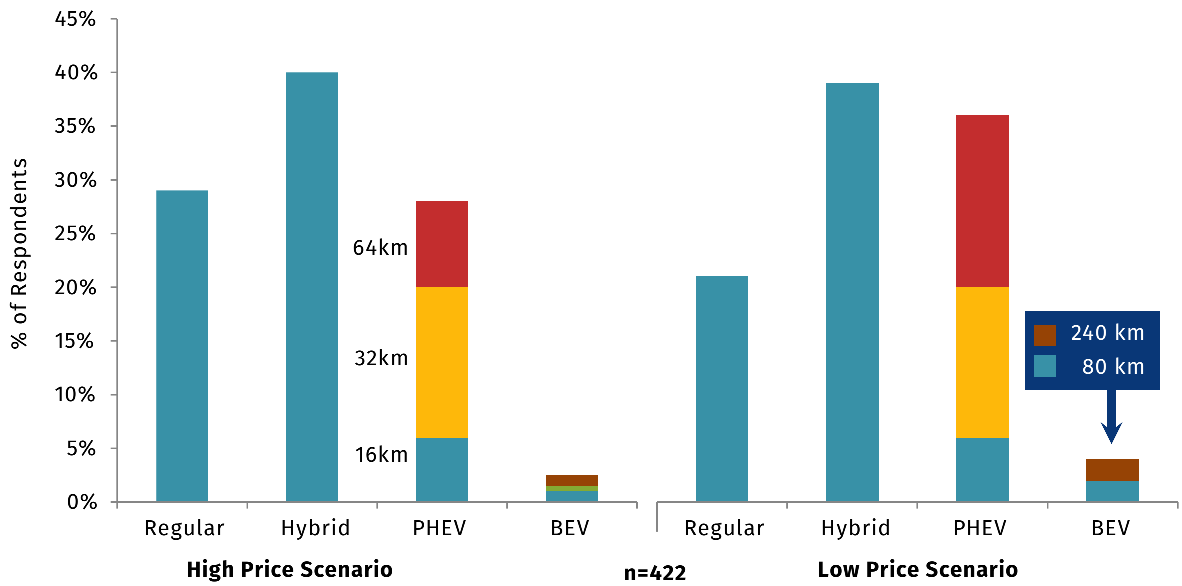
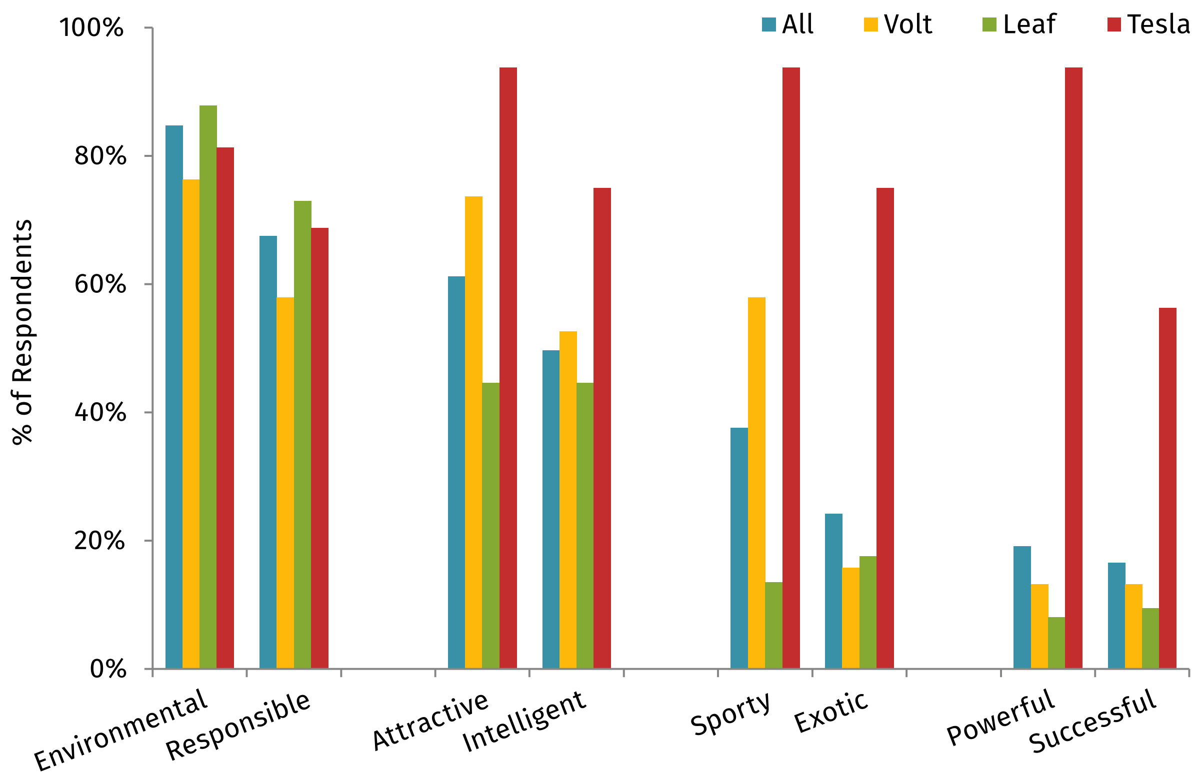


Figure E-7: Reported PEV Pioneer image associations, by PEV owner group (n = 157)



Objective #5: Assess if Charger Awareness Influences PEV Demand

Although there is evidence that the uptake of PEVs may depend on the availability of home charging infrastructure, it is not clear if the visibility of public charging stations actually has an impact on PEV demand. Using Mainstream respondent data from NVOS, we statistically test the associations between public charging visibility and stated PEV interest while controlling for other factors such as socio-demographic variables.

We find that awareness of public charging infrastructure has a weak or non-existent relationship with PEV interest. Instead, the results indicate that having PEV charger access at home is a stronger and more consistent predictor of PEV interest, suggesting that PEV policy ought to prioritize home charging access over public charging deployment.

Objective #6: Characterize Heterogeneity in Preferences and Motives

There is substantial heterogeneity with respect to PEV preferences and motivations among groups of Mainstream new vehicles buyers and PEV Pioneers. We use latent-class analysis to identify five preference-based segments among Mainstream (NVOS) respondents:

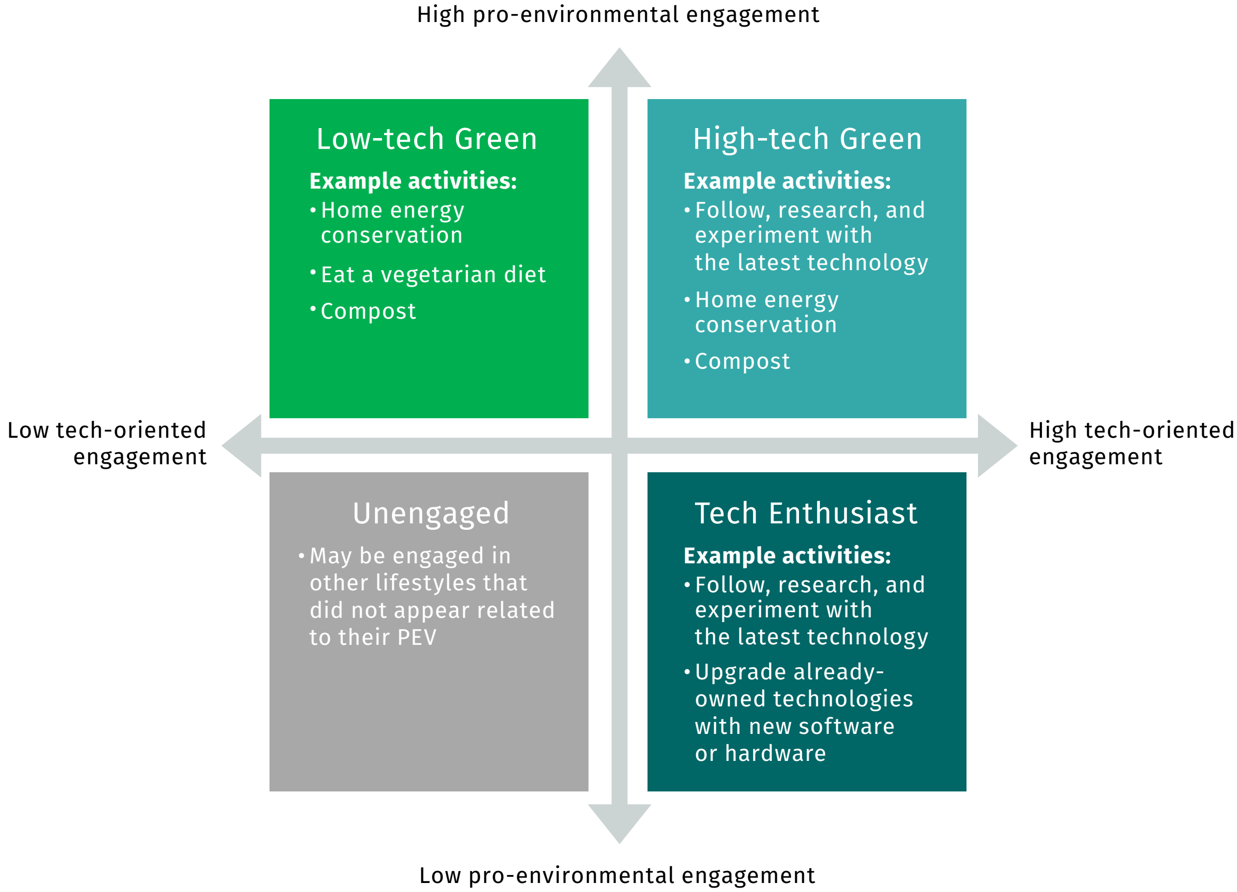
1. The "PEV-enthusiast" class (representing 8% of the sample) place very high value on hybrid, PHEV and BEV designs relative to a conventional gasoline vehicle. This group has high interest in PHEVs and BEVs, but places no significant value on fuel savings.
2. The "PHEV-oriented" class (25% of the sample) has positive and significant valuation of hybrid and PHEV designs, and a negative and significant valuation of BEV designs. This group has high interest in PHEVs and is very conscious of fuel savings.
3. The "Hybrid-oriented" class (16% of sample) prefers hybrid vehicles to other vehicle types, having a mildly positive valuation of PHEVs and a negative valuation of BEVs.
4. The "Hybrid-leaning" class (27%) only has a positive valuation for hybrids, which is smaller than the "Hybrid-oriented class."
5. The "Conventional-oriented" class (23%) has negative valuation for hybrids, PHEVs and BEVs, These respondents have no interest in any vehicle other than a conventional gasoline vehicle.

We also perform a cluster analysis to identify six different segments of Early Mainstream (NVOS) respondents based on their lifestyles. Each segment varies significantly in terms of values and lifestyles, including engagement in environment- and technology- oriented lifestyles.

Interestingly, PEV preferences (i.e. preference for PHEVs) are largely similar across these six Early Mainstream segments, indicating that different consumers may have very different motivations for wanting the same PEV.

There is also substantial variation in PEV interest motivations among PEV Pioneer respondents, including environment- and technology-oriented motives. Using interview data, we constructed lifestyle segments by grouping participants with similar engagement (or disengagement) in environment- and technology-oriented lifestyles (Figure E-8).

Figure E-8: Overview of PEV Pioneer interview lifestyle segments and example lifestyle activities



Objective #7: Characterize PEV Pioneer and Early Mainstream Driving Patterns

Understanding the potential usage of PEVs among current and future PEV buyers can help utilities and governments to anticipate electricity demand. Among Mainstream (NVOS) respondents, the median driving distance for one "driving day" was 36km (mean of 54km). We merged respondents' driving data, recharge access and PEV interest to model potential electricity demand from PEVs (Figure E-9). We constructed three scenarios:

- **Scenario 1:** with current charging access, modeled average daily electricity demand for PEVs is highest for Alberta respondents (8.7 kWh/day per vehicle), followed by respondents in Ontario (8.0 kWh/day) and British Columbia (6.8 kWh/day). Modeled PEV electricity demand is expected to peak around 5—6PM in all three provinces.
- **Scenario 2:** universal workplace Level 2 charging access could increase the proportion of PHEV kilometers that are powered by electricity (by 21% in British Columbia, 14% in Ontario and 5% in Alberta).
- **Scenario 3:** with the adoption of larger battery BEVs (with 240km of range) and universal Level 2 charging access at home and work, daily electricity demand could be substantially higher per vehicle (77% higher in British Columbia, 57% in Alberta, and 79% in Ontario).

Among PEV Pioneer respondents, the median driving distance for one "driving day" was 45 km (mean of 59km). Median "driving days" varied across owners of the Nissan Leaf (37km), the Chevrolet Volt (45km) and the Tesla (39km).

Interview participants indicated that they tend to increase the number of trips they make since purchasing a PEV due to three main reasons: reduced operating costs, interest in further using the technology, and "feeling better" (or less hypocritical) about driving a PEV relative to a conventional gasoline vehicle. Analysis of survey data indicates that about two-thirds of PEVOS respondent charging events occur at home (Figure E-10).

Figure E-9: Electricity demand profiles under three scenarios in British Columbia (n = 201; 603 diary days)

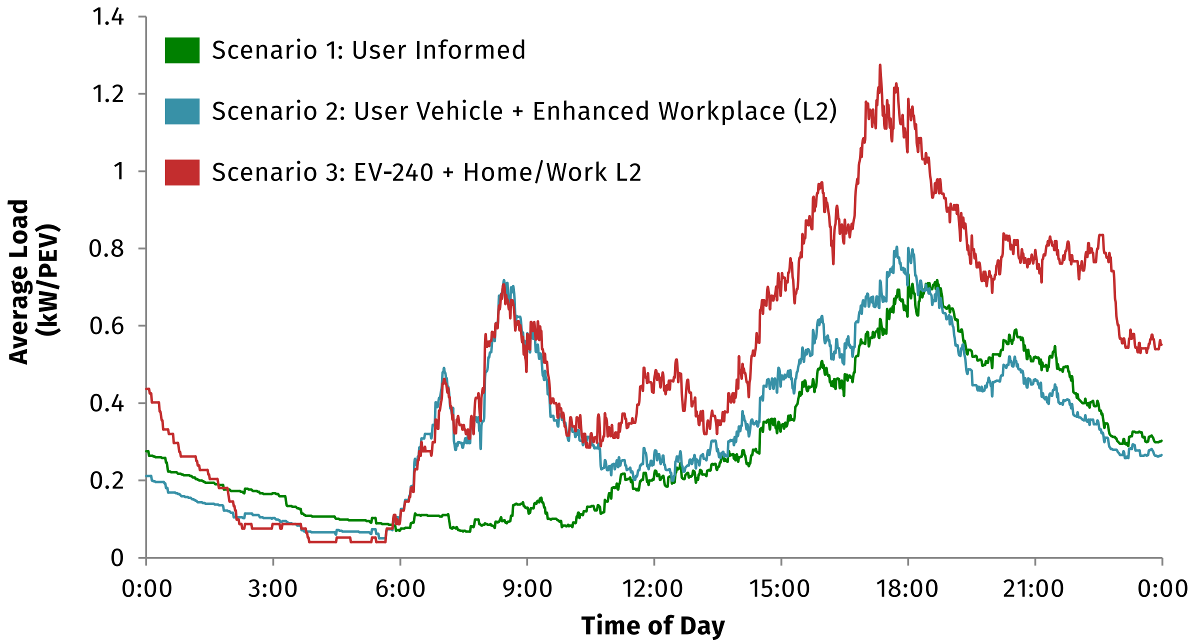
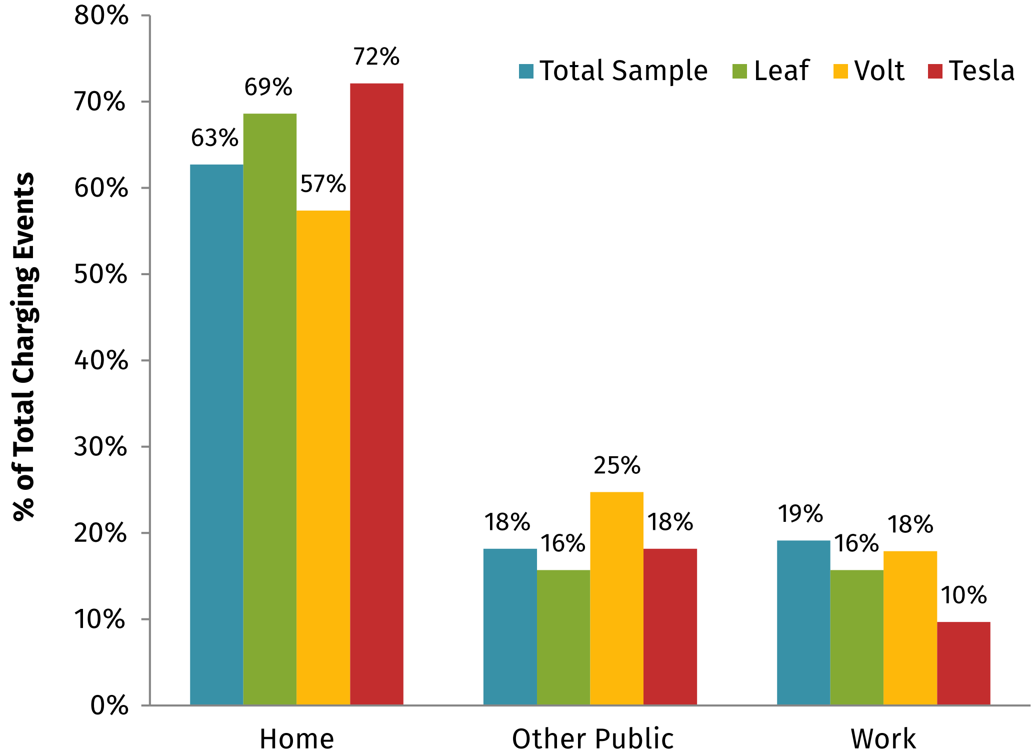


Figure E-10: % Total PEV Pioneer respondent charge events by location (Leaf, n = 312; Volt n = 190; Tesla, n = 165)



Objective #8: Model the Potential GHG Impacts of PEV Usage in Canada

One important benefit associated with PEVs is the ability to reduce GHG emissions relative to conventional gasoline vehicles. However, electricity grids in most regions include some amount of GHG emissions, depending on the sources of electricity.

We use Early Mainstream respondent data to build consumer-informed models that represent potential well-to-wheels GHG impacts among PEV buyers in British Columbia (a hydro-based grid), Alberta (a fossil-fuel based grid), and Ontario (a mixed grid).

Our findings show that (Figure E-11, using a "marginal" approach to GHG emissions attribution):

- **Scenario 1:** with respondent-selected PEV designs (mainly PHEVs) and existing charging access (the "User-informed" scenario), PEVs can cut well-to-wheels GHG emissions by 79% in BC, 44% in Alberta, and 58% in Ontario, relative to conventional gasoline vehicles.
- **Scenario 2:** with enhanced access to workplace charging (leading to more daytime charging), GHG emissions reductions are about the same as in Scenario 1.
- **Scenario 3:** with enhanced charger access and universal BEV-240 adoption, emission reductions are even more substantial in British Columbia (98%) and Ontario (70%), but not much different in Alberta (relative to Scenario 1).

Objective #9: Forecast PEV Market Share

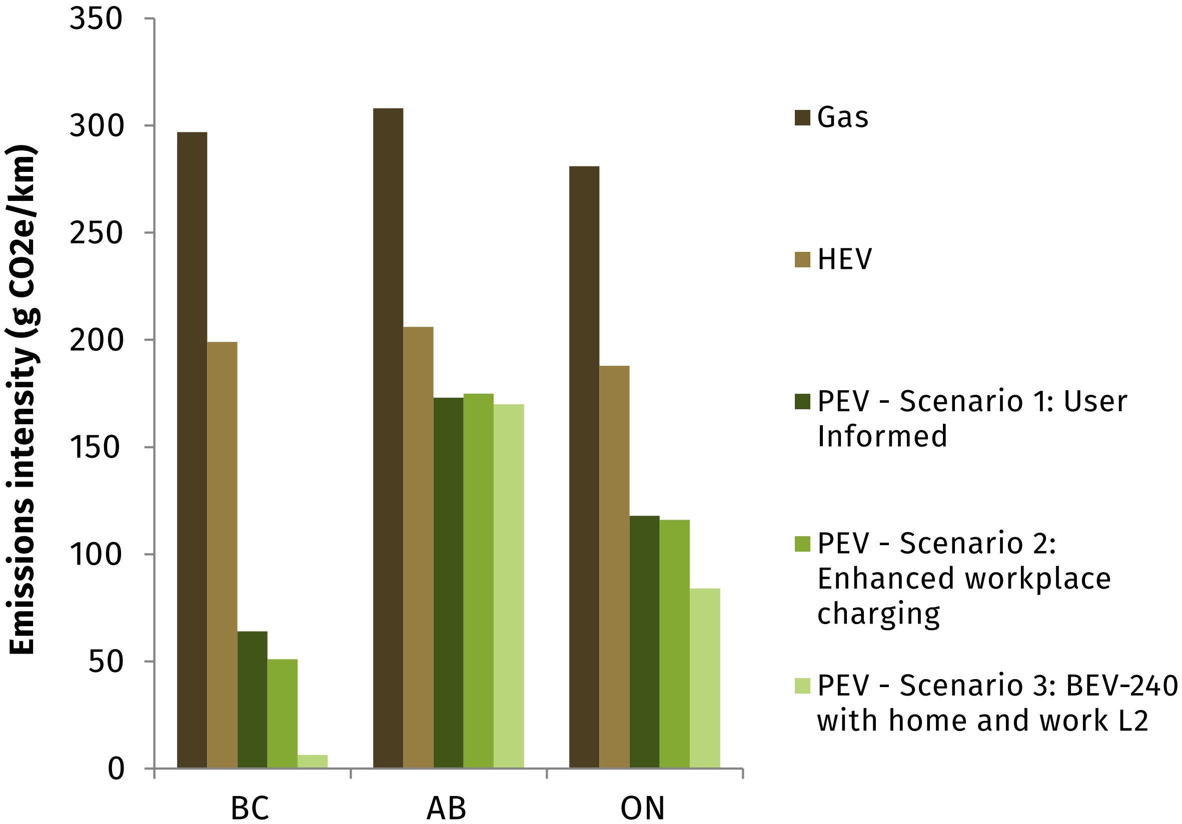
Forecasts of PEV sales (in terms of new passenger vehicle market share) can vary widely—e.g. from 1% to 28% in 2020, and from 1% to 70% in 2030. Here we use the data and analyses (including the analyses presented above) from the NVOS survey to construct a PEV market share forecast model for British Columbia.

Specifically, we build a "constrained choice model" that simulates consumer preferences as well as real-world constraints such as PEV model variety and availability, and lack of consumer awareness. Our findings show that in British Columbia, unconstrained demand (or "latent demand") for PEVs translates to a 32% new market share by 2020 (as described in Objective #4 above); however, various constraints bring this forecast down to 1% (Figure E-12).

With the current supply of PEVs in Canada (7 models), 2030 new market share is not likely to exceed 4—5%; while increasing supply (to 56 models) could increase that share to over 20% (Figure E-13).

This analysis makes the case for the importance of having both demand-focused PEV policies that encourage consumer adoption of PEVs (such as financial and non-financial incentives) as well as supply-focused policies that require automakers to increase the availability and variety of PEV models (e.g. like California's Zero Emissions Vehicle Mandate).

Figure E-11: Emissions intensity of plug-in electric vehicles, well-to wheels grams CO2e/km (using hourly marginal emissions factors for electricity, including regional electricity trade)



Notes: Gas = gasoline vehicle; HEV = conventional hybrid-electric vehicle (e.g. Toyota Prius); PEV Scenarios 1—2 = respondent designed PEV adoption and varied charging access; PEV Scenario 3 = wide-scale 240 km BEV adoption and Level 2 charging access at home and work.

Figure E-12: Impact of constraints on PEV sales in British Columbia, 2020

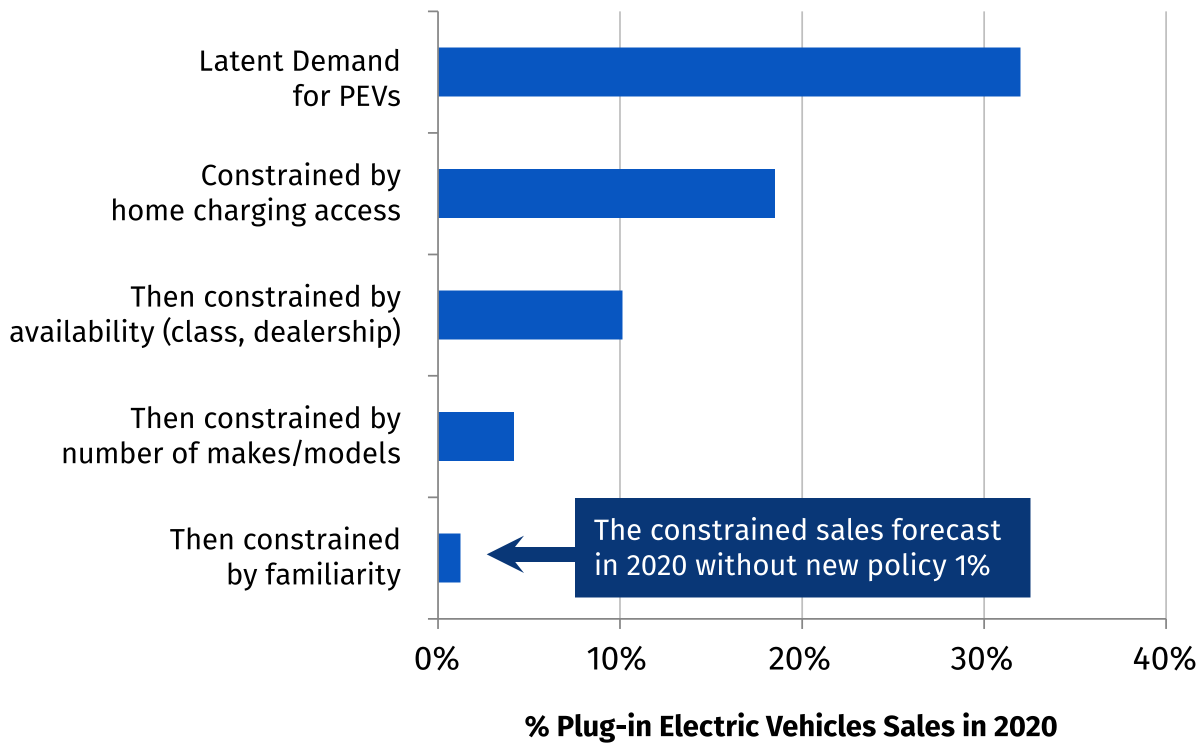
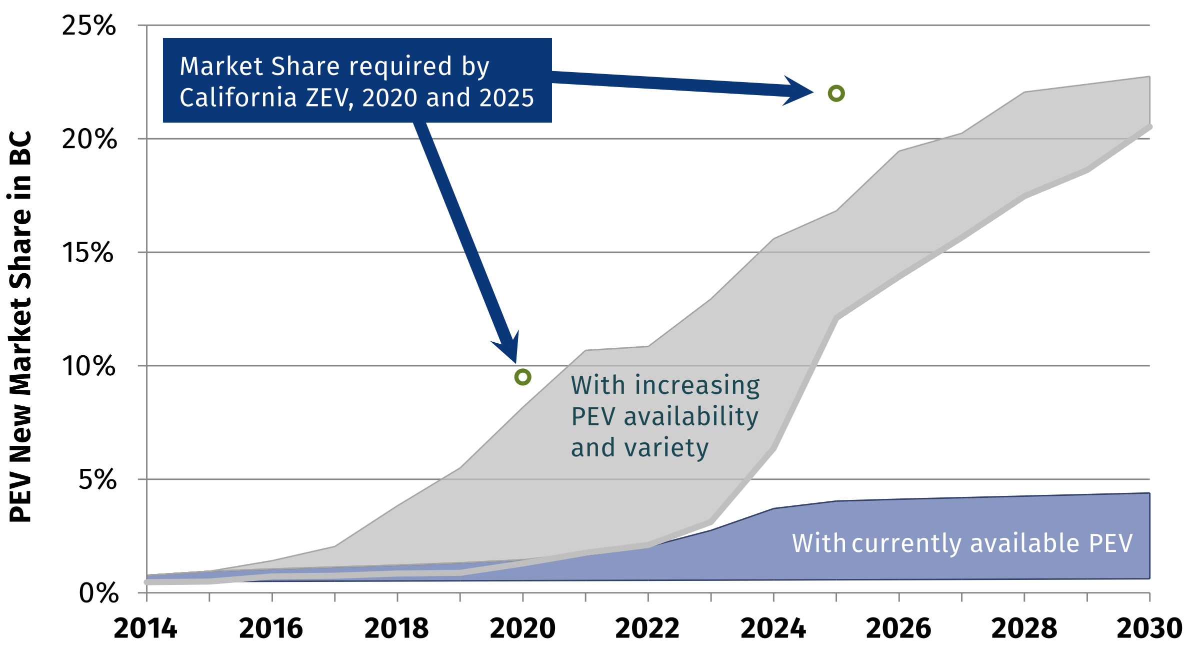


Figure E-13: PEV new market share scenario forecasts (for passenger vehicles in British Columbia)



Objective #10: Assess Consumer Acceptance of Utility-Controlled Charging

"Utility controlled charging" (UCC) could be an important method to control the timing of PEV charging to reduce environmental impacts, increase the use of renewable energy, and potentially reduce grid costs.

We explore respondent acceptance of various UCC programs, finding that among Mainstream (NVOS) respondents, awareness and understanding of electricity sources and the idea of UCC is very low.

Once explained, there is general openness to UCC programs, where probability of enrollment is higher with decreased electrical bill, increased proportion of renewable electricity, and increased "guaranteed minimum charge" each morning. We use latent class modeling to identify four segments of Early Mainstream respondents with differing valuation of UCC:

The "Anti-UCC" class (21% of Early Mainstream respondents) expressed negative valuation of UCC and renewable sources of electricity. The Anti-UCC class was more likely to be significantly older and less highly educated than members of the other classes.

The "Pro-UCC" classes expressed positive valuation of UCC, and include:

1. The "Charged focused" class (33% of Early Mainstream respondents) are relatively sensitive to changes in the guaranteed minimum charge level and monthly electricity bill. These respondents are most likely to see UCC as an "invasion of privacy."
2. The "Cost motivated" class (28%) had a significantly positive constant estimate for UCC. These respondents are the most sensitive to increases in costs savings (e.g. an electrical bill discount) and are willing to pay the least for additional units of renewables relative to the other Pro-UCC classes.
3. The "Renewables focused" class (17%) includes respondents that most highly value UCC and renewable electricity. These respondents are less cost sensitive than the other Pro-UCC classes. These respondents are significantly more likely to be highly educated and have a higher level of biospheric values than the other classes.

Among PEV Pioneer respondents, UCC acceptance is much higher relative to Mainstream respondents, where PEV Pioneer respondents are, on average, willing to pay 50% more for guaranteed minimum charge, and 4 times more for increased renewables.

Interviews indicate that PEV Pioneers' interest in UCC enrollment is primarily related to supporting the environment (renewables) or supporting technology development. Some respondents are also concerned about potential battery degradation.

Future Research

This report presents the latest results from the Canadian Plug-in Electric Vehicle Study (CPEVS) as of May 25, 2015. Several of these analyses are presented in greater detail in other publications (see Section 1.3 for details).

Moving forward, our research team plans to release more publications, white-papers and reports on these and related analyses. Future research directions may include (subject to funding):

- Conducting a dynamic, long-run analysis of how PEV usage could reduce GHG emissions, with regional electricity grids transitioning with the transportation sector.
- Implementing the CPEVS method in other countries to assess PEV market potential.
- Applying the PEV market share forecast model to other Canadian regions (beyond British Columbia) and other countries.
- Linking the PEV discrete choice model with the utility-controlled charging choice model to create an integrated model of PEV choice and usage.
- Linking the PEV usage model with a detailed electricity dispatch model to quantify the potential for utility controlled charging of PEVs to facilitate the deployment of renewable energy.
- Using the PEV market share forecast model to quantify the effectiveness of different demand-focused and supply-focused policies, e.g. deploying public charging infrastructure, providing charging at multi-unit residential buildings, implementing a zero emissions vehicle mandate, and providing various financial and non-financial incentives.

Please contact Jonn Axsen (jaxsen@sfu.ca) or Suzanne Goldberg (sgoldber@sfu.ca) for information on the most recent PEV analyses conducted by the EMRG Sustainable Transportation Group at Simon Fraser University.

1. Introduction to the Canadian Plug-in Electric Vehicle Study

1.1. Plug-in Electric Vehicles as a Societal Transition

Electric-mobility may be a key component in a successful transition toward deep greenhouse-gas (GHG) reductions (Williams et al., 2012). Widespread uptake and use of plug-in electric vehicles (PEVs) will involve meaningful shifts in social and technical systems (Sovacool and Hirsh, 2009). But how close are we from that shift? What do we know about the current PEV market? What do we know about its future potential and its impacts? And how can policymakers best facilitate a transition to electric mobility?

The true societal impacts of PEV deployment are not entirely certain. Analyses in the US indicate that PEV use could halve petroleum use (Axsen and Kurani, 2010; Gonder et al., 2007) and cut GHG emissions by 15 to 65% 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 GHG 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. And even if "latent demand" exists among vehicle buying households, such demand will not be realized if PEVs are not made available in the sizes, functions and styles that vehicle buyers want. PEV demand and supply will likely need to be stimulated by strong climate policy, such as carbon pricing as well as supply-focused regulations like California's Zero-Emissions Vehicle Mandate.

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, some studies suggest that PEVs powered by coal-based electricity offer limited benefits relative to today's conventional vehicles or hybrids (Hadley and Tsvetkova, 2008a; National Academy of Sciences, 2010), whereas PEVs powered by natural-gas based electricity could cut emissions by one third (Axsen et al., 2011), and PEVs powered by renewable sources such as hydro, solar, or wind could almost eliminate GHG emissions if their generation can be matched to the timing of PEV recharge demand.

For these reasons, it is important to anticipate potential PEV usage patterns and how they might evolve to align with a low-carbon electricity grid. Again, climate policy will need to play a role in aligning low carbon electricity generation with PEV use.

This report summarizes a large, multi-method study that collects and analyzes Canadian consumer data to better understand the potential for PEV uptake and usage in Canada, the likely impacts in terms of energy usage and GHG emissions, and the potential role of climate policy in inducing and guiding such a transition. Results hold important implications for policymakers, electric utilities, and auto companies, as well as industry, academics, NGOs and other stakeholders seeking to understand the potential for electric mobility.

1.2. The Study

The **Canadian Plug-in Electric Vehicle Study (CPEVS)** consists of rich analyses of consumers' vehicle preferences and purchase motivations, driving habits, charging patterns (or potential access to charging), as well as their beliefs, attitudes, and interests in PEVs. Data collected for this study comes from two distinct multi-mode survey and interview processes:

» the 2015 **Plug-in Electric Vehicle Owners Survey (PEVOS)** and

» the 2013 **New Vehicle Owners Survey (NVOS)**.

We use a variety of innovative survey and interview techniques to collect data, including "design space" and "discrete choice set" exercises, which are techniques used to ascertain respondent interest in PEVs under different price and resource conditions. The design and implementation of this study follows what we call a reflexive lifestyle approach (further detailed in Section 3.1).

This approach extends the techniques developed to investigate potential BEV demand in California during the 1990s (Kurani et al., 1994, 1996) and more recently to estimate PHEV demand in a 2007 survey of US new-vehicle buyers (Axsen and Kurani, 2009), link PEV demand with green electricity in the US (Axsen and Kurani, 2013a), and assess PEV interest in San Diego, California (Axsen and Kurani, 2013b).

1.3. Overall Study Context

CPEVS is 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."* This project includes funding provided by Natural Resources Canada, BC Hydro, the Pacific Institute of Climate Solutions (PICS), the BC Ministry of Energy and Mines, and the Social Sciences and Humanities Research Council (SSHRC) of Canada.

The overall project is scheduled to run from 2012 to 2016. 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, Clay Howey at the British Columbia Institute of Technology, and Jonn Axsen at Simon Fraser University's Energy and Materials Research Group.

This report summarizes the consumer research portion of this project, led by Dr. Jonn Axsen. The material summarized in this report reflects the most recent analyses produced by SFU's consumer research team:

Reports:

» Axsen, J., H. J. Bailey, and G. Kamiya (2013). The Canadian Plug-in Electric Vehicle Survey (CPEVS 2013): Anticipating Purchase, Use, and Grid Interactions in British Columbia, Preliminary Report, Prepared for BC Hydro and the British Columbia Government, October 31, 2013.

Peer-reviewed Publications:

» Bailey, H., A. Miele, and J. Axsen (2015). Is awareness of public charging associated with consumer interest in plug-in electric vehicles? Transportation Research Part D: Transport and Environment, 36, 1—9.

» Axsen, J., J. H. Bailey, and M. Castro (2015).Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. Energy Economics, 50, 190—201.

» Bailey, J. H. and, J. Axsen (Revise and resubmit). Anticipating consumer acceptance of utility controlled charging for plug-in vehicles, Submitted to Transportation Research Part A: Policy and Practice.

Master's Theses:

» George Kamiya (in progress). "Modeling the GHG intensity of PEVs in Canada using short-term and long-term perspectives on technology."

» Brad Langman (in progress). "Understanding consumer demand for PEVs and green electricity using qualitative interviews."

» Maxwell Sykes (in progress). "Modeling the role of a ZEV mandate in PEV deployment: The case of British Columbia."

» Joshua Cairns (in progress). "Plug-in electric vehicle buyers in British Columbia: Understanding motives and usage patterns."

» Dominique Atherley (in progress). "Modeling the role of refueling infrastructure in alternative-fuel vehicle deployment: The case of PEV chargers in British Columbia."

» The overall NRCan ecoEII project involves a number of other research stages, which are addressed in other reports published by the collaborating universities.

1.4. Regional Context

This report provides a comprehensive characterization of current and potential PEV owners in Canada, with a particular focus on the Canadian Province of British Columbia. PEVOS (2015) includes data only from owners of PEVs in British Columbia, while NVOS (2013) includes data from new vehicle owners residing in all Canadian provinces with the exception of Quebec, including oversamples from British Columbia and Alberta to facilitate regional comparison (e.g. regarding GHG impacts in Section 13).

In some sections of this report, we focus on data from British Columbia to provide comparative analyses of our PEV Pioneer (PEVOS) and Mainstream (NVOS) samples. Readers should understand that British Columbia is unique, in the context of PEV adoption, in two primary ways:

» **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).[1] That said, Section 12 explains that potential (latent) demand for PEVs may be only slightly higher in British Columbia relative to other Canadian provinces.

» **Low-carbon electricity:**
British Columbia provides a particular advantage in terms of low-carbon electricity. The vast majority (86%) of electricity is generated from hydroelectric 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). British Columbia also has a zero-emissions electricity standard in the *Clean Energy Act s.2(c)* that requires at least 93% of total generation be met by clean or renewable resources (SBC, 2010). Clearly, the nature of British Columbia's electric grid holds important implications for the potential GHG reductions among PEVs used in the province (as further detailed in Section 13).

1. 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 BEV ($0.0148/km) for an CV:BEV 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).

1.5. Research Questions and Organization of Report

A transition to widespread PEV use will likely require substantial social and technical shifts in Canadian society. This report explores how consumer interest in passenger (light-duty) PEVs may guide such shifts. We collect rich data from current PEV owners (or PEV Pioneers) as well as new conventional vehicle owners in Canada (or Mainstream vehicle buyers) to investigate several important research questions related to this topic in the sections of this report:

- How do we identify current and potential PEV buyers and collect the necessary data about their preferences, motivations, behaviour and lifestyles? (Section 3 and Section 4)
- Who will buy PEVs in the future? Who are buying PEVs now? (Section 5)
- What do current PEV and new vehicle owners know about PEV models and technologies? (Section 6)
- What level of access to home and public charging infrastructure do current PEV and new vehicle owners have? (Section 7)
- What kind of vehicles do current PEV and new vehicle owners want and how do they value different vehicle attributes? (Section 8)
- What impact does recharge access (e.g. home charging, public charging) have on PEV deployment? What impact does vehicle knowledge have? (Section 9)
- What motivates interest in PEVs among different types of consumers? (Section 10)
- How are PEV owners driving and charging their vehicles? How will future owners drive and charge their vehicles? (Section 11 and Section 12)
- How might widespread PEV adoption impact the electric grid in Alberta, British Columbia and Ontario? (Section 12)
- How might PEV adoption reduce GHG emissions in different regions? (Section 13)
- What rate of PEV adoption can we expect in British Columbia over the next 10 or 20 years, given different assumptions about PEV availability? (Section 14)
- Will consumers allow utilities to use PEV charging to complement intermittent renewable electricity sources (e.g. wind, solar and run-of river hydroelectricity) or balance the electricity grid? (Section 15)

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

2. Background: PEV Technology, Policy and Markets

2.1. What is a PEV and How is it Recharged?

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

- **Plug-in hybrid vehicles (PHEVs)** can be powered by 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.[2]
- **Battery electric vehicles (BEVs)** are powered solely by electricity for a range of 100 to 400+ 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, h**ybrid-electric vehicles (HEVs)** such as the Toyota Prius and Honda Civic Hybrid 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, BEVs, and HEVs with interest in **conventional vehicles (CVs)** powered by gasoline (Table 1).

Table 1: Vehicle types and refuelling options

Vehicle Type	Refuel or Recharge?	
	Gasoline	Electricity
Gasoline (Conventional)	✓	
Hybrid	✓	
Plug-in Hybrid (or Extended Range PEV) *(e.g. Chevrolet Volt, Ford CMAX)*	✓	✓
Battery Electric *(e.g. Nissan LEAF, Tesla Model S)*		✓

2. Sometimes, discussions of PHEVs will include a separate category for "extended range" PEVs. For example, the Chevrolet Volt might be described as a PEV 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).

Recharging plug-in Electric Vehicles

The deployment of PEVs is particularly linked to recharge access (i.e. one's access to technology that charges PEVs). Depending on availability, PEV drivers can potentially recharge at home, work, or other non-home destinations such as shopping malls. There are three different technologies providing different levels of recharge service:

- **Level 1** chargers (or cordset chargers) use the 110/120V outlets, which are common in North American households. Level 1 is the slowest recharge speed, but can be 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** chargers (or charging stations) use 220/240V circuits, which are not ubiquitously available in residences in Canada. Such circuits are typically used for the highest-power household appliances such as a washer or dryer. Home access to Level 2 charging requires installation of a specialized residential vehicle charger. Purchase and installation of a home Level 2 charger can cost anywhere from a couple hundred to a couple thousand dollars. 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 essential for some BEVs.
- **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 BEV can be recharged up to 80% of the vehicle's battery in 30 minutes. The voltage required for Level 3 is too high for most residential applications, so installation of a Level 3 charger is typically only considered for non-home locations.

Chargers in British Columbia

As of October 2014, there were roughly 550 Level 2 public charging stations in British Columbia. The majority of these stations were installed with support from the British Columbia Government's Community Charging Deployment Fund and PlugIn BC (PowerTech Labs and Fraser Basin Council, 2014). In addition to these stations, several Level 1 and DC fast chargers are available throughout British Columbia that are provided by both private and public interest.

For example, the provincial and federal government, in cooperation with BC Hydro, had installed 8 DC fast charging stations (as of July 2014), and Tesla Motors had installed 3 super charger networks, each with 4—6 charging bays (as of April 2015) in the province. Plugshare provides a comprehensive map of charging opportunities across the province.

2.2. PEV Policies

Globally, substantial efforts and resources have been devoted to PEV development over the last few decades. Local air pollution, oil dependence, energy security, and now global climate change have all been drivers of a renewed political push for PEV deployment. Several national governments have set ambitious targets for PEV deployment, such as the US (Revkin, 2008), China (Wan et al. 2015) and Canada (Natural Resources Canada, 2010).

There are a wide range of policies that can induce PEV uptake, which can be split according to their focus on stimulating consumer demand ("demand-focused policies") or on stimulating suppliers ("supply-focused policies"). Examples include:

Demand-focused Policies:

- **Financial incentives:**
  The most common types of financial incentives for PEVs are rebates and tax exemptions. Rebates, such as British Columbia's point-of-sale Clean Energy Vehicle rebate, offer consumers a financial reward for the purchase of a PEV. Tax exemptions are also a common incentive for PEV purchasers. In Norway, PEVs are exempt from sales taxes, a 25% Value-Added-Tax (VAT), and road taxes.
- **Non-financial incentives:**
  These can include access to lanes reserved for high-occupancy vehicles (e.g. California, Norway) and free parking (e.g. Norway, the Netherlands, Germany). They can also include vehicle registration perks, such as in China where PEV purchasers can bypass the registration lottery, allowing them to skip the auction process.
- **Installation of chargers:**
  Many regions have invested in deployment of public chargers (e.g. Germany), while some offer free charging (e.g. the Netherlands). Regions can also promote charging infrastructure through building codes, such as the City of Vancouver, which has mandated that developers allocate at least 20% of parking to stalls with access to with 220V plug-in capability.
- **Information campaigns:**
  Efforts have been made to spur PEV sales through public-sponsored advertising, consumer outreach, and vehicle labeling (e.g. Austria, China, Australia).

Supply-focused Policies:

- **General R&D support:**
Funds can be allocated in the form of research and development for PEV technology. For example, in 2009 the United States pledged $2.4 billion USD in federal grants to fund research in advanced battery and electric drive technology under the American Recovery and Reinvestment Act.

- **Low-carbon fuel standards (LCFS):**
This policy requires that fuel suppliers in a region reduce the carbon intensity of the fuels that they sell. Although an LCFS does not focus directly on PEVs, it can be linked to PEV adoption when electricity is defined as a low-carbon "fuel." For example, in California's LCFS, fuel refiners and producers can purchase credits from electric utilities that supply electricity to the increasing number of PEVs in the state. In theory, such an LCFS puts some of the onus on electric utilities and fuel providers to support the deployment of PEVs, e.g. through further investment in charging infrastructure or the provision of purchase or usage incentives.

- **Zero Emissions Vehicle (ZEV) mandate:**
A zero-emissions vehicle (ZEV) mandate requires automobile manufacturers to sell a certain percentage of PEVs or hydrogen fuel-cell vehicles as part of their overall vehicle sales in a region. Such a policy was originally enacted in California in the 1990s, and now several other US states have joined. This policy can have a very strong effect on stimulating automakers to research, develop, and market PEVs in the region in question.

Both demand- and supply-focused policies can vary widely in their effectiveness in stimulating PEV adoption. We further explore some of these policies throughout this report and, in particular, in Section 14.

Policy Spotlight: Norway

Norway in particular has experienced significant growth in PEV market shares. Norway has enacted several strong demand-focused policies, including a series of tax exemptions which resulted in PEV prices being similar to conventional vehicle prices. For example, in 2013, the price of the Nissan Leaf (one of the top-selling PEVs in Norway, along with the Tesla Model S) was close to $42,500 USD, while the 1.3-lt Volkswagen Golf, a comparable conventional vehicle, was $42,000 USD (Reuters, 2013).

PEVs in Norway are exempt from all non-recurring vehicle fees, which include a 25% VAT, sales taxes (25% on new vehicles), annual road taxes, toll payments, and public parking fees. Additionally, PEVs have access to bus lanes. While these policies were in place, Norway had a higher PEV market share than any other country in 2012 (3%), 2013 (6%) and 2014 (14%), and in the first quarter of 2015 new vehicle market share is reported to be over 20%.[3]

3. Source: Personal communication with Jose Point of EV Sales Blog (ev-sales.blogspot.com).

Global PEV policies

Global PEV policy is primarily demand-focused. Aside from R&D support, only two jurisdictions have implemented substantial supply-focused policy: California with a ZEV and LCFS, and British Columbia with a LCFS. Overall, however, more comprehensive PEV policies have been adopted in Europe and California, compared to Asia, North America (excluding California) and Oceania.

Table 2 provides an overview of the main demand- and supply-focused PEV policies being adopted in regions across the globe.

Table 2: Global PEV policy adoption by regional and policy type

Policy types	Regions Implemented
Demand-focused	
Financial incentives	
» Tax exemptions and tax credits	Belgium, Norway, Greece, UK, Denmark, Germany, Netherlands, France, Japan, Sweden, Denmark, Austria, US, Norway, Netherlands
» Subsidies	South Korea, California, Japan, China, France UK, Sweden, US, Spain, Canada (Ontario, Quebec and British Columbia)
Information campaigns	Ireland, Austria, Australia, Canada (select provinces)
Non-financial incentives (e.g. free parking, HOV lane access)	Select regions in China (Shanghai, Beijing, Guangzhou, Tianjin)
Supply-focused	
R&D support	China, Sweden, Australia, Canada, France
Zero Emissions Vehicle mandate (ZEV)	California (and affiliated states)
Low-carbon fuel standards (LCFS)	California, British Columbia (Canada)

Canadian PEV Policy

Across Canada, PEV policy is fragmented with only a few provinces offering comprehensive PEV policy portfolios. British Columbia, Ontario, and Quebec lead the country by offering mainly **demand-focused** policies, primarily a mix of financial incentives (including purchase subsidies ranging from $5000—8,500) and non-financial incentives.

At the national level, policy is **supply-focused** with federal investments in research and development. Several programs fund and support automotive research initatives directed at innovation, energy efficiency, and emissions reductions such as the Automotive Innovation Fund (Industry Canada), Automotive Partnership Canada (Industry Canada and NSERC), and EcoENERGY Innovation Iniative (NRCan). Table 3 summarizes the key provincial and national policies in Canada.

Policy Spotlight: California

California has also experienced significant PEV sales, behind only Norway and the Netherlands in terms of new vehicle market share. PEVs made up 4.0% of California's new passenger vehicle sales in 2013 (Mock and Yang, 2014) and has been experienced strong growth since then. High PEV sales in California are likely due to the state's strong demand- and supply-focused policies.

In terms of demand-focused policies, California consumers are offered both financial and non-financial incentives for PEV purchases. The US government offers a $7,500 federal tax credit for PEV purchases. The state of California also offers a rebate of up to $5,000 through the Clean Vehicle Rebate Project (CRVP), which began in 2009 and will be offered until funds are exhausted.

PEV drivers are also given Clean Air Vehicle decals, which allow them to use California's high occupancy vehicle lanes. Additionally, the state passed legislation requiring homeowner associations to grant condominium owner requests to install PEV charging equipment. Many municipalities and utilities offer additional incentives, including free downtown parking (Hermosa Beach), free charging (Sacramento, San Jose), other rebates (up to $3,000 in San Joaquin Valley), and reduced residential electricity rates for PEV charging (PG&E in Northern California, Sacramento Municipal Utility District).

In terms of **supply-focused policies**, California has a ZEV mandate and a LCFS. The state has had a ZEV mandate in place since 1990. According to California's 2013 ZEV Action Plan, the state's target is 1.5 million zero-emissions vehicles (PEV or hydrogen fuel cell) sold by 2025 (Office of Governor Edmund G. Brown Jr, 2013). California's low-carbon fuel standard (LCFS) further incentivizes the usage of electricity to power vehicles by allowing electric utilities to sell credits to fuel suppliers.

Table 3: PEV policy across Canada

Region	Policy focus	Policy types
Provincial Policy		
British Columbia	**Demand-focused:**	» Purchase incentives (up to $5000 via Clean Energy Vehicle Program) » Rebates for residential Level 2 charging infrastructure » Financial support for public charging infrastructure (Community Charging Infrastructure Fund) » Information campaigns (e.g. Emotive outreach efforts) » Building bylaws for MURBs (20% of all parking must have access to potential charging + buildings must have sufficient electric capacity – City of Vancouver)
	Supply-focused:	» Low carbon fuel standard, ZEV mandate in legislation but not implemented
Ontario	**Demand-focused:**	» Purchase Incentives (up to $8500) » Access to HOV lanes » Target for public fleet PEV adoption (20% of new vehicle by 2020), » Charging infrastructure incentives (up to $1,000 for Level 2 residential/fleet)
	Supply-focused:	» None
Quebec	**Demand-focused:**	» Purchase Incentives (up to $8000) » Rebate for installation of home charging (up to $1000)
	Supply-focused:	» None
Manitoba	**Demand-focused:**	» Information campaign (stakeholder partnerships, PEV promotion centre)
	Supply-focused:	» None
New Brunswick	**Demand-focused:**	» Charging facilities » Outreach efforts
	Supply-focused:	» None
National Policy[4]		
	Demand-focused:	» None
	Supply-focused:	» R&D and demonstration funding that supports research activities related to PEV development and deployment: Automotive Partnership Canada ($145 million over five years, beginning in 2009); the Automotive Innovation Fund ($550 million over two years, from 2014—2016); EcoENERGY Innovation Initiative ($268 million over five years, from 2011—2016); SDTC (ongoing funds for PEV-related research).

4. For more information on national level policies, please visit the following program websites:
Automotive Innovation Fund (https://www.ic.gc.ca/eic/site/auto-auto.nsf/eng/am02257.html)
Automotive Partnership Canada (http://www.apc-pac.ca/About-Renseignements/Background-Contexte_eng.asp)
EcoENERGY II (http://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/4985)
Sustainable Development Technology Canada (https://www.sdtc.ca/en)

Relative to other Canadian provinces, British Columbia has been a leader in PEV policy with its Clean Energy Vehicle Program, which was in place from December 1st 2011 to March 31st 2014, and was recently renewed in April 2015. This demand-focused program provides point-of-sale incentives of up to $5,000 for PEV purchases (via BC Clean Car Incentive), rebates for the purchase and installation of residential charging infrastructure (via LiveSmart BC) and public charging infrastructure (via Community Charging Infrastructure Deployment Fund). The province, along with several municipalities in British Columbia, has also invested in information campaigns and outreach efforts such as Emotive and Plug-in BC.[5]

At the municipal level, the City of Vancouver has mandated that at least 20% of all parking spaces in new multi-unit family residences have vehicle charging infrastructure capabilities. Additionally, private companies and many municipalities offer free charging at public stations. In terms of supply-focused policies, British Columbia implemented a low-carbon fuel standard (LCFS) policy in 2010 which, like California's LCFS, provides credits to electric utilities providing electricity to PEVs. British Columbia also has the legislation required for a California-like ZEV mandate, but has not yet decided to implement this policy.

Supported by demand-focused policies, Ontario has set a provincial target of 5% of all new vehicles sales being PEVs by 2020. The province offers a rebate of up to $8,500 for the purchase or lease of eligible PEVs, and up to $1,000 for the purchase and installation of home charging stations. Ontario also issues green license plates for PEVs, allowing single occupant vehicles access to the high occupancy vehicle lanes. Another PEV program in Ontario is the replacement of publicly-owned passenger vehicle fleets (target is 20% of new vehicle purchases by 2020) with PEVs. Additionally, private companies and some municipalities offer free public charging.

Quebec's 2011—2020 Quebec Action Plan sets a provincial target of having 300,000 PEVs or 25% of new light passenger vehicles sales being PEVs by 2020. The province has also taken a demand-focused approach by offering rebates between up to $8,000 for PEV purchases and leases. Rebates are also provided for the installation of 240V home charging stations (50% of eligible expenses or $1,000) via Drive Electric. Additionally, Hydro Quebec has partnered with several local businesses to introduce a network of public chargers (Level 2 and DC) across the province.

Other provinces have less in the way of targeted PEV policy (Table 3). For example, Manitoba's Electric Vehicle Road Map, released in 2011, is a promotional information campaign for PEVs, which includes facilitation of partnerships with automakers and other key stakeholders to demonstrate PEVs and provide charging infrastructure, and creating an Electric Vehicle Learning Demonstration Centre to showcase commercially available PEV models and recharging equipment. Nova Scotia has a privately owned PEV-share pilot program (although this is not operating under the auspices of the provincial government), while New Brunswick has launched a project to evaluate the suitability of PEVs and charging infrastructure in the province.

5. More information on the Emotive Campaign and Plug-in BC is available online at the following sites:
Emotive (http://www.emotivebc.ca/)
Plug-in BC (http://pluginbc.ca/)

2.3. PEV Market

Global Market

Market share of PEVs significantly varies by region and country. Here, we define market share as the percentage of new passenger vehicle sales (in a given year) that are classified as a PHEV or BEV. In 2014, PEV market share was highest in Norway (14%), the Netherlands (4%), and Iceland (3%). The prevailing PEV drivetrain (i.e. PHEV or BEV) varies significantly between countries. For instance, Norway sells mostly BEVs, while the Netherlands predominantly sells PHEVs (Mock & Yang, 2014). The majority of other countries with high PEV market shares are in Europe or East Asia. Table 4 shows global passenger PEV market shares for regions with market shares greater than 0.1%.

Table 4: Global light-duty PEV market shares (as a % total of new passenger vehicle sales)

	Annual Sales	% New Market Share	
Country	**2014**	**2014**	**2013**
Norway	20,083	13.93%	6.10%
Netherlands	15,270	3.94%	5.55%
Iceland	204	2.71%	0.94%
Estonia	353	1.67%	0.68%
Sweden	5,029	1.66%	0.71%
Japan	32,613	0.98%	0.92%
France	16,294	0.91%	0.84%
Denmark	1,657	0.88%	0.29%
Switzerland	2,275	0.75%	0.44%
USA	119,804	0.73%	0.62%
UK	14,358	0.58%	0.16%
Austria	1,645	0.54%	0.26%
Hong Kong	246	0.46%	0.39%
Germany	13,242	0.44%	0.23%
Belgium	2,105	0.44%	0.17%
Finland	440	0.42%	0.18%
Canada	5,025	0.27%	0.18%
Ireland	258	0.27%	0.08%
Portugal	362	0.25%	0.23%
China	57,144	0.24%	0.09%
Spain	1,957	0.23%	0.18%
New Zealand	252	0.20%	0.007%
Italy	1,656	0.12%	0.11%

Source: EV Blog Spot (http://ev-sales.blogspot.com)

Canadian Market

The market in Canada is small, but growing. As of February 2015, over 11,000 PEVs have been sold in Canada; however, the national PEV market share was only 0.27% of new vehicle sales in 2014 (Klippenstein, 2015). PEV sales in Canada have largely been concentrated in Quebec, Ontario, and British Columbia, where there tends to be stronger PEV policy (as portrayed in Table 3).

Combined, these three provinces accounted for over 90% of total electric vehicle sales in Canada from January 2013 to March 2015.[6] The Chevrolet Volt, Tesla Model S and Nissan Leaf, respectively, were the three most popular PEVs in Ontario, Quebec and British Columbia between January 2013 and March 2015.[7] Table 5 shows cumulative PEV sales in Canada by province as of 2014.

Table 6 shows sales data for the Chevrolet Volt, Tesla Model S and Nissan Leaf sales from January 2013 to March 2015. In British Columbia, the market for PEVs has been growing since 2011, with over 1400 PEVs sold since 2011.

Table 5: Cumulative PEV sales in Canada by province as of January 2014

Province	PEV Sales	Proportion of national PEV sales (%)
QC	2580	44.0
ON	2016	34.4
BC	969	16.5
AB	176	3.0
MB	50	0.9
SK	24	0.4
NS	22	0.4
NB	18	0.3
NFL	6	0.1
PEI	3	0.1

Source: (Stevens, 2014) http://www.fleetcarma.com/canadian-electric-vehicle-sales-jan-2014-provincial-summary/

Table 6: Chevrolet Volt, Tesla Model S and Nissan Leaf sales from January 2013 to March 2015

	2013 (Jan - Dec)	2014 (Jan - Dec)	2015 (Jan-March)
Chevrolet Volt	164	681	1901
Tesla Model S	443	939	403
Nissan Leaf	363	500	901

Source: Personal email communication with Matthew Klippenstein. May 9th 2015. Market data from IHS.

6. Personal email communication with Matthew Klippenstein. May 9th 2015. Market data from IHS.
7. Ibid.

3. PEV Market Research: Understanding the Potential

Traditional approaches to PEV market research tend to focus on the functional aspects of PEV technology and the factors that either facilitate or hinder adoption. The present study follows a more comprehensive and in-depth approach to consumer research, seeking to understand consumer preferences (and how these preferences form), consumer motivations, and how consumers differ from one another (e.g. segmentation and heterogeneity analysis). We further describe our perspective in this section.

3.1. Approaches to PEV Market Research

Previous PEV market research has typically taken one of three main approaches: constraints analysis, discrete choice modeling and reflexive lifestyle analysis. To explain our present research design, we begin with a discussion on the three approaches, where our present study focuses on the latter approach, but also integrates elements of the other two.

First, **constraints analyses** produce forecasts of PEV market penetration based on vehicle 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 example, Nesbitt et al. (1992) estimated the proportion of residences with recharge access to be 28% in the US.

More recently, Williams and Kurani (2006) estimated the proportion to be 15 to 30% 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% of US 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 quantify consumer preferences (often as willingness-to-pay) and to forecast PEV market share based on different vehicle or infrastructure attributes. Discrete choice models typically assess demand by representing consumers as self-interested individuals who consciously trade off 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 vehicle 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 the discrete choice modeling 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 r**eflexive lifestyle** approach. Researchers have used this approach in PEV market research to examine the effects of consumer learning on the prospects for transitions to PEVs as well as to address the limitations of the constraints studies and choice models noted above. For example, focus groups and interviews conducted regarding BEVs in the 1990s (at the advent of BEV policy, technology, and market activity) reported that most consumers had so little familiarity with BEVs 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 vehicle purchases are opportunities for preference construction, and thus preference change.

The reflexive lifestyle research approach was also utilized to assess the early US market potential for PHEVs (Axsen and Kurani, 2008, 2009). A three-stage web-survey was based on insights gained from prior BEV research (Kurani et al., 1994) and qualitative interviews of early PHEV drivers (Heffner et al., 2007). The survey was administered to a representative sample of 2,373 new vehicle buying households across the US in 2007. The survey directly consulted respondents regarding their ability to park a vehicle where it could be charged. A constructive design space exercise assessed consumer interest in PHEV designs and priorities for attributes.

Unlike a standard discrete 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.

Our present study (CPEVS) follows the reflexive lifestyle approach and assumes that consumers construct their interests and preferences as they learn about PEV technology – through social interaction, information provision or actual use – and that these interests may or may not be constrained by past or present driving patterns, recharge availability or consumer motivation. Building on the 2007 US PHEV survey (Axsen and Kurani, 2008, 2009), we extend the vehicle design space

exercises to include a wider range of vehicle options (conventional, hybrid, plug-in hybrid and pure battery electric vehicles). Aspects of this survey method have been further tested with a survey of new vehicle owners in San Diego, California (Axsen and Kurani, 2012c; Axsen and Kurani, 2013b), and with a survey of interest in green electricity among US vehicle buyers (Axsen and Kurani, 2012b; Axsen and Kurani, 2013a).

3.2. PEVs and Consumer Perceptions

Research on PEV markets can also vary by focus on technology versus a focus on 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 7). This two-dimensional conceptualization is further explored by Axsen and Kurani (2012a).

Table 7: Conceptualization of PEV benefits (examples from Axsen and Kurani, 2012a)

	Functional	Symbolic
Private benefits	» Save money » Reliable » Fun to drive (experiential)	» Expression of self-identity » Convey personal status to others » Attain group membership
Societal 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, as the present study aims to do.

3.3. Distinguishing Consumers: Pioneers, Early Mainstream and Late Mainstream

To research the potential market for PEVs and other emerging technologies, it is also important to recognize that consumers can vary widely in their perceptions, tastes, preferences and motivations. Thus, it can be useful to divide potential buyers into a number of consumer segments. One of 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 the limitations that come with the diffusion of innovations model. We introduce this classification within the context of this study:

» **PEV Pioneers:**
These are the very first buyers of PEVs, and are enthusiasts by nature. Research shows that such buyers are different than the larger passenger vehicle market, with Pioneers having higher income and education levels, more significant pro-technology and pro-environmental values, and greater willingness to explore and experiment (Axsen and Kurani, 2013a). These Pioneers are a relatively small, specialized group and are generally different from the Early Mainstream buyers.

» **Potential Early Mainstream PEV buyers:**
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 to ultimately become a widely accepted technology.

» **Potential 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 substantial changes will likely be required in terms of policy, costs, technology, or cultural norms.

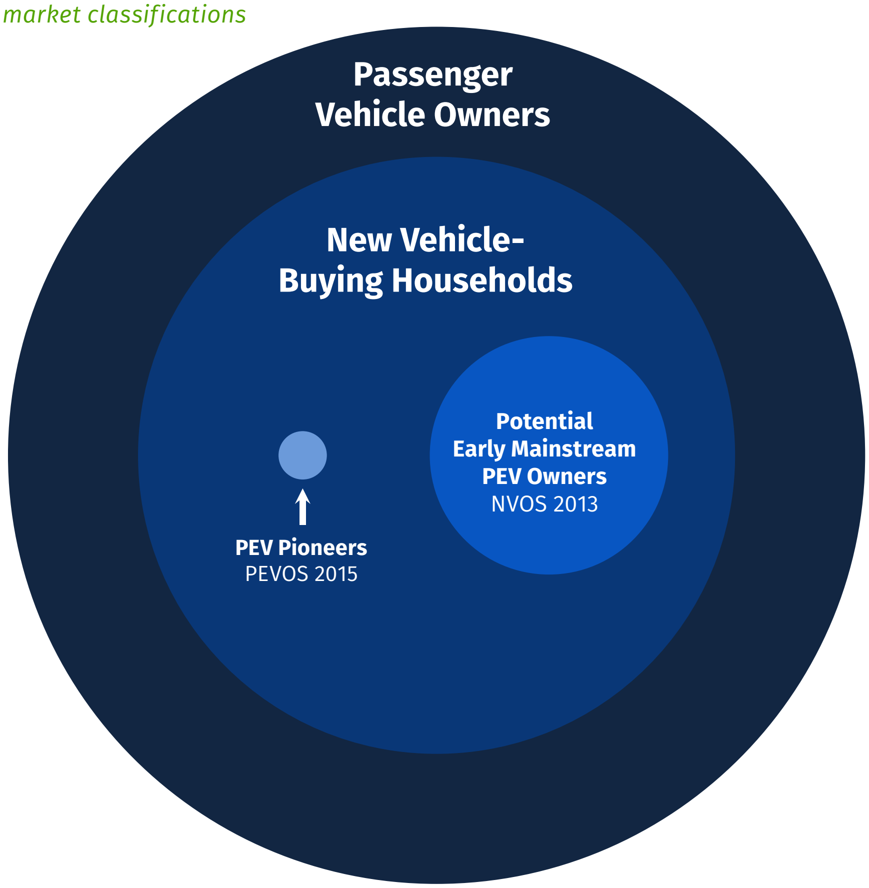
Figure 1 illustrates these groups in the present study. The largest ellipse represents the total population of households that own passenger vehicles, while the smaller ellipse includes only those households that buy or lease new vehicles (not just used vehicles). Within that ellipse are two circles, the smaller of which represents the PEV Pioneers that have already purchased a PEV, and the larger of which represents the subset of new vehicle buyers that is more likely to be the "next" buyers of PEVs—this is the Early Mainstream market.

As already noted, our study collects consumer data from two distinct populations to investigate current and anticipated PEV purchase and use patterns both in Canada and British Columbia:

- The **Plug-in Electric Vehicle Owners' Survey (PEVOS)** (2015) targeted PEV Pioneers or households that own one or more commercially produced PEVs (after-market conversions were not included).
- The **New Vehicle Owners' Survey (NVOS)** (2013) targeted the broader segment of Mainstream new vehicle buying households. We used data collected through the survey to distinguish the potential Early Mainstream buyers from the Late Mainstream buyers.

Households that purchased used vehicles or made no vehicle purchases at all were not included in our study, as we assume that only new vehicle buying households will be potential PEV buyers in the shorter term.

Figure 1: Vehicle market classifications



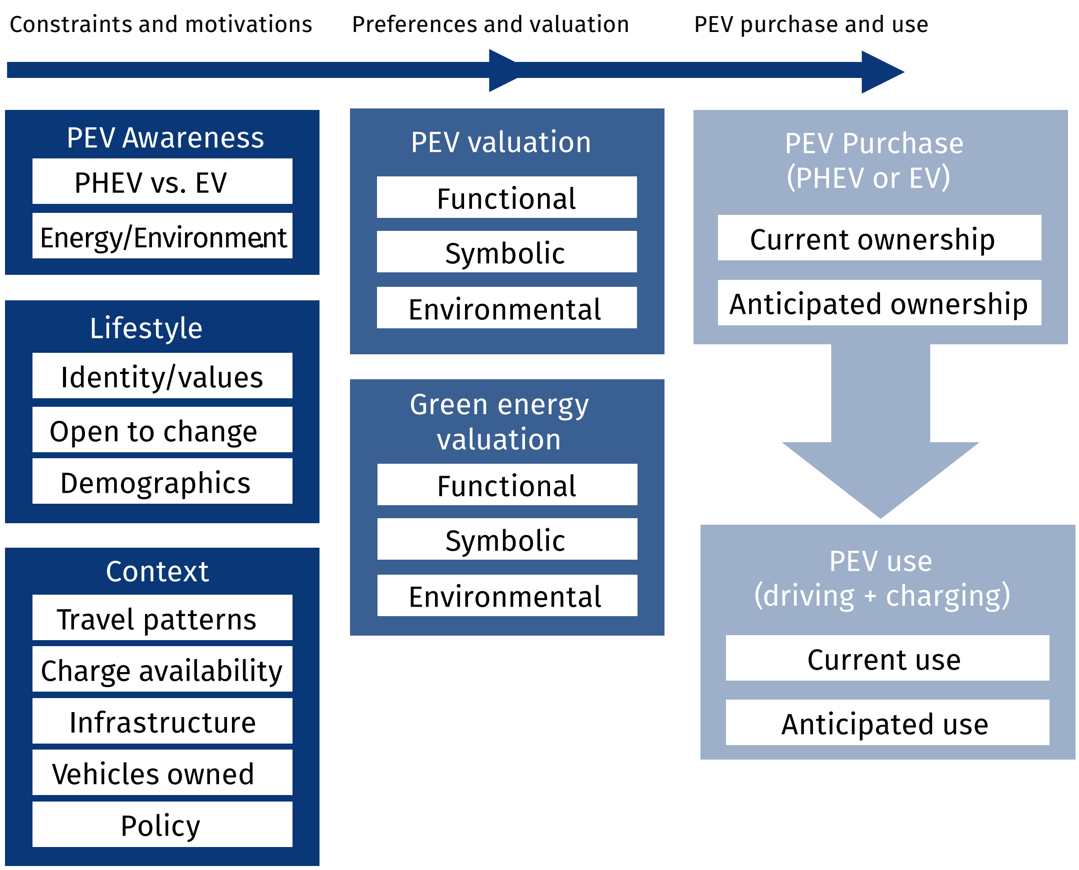
3.4. Conceptual Framework: Actual and Anticipated PEV Purchase and Use Behaviour

Figure 2 shows the conceptual framework that guides our present study, where a "conceptual framework" illustrates the flow of ideas, theories, and context that underlie the design and implementation of a study. Our conceptual framework explores several aspects of respondents' backgrounds, including awareness of PEV and energy technology, their values and lifestyle, and their context regarding travel patterns and access to infrastructure.

We also look at how these details link to consumer valuation of PEVs and their attributes (including functional, symbolic and environmental benefits), as well as valuation of the electricity used to charge the vehicle (in particular if it is "green" or "renewable" electricity). Finally, we look at how context and valuation relate to PEV purchase and usage in terms of driving and charging behaviour.

We implement this conceptual framework by collecting survey and interview data from PEV Pioneers (PEVOS 2015) and Mainstream new vehicle buyers (NVOS 2013) in Canada. We further detail our methods in the next chapter.

Figure 2: Conceptual framework: Actual and anticipated PEV purchase and use



4. CPEVS Methods

4.1. Data Collection

The **reflexive lifestyle** approach (detailed in Section 3.1) assumes that consumers construct their interests and preferences as they learn about PEV technology – through information provision or actual use. It also assumes that these interests may or may not be constrained by past or present driving patterns and recharge availability. Following this approach, we designed and implemented two multi-phased surveys and in-depth interview protocols to collect rich details from samples of Early Mainstream, Late Mainstream and Pioneer PEV buyers. We collect data on Mainstream PEV buyers from a sample of Canadian new vehicle buyers (NVOS), and collect data on PEV Pioneers from a sample of PEV British Columbian PEV owners (PEVOS).

We assessed potential PEV demand among the potential Mainstream vehicle market by recruiting a sample of Canadian new vehicle owners, which we define as households who have purchased a new vehicle (powered by gasoline) in the past five years and use a vehicle regularly. A market research company (Sentis) was contracted to recruit the representative sample of Canadian new vehicle buying households and to deploy the three-part NVOS survey between April and October 2013. NVOS interview participants were recruited from survey respondents who expressed interest in participating in future research, and interviews were conducted between August 2013 and February 2014. Participants were compensated with gift cards valued at $20 and entry into a $500 cash draw for completing the survey, and $50 for completing the interview.

Data were also collected from PEV Pioneers (or PEV owners) in British Columbia. We define PEV owners as households that have purchased or leased a commercially available PEV (i.e. a vehicle that plugs into an outlet to recharge its battery) like the Chevrolet Volt or Nissan Leaf; we did not include owners of after-market conversion PEVs. PEVOS survey participants were recruited from the British Columbia Government's Clean Energy Vehicle Program, the Vancouver Electric Vehicle Association (VEVA) and Emotive BC. Survey data were collected from June 2014 to February 2015. Survey respondents received a $50 gift card for their participation. PEVOS interview participants were recruited from survey participants who indicated a willingness to participate in additional research. Interview data collection started in December 2014 and is ongoing, where interviewees received a $50 gift card for their participation.

4.2. New Vehicle Owners Survey (NVOS)

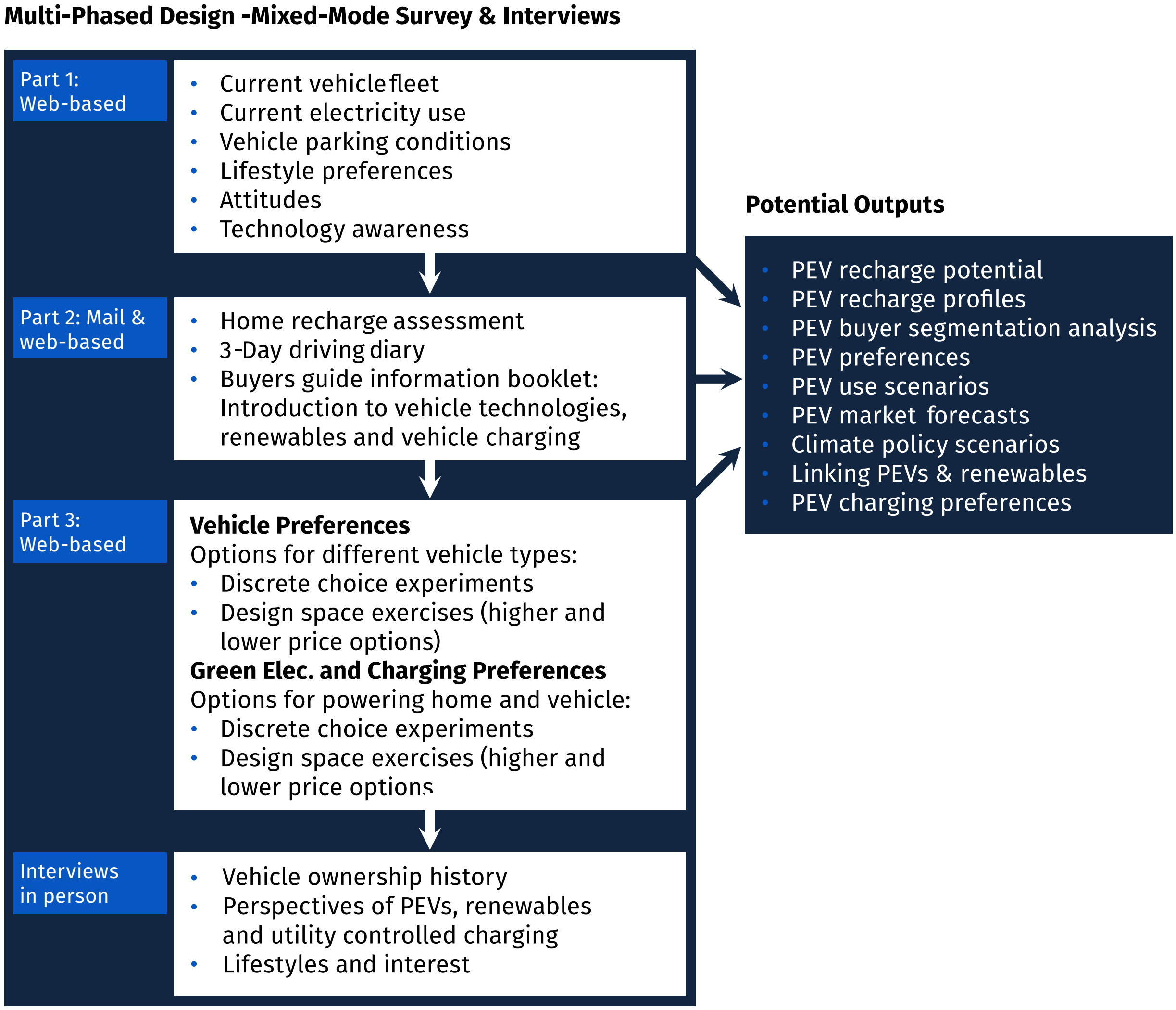
NVOS assumes that the vast majority of Mainstream new vehicle owners have little prior experience with PEVs, and have not previously thought about PEVs. Our multi-phased method seeks to learn many details about the respondent (Part 1), provides respondents with opportunities to learn about their own interest in PEVs and how the technology may relate to their lifestyle (Part 2), elicits respondent interest in buying and using a PEV (Part 3), and attempts to understand respondent perspectives on PEVs, as well as their motivations and interests (through subsequent interviews with a subset of respondents).

The overall flow of the survey and interview process is depicted in Figure 3 and described below. Figure 3 also identifies some of the potential outputs of survey and interview data analysis, only a subset of which is reported in this document. In summary, this study design consisted of:

- **Part 1: Background questionnaire** investigated the respondent's vehicle ownership, home electricity conditions and also general lifestyle.
- **Part 2: Driving diary and PEV readiness questionnaire** elicited respondent 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, type of parking locations, as well as the proximity of those locations to an electrical outlet or existing PEV charging station. Respondents were also provided with a "Buyers Guide"—a short booklet introducing them to vehicle technologies and green electricity, providing a primer for Part 3.
- **Part 3: Consumer preference design and choice survey** investigated consumer preferences and interests regarding PEVs and the charging of PEVs. The survey also combined a series of attitudinal questions with discrete choice exercises and design exercises to investigate the tradeoffs involved in purchasing and charging PEVs.
- **Qualitative interviews** were conducted with a small subset of survey respondents. The interviews provided additional insight into respondent survey responses, specifically related to technology awareness, vehicle and charging preferences, lifestyle and purchase motivations.

The full survey instrument is available in PDF form, following this link. We provide more details on the design and theory supporting the survey instruments in the remainder of this section.

Figure 3: New Vehicle Owner Survey and Interview design



4.2.1. Background Questionnaire (NVOS Part 1)

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:

- **Vehicle ownership:** the household's fleet of vehicles (e.g. make/model, use, and purchase history) and fuel costs.
- **Electricity use:** perceptions of 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.
- **Vehicle Technologies:** gauged respondent familiarity and experience with different vehicle technologies/models and PEV charging stations (Axsen and Kurani, 2008).
- **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).
- **Your Household:** included demographic questions (e.g. education, income, home type).
- **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.

4.2.2. Home Recharge Assessment (NVOS Part 2)

Part 2 collected data on respondents' PEV readiness by assessing household driving patterns and potential charging access. Respondents that completed Part 1 online were mailed (or emailed) Part 2, which included the "Home Recharge Assessment", a three-day driving diary, and a PEV "Buyers' Guide".

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. In contrast to previous studies, we directly ask 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. (A copy of the home recharge assessment can be downloaded from this link).

The three main purposes for implementing this recharge assessment were:

- Following a **reflexive lifestyle** approach, this Home Recharge Assessment helped the survey respondents to better understand their own recharge access.
- We wanted to understand what proportions of new vehicle owners in British Columbia presently have access to Level 1 or Level 2 charging at home, or have the potential to install Level 2 charging at home.
- We wanted to provide a customized option for Level 2 installation as part of the PEV design space exercise (described for Part 3 below). provides a detailed description of the charger cost model.

4.2.3. Three-Day Driving Diary (NVOS Part 2)

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 this link). 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, and trip purpose. At each destination, parking data was recorded, including the type of parking (e.g. garage, street) and any availability of 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. Respondents recorded their data in a physical diary document and then later entered their data online.

The two main purposes for implementing this three-day diary were:

- Following a **reflexive lifestyle** approach, this diary helped the survey respondents better understand their own driving patterns and recharge access. This “reflection” helped respondents think about their own lifestyle and mobility needs and opportunities, which may have improved the quality and reliability of preferences we elicited from them.
- We used the diary data itself to help us build models that simulate how Early Mainstream PEV buyers may drive and recharge potential PEVs they may desire—and how this usage may impact, and potentially interact with the electrical grid.

Simulating Early Mainstream PEV Driving Patterns

For our model simulations of Early Mainstream PEV driving behaviour in Section 12, we assume that current driving patterns (in conventional vehicles) reflect the driving patterns of the same respondents if they were to buy a PEV. It is not clear how driving behaviour may actually differ between drivers of conventional vehicles and PEVs. One theory is that the cheaper costs of operating a PEV could result in a "rebound effect," where drivers actually increase the total distance they drive.

However, one study of new Toyota Prius HEV buyers in Switzerland found no evidence of rebound effects (De Haan et al., 2006), while another found evidence of improved driving efficiency (e.g. moderated acceleration) (Caperello and Kurani, 2011). Insights from the PEVOS surveys and interviews regarding actual PEV driving patterns in Section 11 provide some context to these assumptions, but have not been included in the simulation model at this time.

PEV Buyers Guide (NVOS Part 2)

A PEV Buyers Guide was mailed to each Part 2 participant to introduce them to the technologies and concepts included in Part 3. The Guide provided a primer on PEV technologies (those discussed in Section 2.1), charging levels and infrastructure, renewable or "green" energy sources and utility controlled charging. The Buyers Guide was based off similar documents used in consumer research for PHEVs in the US (Axsen and Kurani, 2009) and PEVs in San Diego, California (Axsen and Kurani, 2013b), and was extensively pre-tested to maximize respondents' ability to comprehend survey questions and concepts, while attempting to minimize bias-inducing information.

Utility Controlled Charging

Utility controlled charging occurs when an electric utility somehow controls the charging of PEVs. This may include the utility controlling the timing of PEV charging or the utility taking power from the PEV for use on the grid (i.e. vehicle-to-grid). Utility controlled charging has the potential to help manage load, reduce systems costs, or increase renewable integration associated with an electric grid.

4.2.4. Vehicle Design Exercise (NVOS Part 3)

Part 3 of the survey included the PEV design space exercise and choice experiment. First, the PEV 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 4 provides a screenshot of the PEV design space game.

Following the **reflexive lifestyle** approach explained in Section 3.1, 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 with the Home Recharge Assessment, driving diary and PEV Buyers Guide.

To begin the design space exercise, the questionnaire elicited information about the anticipated price, make and model of the next vehicle the respondent's household would buy; respondents were restricted to first select only conventional gasoline models. The design space presented to each respondent was their selected conventional vehicle (CV) and three other versions of that vehicle: a hybrid (HEV), plug-in hybrid (PHEV) and pure battery electric (BEV) versions of the same vehicle (Table 8). In the design space, respondents were asked to select one option from three key vehicle attributes: vehicle type (CV, HEV, PHEV or BEV), kilometers of electric range (16km-240km) and if available, speed of home recharge (Level 1 or Level 2). The design exercise was completed under "higher" price and "lower" price conditions. The higher price condition was designed to approximate current vehicle costs and the lower price condition was designed to represent costs after subsidies or cheaper batteries (Table 8).

The NVOS survey instrument used data from Part 2 to personalize the cost of installing a Level 2 charger (6 kW) at home for those respondents that had the potential to do so (i.e. respondents that reported access to a reliable parking spot at home and authority to install a Level 2 charge in the Home Recharge Assessment).[8] Respondents were given the option to "pay" to install Level 2 charging at home (installation prices ranged from $500 to $3500) if they designed some type of PEV, either a PHEV or BEV. If respondents had no access to home recharging or if they had a Level 2 recharger already available at home, then this installation option was not included in their NVOS design space exercise.

8. 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).

Figure 4: Screenshot of PEV "design space" exercise

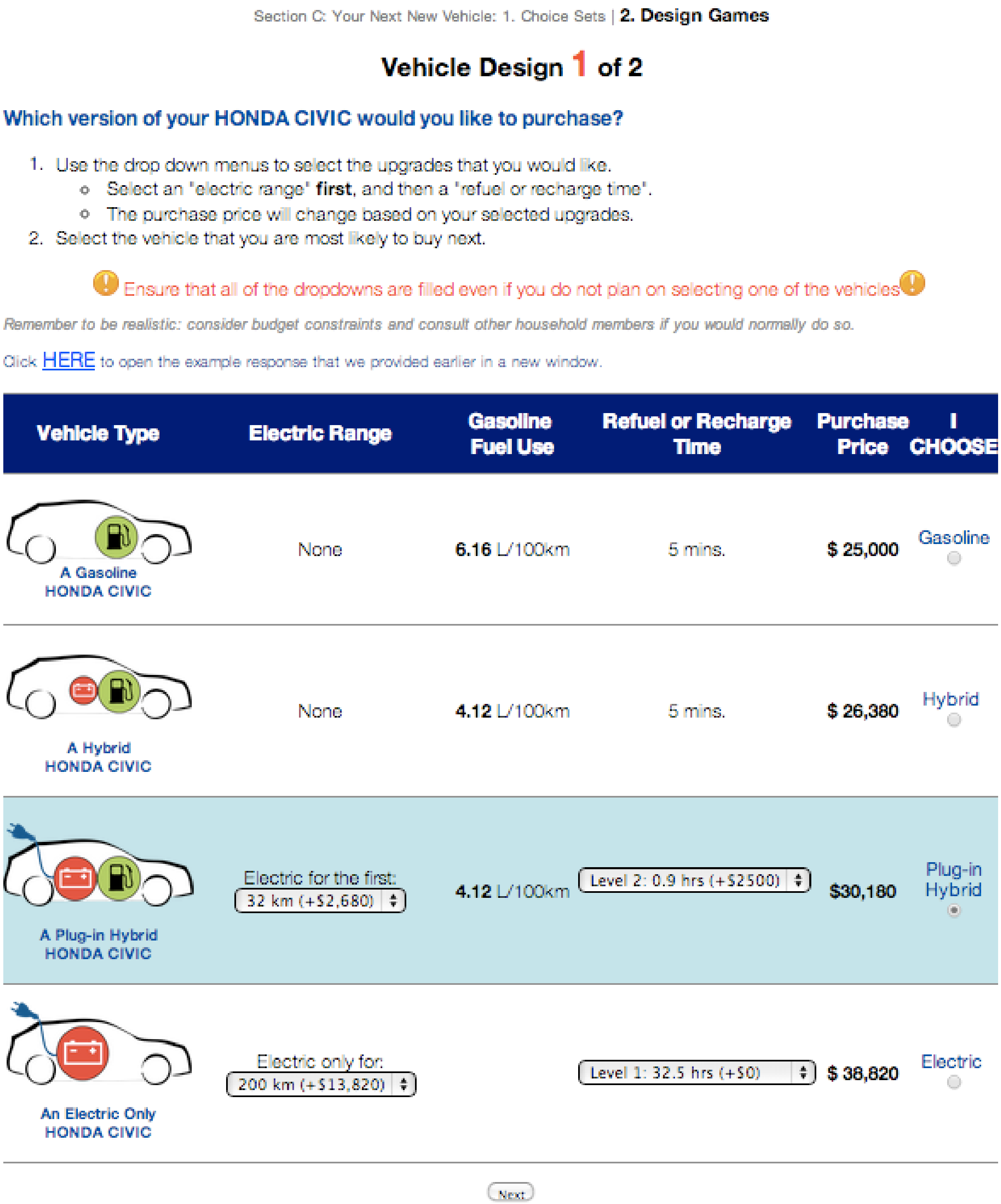


Table 8: PEV "Design space" exercise options and prices (prices incremental to respondents' next anticipated conventional vehicle).

	Higher Price				Lower Price			
Vehicle type and battery range (km)	**Compact**	**Compact**	**Mid-SUV**	**Full-SUV**	**Compact**	**Sedan**	**Mid-SUV**	**Full-SUV**
Hybrid-electric (HEV)								
HEV	$1380	$1740	$2050	$2470	$930	$1070	$1200	$1370
Plug-in Hybrid (PHEV)								
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
Battery-electric (BEV)								
BEV-80	$6500	$7880	$10150	$12150	$3220	$3620	$4600	$5300
BEV-120	$8940	$10690	$13930	$16600	$4440	$5030	$6490	$7520
BEV-160	$11380	$13500	$17710	$21050	$5660	$6440	$8380	$9750
BEV-200	$13820	$16310	$21490	$25500	$6880	$7840	$10270	$11970
BEV-240	$16260	$19130	$25260	$29940	$8100	$9250	$12160	$14200

Incremental Vehicle Cost Assumptions

The prices in Table 8 are largely hypothetical, where "higher" and "lower" price 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 US (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.

4.2.5. Vehicle Discrete Choice Experiment (NVOS Part 3)

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 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 research to the model consumer demand for alternative-fuel vehicles (Bunch et al., 1993a; Ewing and Sarigollu, 2000; Hidrue et al., 2011) and in the renewable energy literature to model 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, it can enrich analyses when combined with other statistical data such as data from our survey questions or design exercises.

In the previous design exercises, every respondent indicated the make, model, purchase price and fuels costs of their next anticipated new vehicle conventional purchase (which initially we asked them to limit to being a conventional vehicle). This information was then used to present six customized vehicle choice sets to the respondent. Each choice set presented four different vehicles: a conventional vehicle (their next anticipated vehicle purchase), or a HEV, PHEV or BEV version of that vehicle. Aside from the drivetrain and the attributes depicted in Table 9, 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 5 depicts how the vehicle choice set appeared to respondents.

The experimental design is detailed in Table 9, which included incremental purchase price increases, fuel cost differences, and electric-powered driving ranges. The choice set also specified the availability of slower (Level 1) or faster (Level 2) vehicle charging at respondents' home. The four attributes (purchase price, weekly fuel cost, vehicle electric range and charge speed) appear consistent with previous research—see Hidrue et al. (2011) and Tanaka et al. (2014) for recent reviews. We did not include representation of public charging infrastructure; empirical research suggests that home charging infrastructure is more likely to be important among potential Early Mainstream buyers (Bailey et al., 2015).

The experimental design we used was based on the attribute levels in Table 9 which resulted in a full factorial design of 47 × 31 × 22. We used SAS's "MktEx macro" function to generate a main-effects fractional factorial version of this experimental design and set the number of choice sets to 48 (Kuhfeld, 2005). As part of the design generation we ensured that all choice sets were different and that unrealistic attribute combinations were not created. The final D-efficiency was 98%, where a "good" D-efficiency rating is 80% or greater, indicating that the design is balanced and orthogonal (Bliemer and Rose, 2011). This series of choice sets was then divided into eight blocks of six choices and each respondent completed one randomly assigned block and 6 choice sets. Each choice set presented all four vehicle drivetrains.

Strengths of Choice Experiments

An important strength of choice models is that they can be used to estimate a quantitative measure of respondents' valuation or willingness-to-pay (WTP) for PEVs. WTP for a given attribute is calculated as the ratio of the estimated coefficient for that attribute to the price coefficient; WTP is thus the average trade-off that the sample is willing to make between a dollar of purchase price and an extra unit of that attribute, e.g. one extra mile of range. The WTP of the PHEV or BEV constant represents consumers' valuation of PHEVs or BEVs relative to conventional vehicles, holding the other variables equal between the alternatives. Discrete choice models can also be used to simulate the probability of a given respondent selecting each vehicle in a given choice set, or to represent the proportion of the sample that would choose different vehicles in the choice set (which can be equated to market share).

Limitations of Choice Experiments

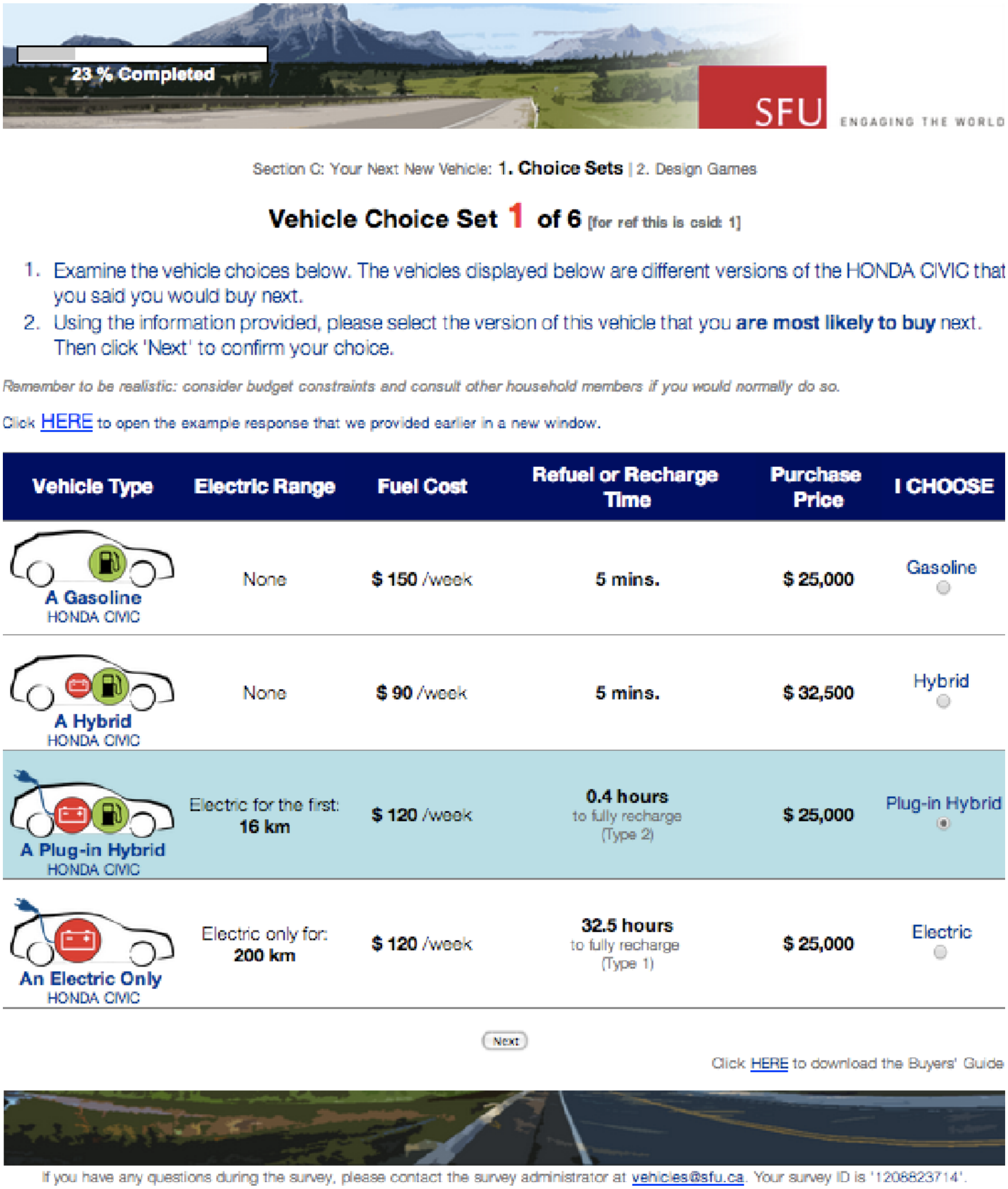
Although the vehicle choice experiment was intended to specify some of the major attributes that differentiate a conventional vehicle from a HEV, PHEV and BEV, many important attributes are likely missing. Implicitly, these missing attributes are captured by a constant (or ASC) in estimated MNL models 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. Further, some researchers critique discrete choice models as being unrealistic representations of actual consumer decision making and purchase behaviour. Nevertheless, we feel that these experiments serve as one useful assessment of consumer preferences—which can also be compared with results from the design space exercise, and household interviews.

Table 9: PEV choice model experimental design (6 choice sets per respondent)

Attributes	Next anticipated conventional vehicle	Hybrid vehicle	Plug-in hybrid vehicle	Electric vehicle
Purchase Price	Selected by respondent	Conventional price 10% more 20% more 40% more	Conventional price 10% more 20% more 40% more	Conventional price 10% more 20% more 40% more
Weekly fuel cost	Selected by respondent	40% less 30% less 20% less 10% less	80% less 60% less 40% less 20% less	80% less 60% less 40% less 20% less
Electric-driving range	n/a	n/a	16 km 32 km 64 km	120 km 160 km 200 km 240 km
Home recharge access	n/a	n/a	Level 1 (1 kW) Level 2 (6 kW)	Level 1 (1 kW) Level 2 (6 kW)
Recharge time [a]	n/a	n/a	Calculated	Calculated

a. The discrete choice experiment showed “recharge time” to respondents to help them understand the recharging needs of the PHEV or BEV. Recharge time was calculated as the time required for the respondent to fully recharge a depleted battery using their home charger. This time is a function of the vehicle’s electric driving range, the base vehicle type (where larger vehicle bodies are assumed to require more electricity consumption or have a higher kWh/mile), and the speed of the home charger (Level 1 or Level 2).

Figure 5: Illustrative PEV choice set (screenshot from survey)



23 % Completed

SFU ENGAGING THE WORLD

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

Click HERE to download the Buyers' Guide

If you have any questions during the survey, please contact the survey administrator at vehicles@sfu.ca. Your survey ID is '1206823714'.

4.2.6. PEV Charging Design Exercise (NVOS Part 3)

In Part 3 we also assessed respondent interest in "green electricity" and how that might relate to recharging of a PEV. As with PEV preference, green electricity and charging interest was assessed through design space exercises and discrete choice experiments. Here, we define "green electricity" as electricity produced by intermittent zero-carbon sources such as wind, solar, and run-of-the-river hydroelectricity. Our present definition of "green" excludes large hydroelectric dams, which closely aligns with the approach taken by the California renewable energy program.[9]

The charging design space exercise asked respondents to design a "green" electricity program in that respondents were given the option to replace their current mix of electricity sources with "green" sources, which 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 US new vehicle owners (Axsen and Kurani, 2013a). The design space was customized to each respondent, based on their reported household electricity costs (Figure 6). We estimated the monthly kWh consumption of each respondent by using their household electricity costs 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 designed PEV. If the respondent did not design a PEV, th their home electricity bill did not include an additional PEV charging cost.

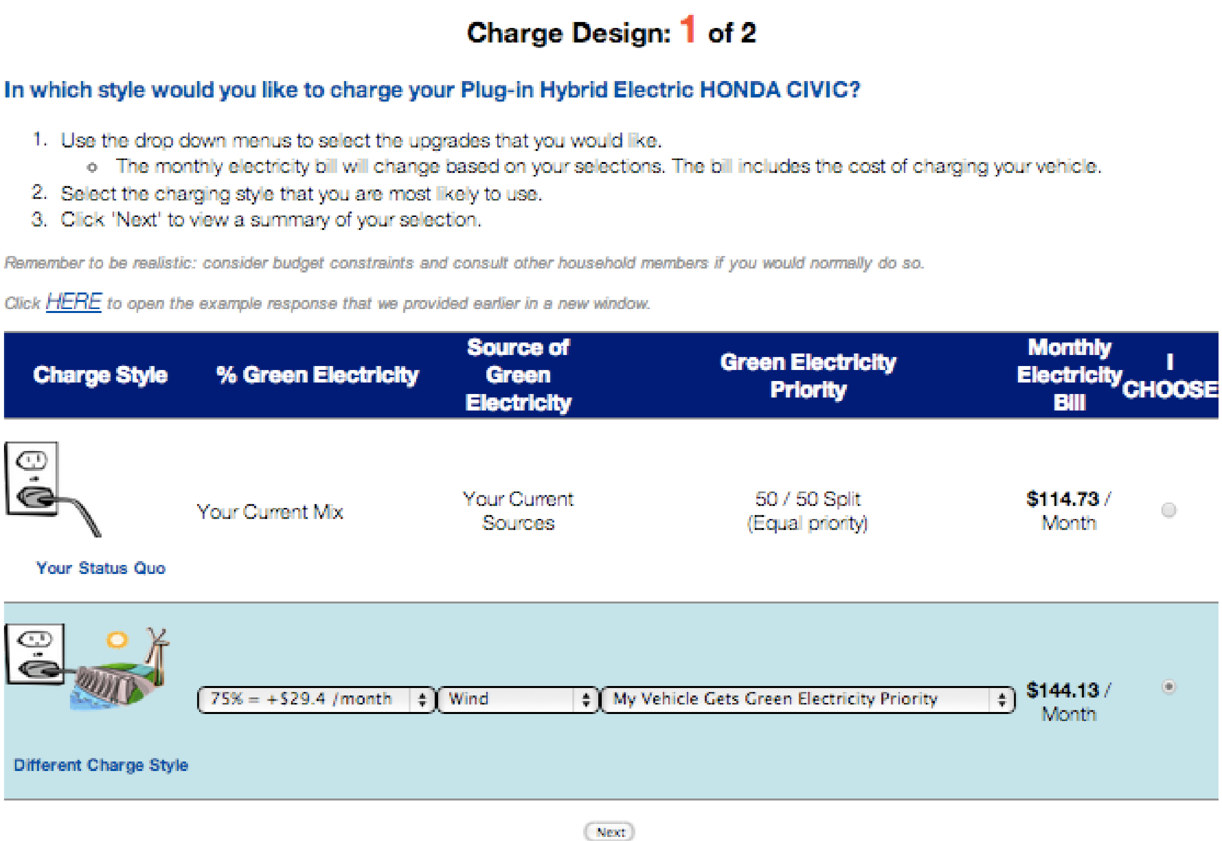
Respondents could design and select some version of a "green" electricity program, or select no program at all. The "green" electricity program allowed respondents to specify the amount and source of green electricity delivered to their homes and/or vehicles. Two price scenarios were presented to each respondent: the higher price scenario charged $0.03/kWh for green electricity, while the lower price scenario charged $0.015/kWh. The design space options are summarized in Table 10. Respondents could select the percentage of their home's electricity that would be provided from "green" sources (25% to 100%); based on the percentage of green electricity selected, the respondents' monthly bills would increase accordingly. Respondents could also select a particular source of green electricity, and, if they designed a PEV in the lower price design exercise, could specify whether that green electricity would be directed towards their home, PEV or both.

9. 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 10: 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 6: Illustrative green electricity design space (screenshot from survey)



4.2.7. PEV Charging Choice Exercises (NVOS Part 3)

We also assessed respondent interest in green electricity and PEV charging behaviour through a second discrete choice experiment. Here we specifically explored consumer acceptance of utility controlled charging (UCC). The idea of UCC is that the electric utility (e.g. BC Hydro) or a third party could have direct control over the timing of PEV charging 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 availability of renewable sources. 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 renewable integration.

We used four attributes to represent the UCC charging decision in the choice exercises. Each attribute was assigned four levels that varied between the alternatives depicted in each choice set (Table 11). To represent the inconvenience associated with UCC (due to the integration of intermittent sources of renewable electricity), we use the attribute ”guaranteed minimum charge” (GMC). This GMC attribute aligns closely with the guaranteed minimum range attribute used by Parsons et al. (2013) in their V2G choice experiment. We informed respondents that, as part of a UCC program, their electric utility might delay charging of the PEV until later in the evening or take electricity from the vehicle battery when it is plugged-in. GMC was described as: “the minimum level of charge that your battery would have after a night of being plugged-in. For example, if your GMC were 50%, then in the morning your battery would be at least half full. There is a chance that the level of charge could be higher than this.” We represented this GMC as a percentage of charge (e.g. 90% charged) and informed respondents of their consequent electric driving range in km (dependent on their vehicle design).

Given our research focus on the potential for UCC to increase the uptake of intermittent, renewable sources of electricity, the two main attributes that varied in the choice experiments were percentage of green electricity and source of green electricity. We chose to set each level of the percentage of green electricity attribute at 25% or higher (lower percentages were not viewed as attractive among pre-testers). In the experiment, we focused on popular sources of intermittent green electricity: wind, solar and small hydro, as well as a ”mixed” source of green electricity, as done by Borchers et al. (2007).

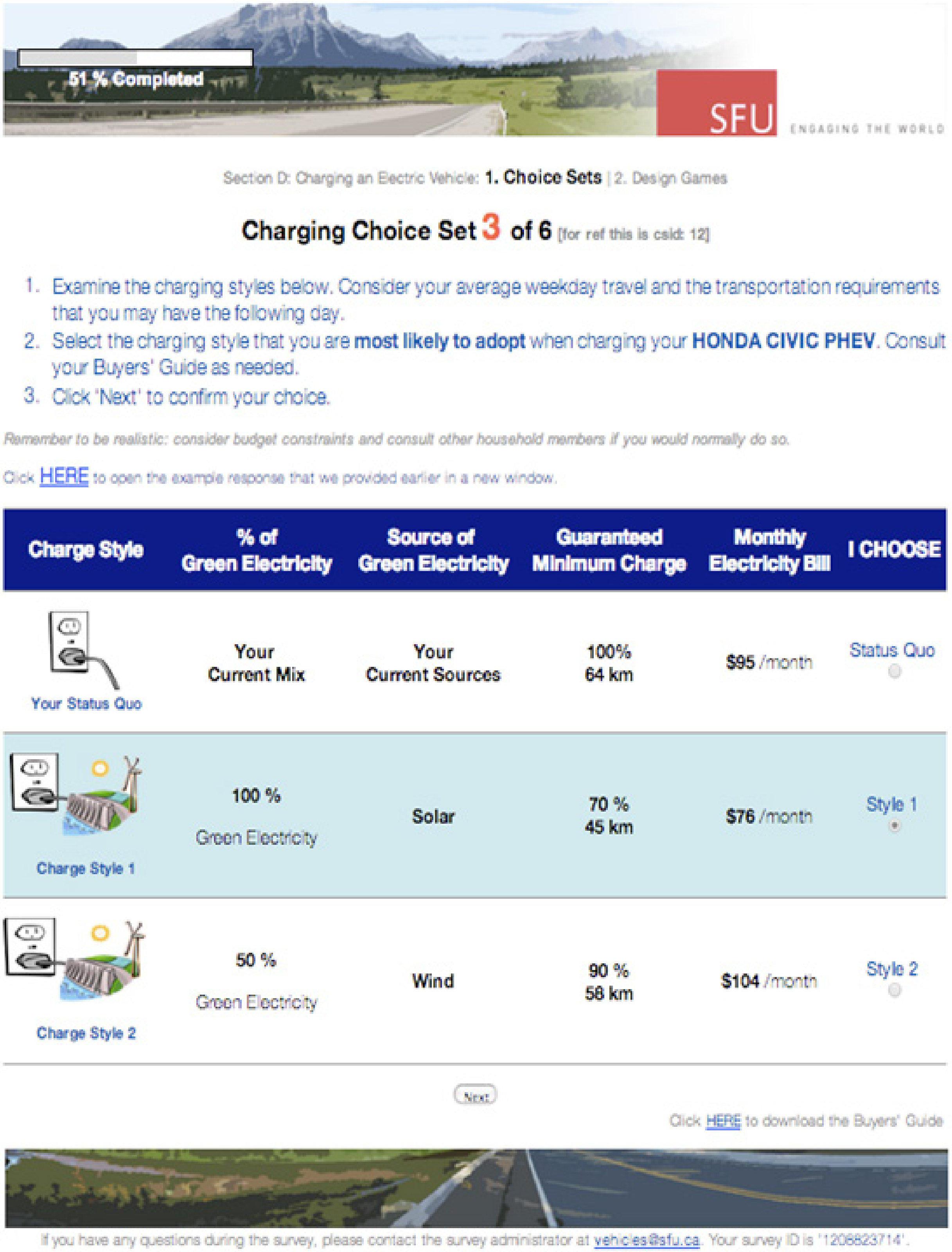
As in the design exercise, we customized the experiment for respondents with their reported monthly electricity bill, and the estimated additional cost of charging a PEV, if one was selected in the low price vehicle design exercise. Each choice set presented the respondents’ customized electricity bill and two hypothetical UCC programs that they might enroll in. To represent the cost (or savings) of the UCC program, respondents’ customized electricity bills were adjusted by 110%, 80% and 60% (Figure 7). Depending on the vehicle selected in the low price vehicle design exercise, respondents completed the choice set experiments either once or twice. Respondents that selected a PHEV completed one round of choice sets in the context of their designed vehicle and another in the context of a 240km BEV. Participants that selected a CV or HEV completed only one round in the context of a 240km BEV (respondents were asked to consider their UCC participation assuming they owned a 240km BEV).

The discrete choice experiments each featured six randomly assigned choice sets. The original experiment featured a 44 full factorial design. As in the case of the vehicle discrete choice experiment, we used SAS's choice mktEx macro function (Kuhfeld, 2005) to generate a main-effects fractional factorial version of this experimental design, reducing the total number of choice sets to 48. The mktEx 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.

Table 11: Renewable energy and utility controlled charging choice experiment

	Electricity system powering respondent home and vehicle		
Attributes	**Status Quo**	**Alternate Design 1**	**Alternate Design 2**
Percentage of Green Electricity: Percentage of current electric supply powering the respondents' home and vehicle.	Current Green Electricity %	25% 50% 75% 100%	25% 50% 75% 100%
Source of Green Electricity: The source of the green electricity to supply the respondents' home and vehicle.	Existing grid supply mix	Wind Solar Small Hydro Mixed	Wind Solar Small Hydro Mixed
Guaranteed Minimum Charge: The amount of charge that the vehicle's battery would have 'the next morning'. This was displayed to the respondent as both percentage charge and electric range in km.	100% charge	50% charged 70% charged 90% charged 100% charged	50% charged 70% charged 90% charged 100% charged
Monthly Electricity Bill: Current bill or with green electricity, user's current electric bill plus the expected cost of charging a vehicle multiplied by a scalar.	Current bill provided by respondent	60% of current bill 80% of current bill 100% of current bill 110% of current bill	60% of current bill 80% of current bill 100% of current bill 110% of current bill

Figure 7: Illustrative UCC choice set (screenshot from survey)



4.3. Plug-in Electric Vehicle Owners' Survey (PEVOS)

In the previous section we outlined our survey methodologies for our sample of Canadian new conventional vehicle owners (NVOS). In this section, we turn to the survey instrument used to collect data from our sample of **PEV owners in British Columbia** (PEVOS).

The PEVOS survey instrument is largely based on the NVOS instrument, and many elements are almost identical, including its structure and theory. Thus, outputs from both surveys generate a large number of comparative data sets (see analyses in Sections 6, 7 and 8). However, there are some differences in the research objectives and questions addressed with the PEVOS. Below we describe these differences.

» **Part 1: Background questionnaire:** this builds on the NVOS background survey, but also incorporates additional questions about the vehicle purchase process, vehicle use, and charging access. The objective of the background survey was to develop a comprehensive characterization of electric vehicle ownership and use in British Columbia, including key purchase motivations, respondent lifestyles and values, and technology/brand awareness. Outputs of the background survey are used to conduct comparative analyses on lifestyles, technology knowledge, and demographics, with new conventional vehicle buyers and PEV owners (presented in Sections 5 and 6).

» **Part 2: Driving diary:** a five-day driving diary which recorded trip and charging information, including distance and purpose of trips, state of charge, and number and types of charging events. The dairy is similar to that used in Part 2 of NVOS, but is longer (5 versus 3 days) and includes additional questions to collect respondent range and recharge data. Outputs from the driving diaries are used to generate analyses on actual PEV vehicle and charging behaviour (see Section 11).

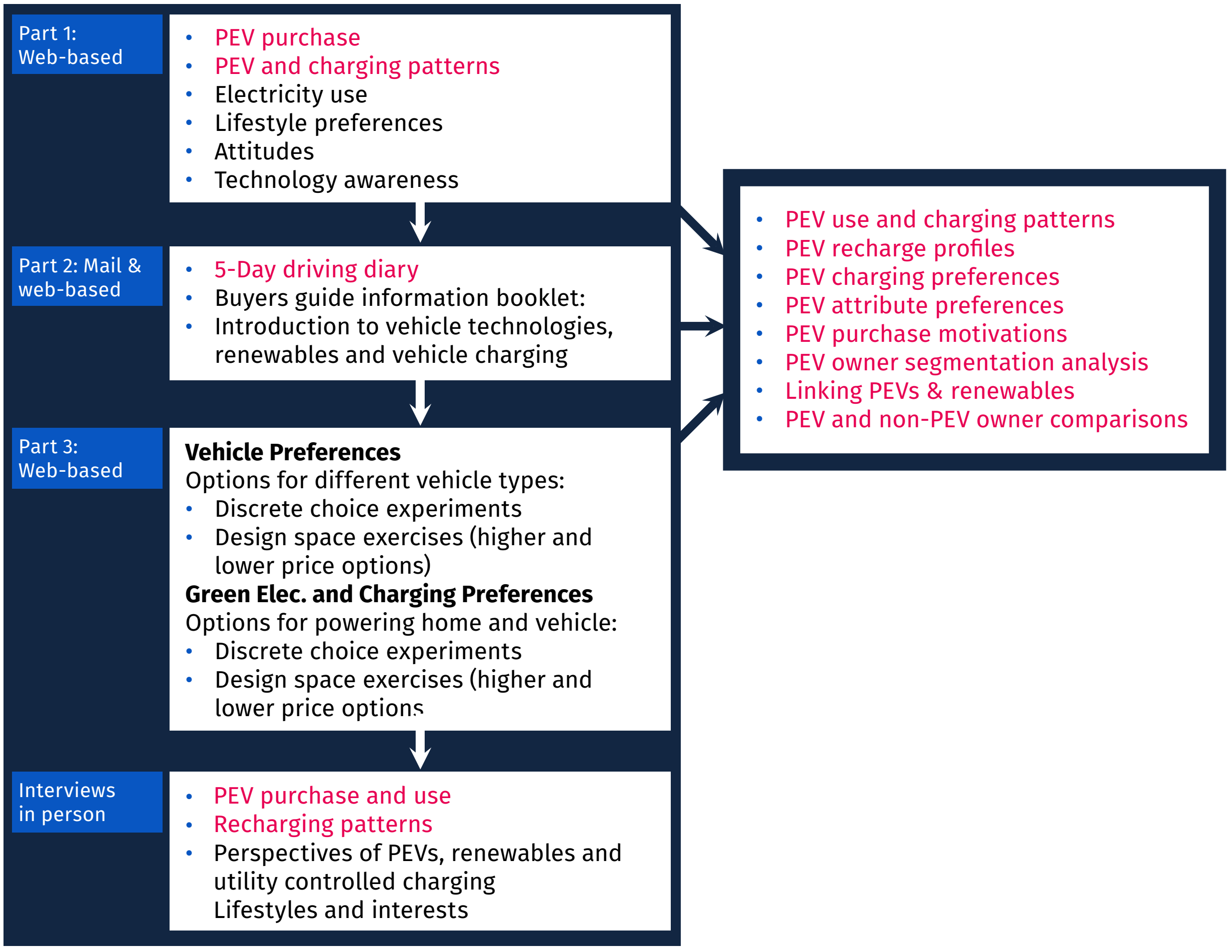
» **Part 3: Consumer preference design and choice survey:** assessed consumer preferences for PEVs, using discrete choice experiments and design exercises, and was almost identical to the NVOS instrument.

» **Qualitative Interviews** provided additional context to PEVOS survey data, specifically data related to purchase motivations, respondent lifestyle and values, as well as charging and driving patterns.

The multi-phase, mixed-mode survey design applied to PEVOS is almost identical to that used in the NVOS. Figure 8 provides an illustration of the PEVOS survey and interview design and its outputs. Because of the similarities between the two methodologies, we provide only a brief description of the survey and interview instruments, focusing on the key differences between the NVOS and PEVOS (indicated with red text in Figure 8). For a detailed description of survey design and theory, please refer back to Section 4.2. The following subsections further detail important aspects of PEVOS that differ from NVOS.

Figure 8: Plug-in Electric Vehicle Owners' Survey design

Multi-Phased Design -Mixed-Mode Survey & Interviews



Note: Red text indicates key differences between the NVOS (Figure 3) and PEVOS (Figure 8) survey designs.

4.3.1. Background Survey (PEVOS Part 1)

The background survey was based on Part 1 of the NVOS. The objective of the background survey was to develop a comprehensive characterization of electric vehicle ownership and use in British Columbia, including key purchase motivations, lifestyle and value segments, and technology/brand awareness. The background survey was adapted directly from the NVOS, and like Part 1 of the NVOS, was an in-depth questionnaire of vehicle ownership, household demographics, electricity use and technology knowledge.

To tailor the questionnaire to PEV owners, we added sections on pre and post purchase experience, as well as vehicle and charger use. Consequently, the PEVOS questionnaire was much larger than the NVOS questionnaire, having nine sections instead of six, including:

- **Your Plug-in Vehicle Purchase:** the number and type of PEVs owned (e.g. make, model, range, purchase price).
- **Expected Vehicle Use:** pre-purchase experience, including motivations, influences and expectations. Respondents were instructed to answers questions from the perspective of when they first purchased their vehicle (i.e. "Please think back to the time when you first committed to buying or leasing your PEV").
- **Actual Vehicle Use:** questions about current (or post-purchase) ownership, driving and charging experience, including how and where they charge, how they plan trips, and how they experience range.
- **Your Other Vehicles:** the number and type of other household non-electric vehicles.
- **Vehicle Technology:** familiarity and experience with different vehicle technologies/models and PEV charging stations (Axsen and Kurani, 2008). This section was identical to the equivalent section in NVOS Part 1.
- **Your Electricity Use:** perceptions of sources of electricity and current expenditure on home electricity, including familiarity with renewable sources of electricity. This section was almost identical to the equivalent section in NVOS Part 1; however, small adjustments were made to tailor questions to the British Columbia context and two questions on trust (of utility and other energy providers) were added.
- **Your Lifestyles and Values:** 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). This section was identical to the equivalent section in NVOS Part 1.
- **Your Household:** household demographic (e.g. education, income, home type). This section was identical to the equivalent section in NVOS Part 1.
- **Preparing for Your Driving Diary:** provided preparatory information about Part 2 and asked two additional questions about vehicle use and parking.

4.3.2. Driving Diary (PEVOS Part 2)

Part 2 was a five-day driving diary which asked respondents to record detailed trip and charging information. The objective of the driving diary was to develop a rich dataset of typical vehicle use and charging activity. The diary was administered on-line, although respondents were also given the option to complete the diary in print form.

Respondents that completed Part 1 were emailed a link to the driving diary as well as a guide to completing the diary a week prior to their diary start date. To ensure comprehensive coverage of weekday and weekend driving activity, assigned start dates for each participant were stratified across days of the week. The driving diary asked respondents to record detailed trip and charging information, including:

» PEV vehicle use: unlike NVOS, non-driving days were included in the diary.

» Electric battery state of charge: starting and ending range (in kilometers) for each trip.

» Trip start and end time: we were able to calculate trip duration with these values.

» Trip purpose: a list of common locations such as home, work, and school, were provided as options, along with an 'other' category.

» Trip location: respondents were asked to provide the address of their trip destinations (optional).

» Type of parking location: a list of parking location types (e.g. covered parking lot, carport, personal garage) were provided as options.

» Charging status: options included Level 1, Level 2, DC or not charging.

» Starting and ending odometer reading: to imply trip distance.

» Respondents were also asked about other vehicle use and gasoline consumption (for PHEV owners only) as well as reasons for not using their PEV on non-PEV-driving days.

Unlike NVOS, Part 2 of PEVOS did not include a recharge access questionnaire to estimate charging infrastructure upgrade costs for Part 3. Instead, cost estimates for charging infrastructure upgrades (from Level 1 to Level 2) for PEV owners with only Level 1 or no charging access were estimated from the average reported installation costs of PEVOS respondents.

4.3.3. Consumer Preference Design and Choice Survey (PEVOS Part 3)

The consumer preference design and choice survey assessed consumer preferences for vehicle features, green electricity and utility controlled charging using discrete choice experiments and design exercises. Part 3 of PEVOS is almost identical to Part 3 of NVOS, with some minor adaptations. As a result, we do not describe the design and theory supporting these survey components as they are detailed in Section 4.2.

To tailor Part 3 from the NVOS to the target sample in PEVOS (PEV owners) the following adjustments were made:

» The PEVOS vehicle design exercise, included an additional 320km option for the all-electric BEV. Incremental costs for the addition 320km BEV as well as the other vehicle options are summarized in Table 12. The PEVOS vehicle choice experiment was identical to the NVOS vehicle choice experiment (see Table 9 and Figure 5).

» Design exercise and choice experiments related to **"green" electricity and utility controlled charging** used the respondent's current PEV as the reference vehicle. In other words, respondents were presented with choices or design options for powering their current PEV with green electricity or for accepting some level of utility controlled charging with their current PEV (see Figure 6). In NVOS these exercises were completed with hypothetical PEVs. In addition, we used the respondent's current household electricity costs, provided in Part 1, as their 'monthly electricity bill' value in the design (Figure 6) and choice exercises (Table 11). In NVOS, an estimated PEV charging cost was added to respondents' current electricity costs to proxy 'monthly electricity bill' values with PEV charging.

» **Additional questions** about driving behaviour were included at the beginning of Part 3 of PEVOS. Also, an additional follow-up question to the vehicle design game was included. The question asked respondents if they would prefer the vehicle they designed in the design space exercise, or an already commercially available PEV as their next vehicle purchase; response data provided additional insight into vehicle preferences and potential drawbacks of existing PEV models (e.g. limited body size or range).

Aside from the adaptation noted above, the design and choice exercises used in the PEVOS were identical to the NVOS. Please refer to Section 4.2 for complete survey design, methodology, assumptions and theory details.

Table 12: PEV "Design space" exercise options and prices (prices incremental to respondents' next anticipated conventional vehicle).

	Higher Price				Lower Price			
Vehicle type	**Compact**	**Compact**	**Mid-SUV**	**Full-SUV**	**Compact**	**Sedan**	**Mid-SUV**	**Full-SUV**
Same as NVOS								
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
BEV-80	$6500	$7880	$10150	$12150	$3220	$3620	$4600	$5300
BEV-120	$8940	$10690	$13930	$16600	$4440	$5030	$6490	$7520
BEV-160	$11380	$13500	$17710	$21050	$5660	$6440	$8380	$9750
BEV-200	$13820	$16310	$21490	$25500	$6880	$7840	$10270	$11970
BEV-240	$16260	$19130	$25260	$29940	$8100	$9250	$12160	$14200
Only in PEVOS								
BEV-320	$21140	$24770	$32800	$38820	$10540	$12070	$15940	$18660

4.4. NVOS and PEVOS Interviews

To further support the reflexive nature of our approach we interviewed a subset of NVOS and PEVOS respondents about their perceptions of PEVs and utility controlled charging. In-person qualitative interviews can further the understanding of respondent preferences and provide important insight into individual (and household) motivations and decision-making processes. For example, this approach allows space for complex, complete, and unanticipated answers (Auerbach & Silverstein, 2003; McCracken, 1988).

With qualitative interviews, participants are able to provide any data they see as relevant, and to provide those data in their own words, without being limited to predetermined categories. Participants also provide non-verbal data, intentionally or otherwise, such as through facial expressions, tone of voice, or pauses in speech. Further, the interactive elements of this method give participants the opportunity to think through and develop their responses, and that process itself can also be observed and documented.

4.4.1. NVOS Interviews

The NVOS interviews were semi-structured following the general principles and procedures described by McCracken (1988) and others. Each interview was carried out in the participants' own homes and ranged from 1.5 to 2.0 hours in duration. A basic outline of topics was used to guide the interviews, but questions were open-ended and we allowed the conversation to flow in a generally natural manner. The following topics were addressed in the interviews:

- Opening: The interview opened with a review of participants' rights, description of the interview, and an explanation of the consent forms.
- Vehicle ownership: a discussion of households' current vehicle ownership, and recent and anticipated vehicle purchase decisions.
- PEV knowledge: a discussion of different vehicle types and participants' knowledge and experience (or lack of) with these vehicles.
- PEV design game: participants were then provided with information about the different vehicle types and asked to complete a vehicle design game adapted from NVOS Part 3 (see Section 4.2) and described below.
- Knowledge of electricity sources: Participants were also asked about their knowledge of electricity sources and the current electricity system in British Columbia and then provided with a basic explanation of both.
- Utility controlled charging (UCC) design game: Participants then completed another set of design games related to utility controlled charging and green electricity.
- Participant characteristics: The interview closed with a discussion about participants' values, lifestyles, and environmental concerns.

The interview design games (vehicles and green electricity) were similar to those used in Part 3 of the NVOS, but were simplified for ease of application (see Section 4.2 for theory). Outputs from the games provided qualitative data on respondents' vehicle preferences as well as perceptions of UCC and green electricity. The games involved numerous options, trade-offs, and comparisons and were tailored to each household by incorporating data collected in Parts 1—3 of the NVOS. Table 13 below shows an example of the design space presented to a participant who indicated in Part 3 of the survey that a $25,000 Honda Civic was their next likely vehicle purchase.

In the interview design game, the participant was presented with essentially 10 different vehicle designs options – a regular (CV) Honda Civic, as well as an HEV, PHEV or BEV version of the Civic; BEV and PHEV versions were presented with a range of batter sizes. The implications of each design with regards to range, recharging or refueling time, fuel efficiency, and price were all presented for comparative consideration. As these games were completed, the interviewers continually asked participants to 'talk them through' their choices. In this way the design games served to facilitate discussion as well as to elicit data regarding participants' preferences and related perceptions.

Table 13: Example PEV design game attributes from interviews

Vehicle type	Electric Range	Recharge or Refuel Details	Gasoline Fuel Use	Purchase Price
Regular (CV)	none	Gas station,5 minutes	7.1L/100 km	$25,000
Hybrid (HEV)	none	Gas station, 5 minutes	4.3L/100 km	$26,070
Plug-in hybrid (PHEV)	Electric for the first: 16 km	3.0 hrs to charge from empty to full	None during battery range; 4.3L/100 km after	$27,100
	Electric for the first: 32 km	6.0 hrs to charge from empty to full		$27,440
	Electric for the first: 64 km	12.0 hrs to charge from empty to full		$28,130
Battery electric (BEV)	80 km	15.0 hrs to charge from empty to full	None	$29,600
	120 km	22.5 hrs to charge from empty to full		$31,490
	160 km	30.0 hrs to charge from empty to full		$31,440
	200 km	37.5 hrs to charge from empty to full		$33,380
	240 km	45.0 hrs to charge from empty to full		$37,160

We also used a design game to facilitate discussion of UCC and elicit data regarding participants' preferences and perceptions of the concept. The games were scaled-down versions of those used in NVOS, and used a simplified definition of guaranteed minimum charge. We presented guaranteed minimum charge without reference to time of day; in Part 3 it was presented in the context of overnight charging.

The UCC design games involved first choosing a preferred source of green electricity (either solar, wind, small hydro, or a mix of these) and then selecting a level of guaranteed minimum charge to represent the inconvenience participants were willing to accept to facilitate more green electricity. A greater willingness to accept UCC was represented by a lower guaranteed minimum charge (i.e. less charge). Table 14 shows the design game options presented to interview participants.

Table 14: Interview UCC design game options

Attributes	Status Quo	Design
Percentage of Green Electricity: Percentage of current electric supply powering the respondents' home and vehicle.	0%	25% 50% 75% 100%
Guaranteed Minimum Charge: The amount of charge that the vehicle's battery would have 'the next morning'. This was displayed to the respondent as both percentage charge and electric range in km.	100% charge	25% charged 50% charged 75 % charged 100% charged
Monthly Electricity Bill: Current bill or with green electricity, user's current electric bill plus the expected cost of charging a vehicle multiplied by a scalar.	Current bill provided by respondent	Current bill provided by respondent

4.4.2. PEVOS Interviews

Like NVOS, interviews were also conducted with a subsample of PEVOS participants. The interview protocol was adapted from the NVOS interview protocol and thus has a similar structure and flow. Each interview was carried out in participants' homes and ranged from 1.5 to 2.0 hours in duration. The following topics were addressed in the interviews:

» Opening: a review of participants' rights, description of the interview, and an explanation of the consent forms.

» PEV purchase: a discussion on the household's PEV purchase (purchase process and purchase motivations) and perceived benefits and limitations of their vehicle. Participants were also asked about their perceptions of other PEV models (e.g. Volt, Leaf, Tesla).

» Recharge and driving behaviour and perceptions: a series of questions designed to facilitate discussion about their experience and perceptions of operating and recharging their PEV.

» Image, charging and UCC exercises: Participants also participated in three exercises related to their vehicle's image, public charging and UCC design. These exercises are described below.

» Lifestyle: The interview closed with a discussion of participants' lifestyles, leisure activities, interests, and values.

Participants completed three exercises in the PEVOS interviews: a vehicle image, public charging and UCC design exercise. The first exercise asked participants to select two or more pictures that expressed their thoughts and feelings about their electric vehicle. The second exercise asked participants to consider five locations where they would benefit from additional charging stations. The third exercise, UCC design games identical to those used in NVOS interviews, asked participants about their willingness to participate in a UCC program. Outputs from the three exercises were used to collect qualitative data on vehicle symbolism, charging needs, and UCC perceptions.

4.5. Data Analysis

As discussed in the previous sections, the Canadian Plug-in Electric Vehicle Study used several survey tools and instruments to collect data from Mainstream vehicle buyers (NVOS) and Pioneer PEV owners (PEVOS). The result is a large dataset from which we can draw a wide range of analyses of Early Mainstream, Late Mainstream and Pioneer PEV buyers. We use a variety of methods to analyze this data, but do not have the space to completely detail each analysis in this report. Here, we provide brief summaries of the main types of analyses that we utilized for this report:

» **Frequency analysis** provides basic counts and distributions of data points. For example, the number of respondents indicating awareness of PEV models and public chargers, or access to Level 2 home charging, as reported in Sections 6 and 7, were obtained using frequency analysis.

» **Driving and recharge models** were constructed based on data collected from respondent driving diaries and home recharge assessments (NVOS only). These data were used to generate profiles of vehicle and charging behavior, including statistics on distance travelled, charging use and anticipated charging access and demand (based on a set of assumption).

» **Interest in PEVs** was elicited from respondents by allowing them to design their ideal next vehicle. Stated interest in PEVs was an important factor in identifying the Early and Late Mainstream PEV buyers, and providing insight into the types of vehicles consumers are interested in. In Section 8, we explore participants' vehicle interests and the narratives underlying their decisions.

» **Discrete choice models** collect choice data from respondents via a choice experiment (as detailed in Section 4.2). Choice sets are constructed after determining the range of attributes and attribute levels that are to be tested. Based on respondent choices in the discrete choice survey, a discrete choice model is estimated to statistically quantify how respondents make trade-offs between different attributes and product options.

» **Consumer segments** – Consumers can be segmented into groups of individuals with similar characteristics such as interests or demographics. Throughout the report we look at key differences between consumer groups, as well as the heterogeneity within each group, in terms lifestyles, values, motivations and preferences (see Sections 8 and 10). Specifically, we use four different types of segmentation analysis:

  » **"Known class" or "known cluster" segmentation** occurs when the researcher manually determines which segment each respondent belongs to. For example, in Section 3.3 we introduced three important PEV buyer segments which group consumers according to their interest in PEVs. In this report, we use data from the design space exercise to differentiate the Early Mainstream NVOS respondents from the Late Mainstream respondents.

  » **Cluster analysis** is a quantitative segmentation method that takes a number of respondent variables (e.g. values or lifestyle) and constructs some number of segments (or clusters) where members of each cluster are relatively homogenous, while the average characteristics of each segment are significantly different from one another. In this report, we conduct cluster analysis using the K-means method in SPSS 14.0.

  - **Latent class modeling** is a type of discrete choice modeling that identifies multiple segments (or classes) of respondents, and estimates different coefficients and willingness-to-pay values for each cluster. In this report we conduct latent class analysis using the Latent Gold software package.
  - **Qualitative segmentation** occurs in an interview-based study when the researcher places interview participants into different segments based certain characteristics using theory or researcher judgement. For example, interviewed households might be categorized according to PEV interest or engagement in pro-environmental activities.

- **Content analysis** analyzes interview data by coding different phrases and content based on themes. Themes might be derived from theory, from the data itself, or a combination of both. Researchers in this study use NVIVO software to code interview transcripts.
- **Modeled GHG emissions from PEVs** can be estimated from driving and charging potential profiles of PEV consumer segments, combined with analysis of regional electrical grids. In Section 13, we estimate the potential GHG impacts of different scenarios of PEV adoption among Early Mainstream PEV buyers.
- **PEV market share forecasts** can be simulated using a variety of techniques. A basic discrete choice model can simulate vehicle market share for a particular choice set, though this method tends to neglect real-world supply constraints. In Section 14 we explore scenarios of future PEV adoption using a discrete choice model that takes into account realistic constraints on the demand side (e.g. limited consumer familiarity or awareness) and the supply-side (e.g. limited variety of PEV models or limited availability of PEVs in vehicle dealerships).

5. Sample Details: New Vehicle Buyers and PEV Owners

Research highlights for Section 5

To better understand the current and anticipated PEV market we look at the demographics, lifestyles, and values of current PEV and new vehicle owners. Data for this study were collected from two samples of vehicle owners: the Mainstream (new vehicle owners) and "PEV Pioneer" (PEV owners). Comparing data across these two samples reveals some interesting insights.

Among Mainstream (NVOS) respondents in British Columbia and Canada we find that:

» Participants tend to be older, higher income and more highly educated than the general Canadian Census population.

Among PEV Pioneer (PEVOS) respondents we find that:

» Participants tend to have higher education and income, and are more likely to be male and to own their own home, than the British Columbia Mainstream sample.

» Participants tend to have higher engagement in technology- or environment-oriented lifestyles, and higher levels of environmental concern than the British Columbia Mainstream sample.

» Over 80% own either the Nissan Leaf (46%), Chevrolet Volt (24%), or Tesla Model S (10%).

» Tesla owners report the highest income and education, and are most likely to be in the 55—64 age range.

As explained in Section 3.3, we divide the total market of potential PEV buyers into three segments: Pioneers (very early buyers), the potential Early Mainstream, and the Late Mainstream. In this study, we collected data from households in the potential Early and Late Mainstream or the Mainstream through the New Vehicle Owners Survey (NVOS, 2013), and PEV Pioneers through the Plug-in Electric Vehicle Owner Survey (PEVOS, 2015). We describe both samples below.

5.1. Mainstream New Vehicle Owner Sample (NVOS)

We hired a market research company (Sentis Market Research) to recruit survey respondents for NVOS (2013). Screener data was collected to ensure that the realized sample would match the target population (new vehicle buying households in Canada) in terms of basic demographic information, e.g. income, education and age and gender. Interview participants were recruited from a sub-set of British Columbian participants. The full Canadian survey sample included all provinces except for Quebec.

In total, 1754 respondents completed all three part of the survey, with oversamples in Alberta (n = 326) and British Columbia (n = 538). We oversampled British Columbia 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. Figure 9 shows the geographic distribution of respondents. Because collected data was missing or inappropriate in some survey sections, some parts of this analysis draw from different subsets of the total sample (as will be noted in the text).

Demographic data on the target population (new vehicle owners in Canada) is not accessible, so we compare our NVOS sample to Canadian Census data representing the general population (Table 15). As is typical of new vehicle buying households, our NVOS sample is slightly older, and has higher education and income than the general population.

As this report focuses on the British Columbia sample, we provide a brief comparison of this sample to the corresponding Census data for the general British Columbia population:

- **Age:** NVOS respondents are generally older than the Census, which aligns with previous studies and data on new vehicle buyers in the US (Axsen and Kurani, 2010; Harris-Decima, 2013).
- **Education:** NVOS respondents are more likely to have a higher education than the general population, which is characteristic of new vehicle buyers (Busse et al., 2013).
- **Income:** NVOS respondents tend to report higher income than the Census, which is typical of new vehicle buyers (Busse et al., 2013).
- **Home ownership:** NVOS 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.

Table 15 compares the realized sample distributions from the British Columbia survey and interview, as well as the larger Canada survey, to the corresponding Census data distributions. Overall, we are confident that the realized sample is representative of new vehicle buying households in British Columbia and in English-speaking Canada (i.e. excluding Quebec).

Table 15: Sample representativeness: Mainstream sample demographics and the Census

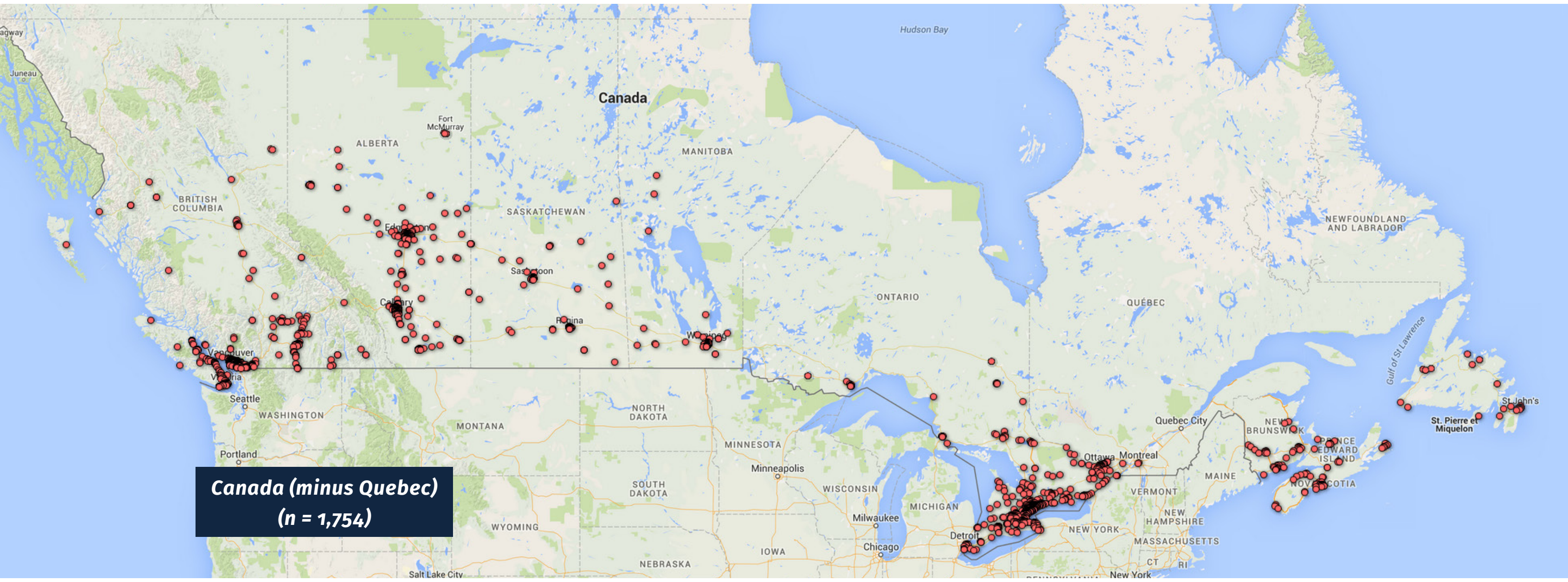
Region	Mainstream Sample				
	British Columbia			Canada	
	Survey (Part 3)	Interview	Census	Survey [a] (Part 3)	Census
Sample Size	538	22	4,400,057	1,754	33,476,688
Household Size					
1	15%	36	28%	13%	28%
2	42%	23%	35%	40%	34%
3	19%	14%	15%	21%	16%
4+	24%	27%	22%	26%	23%
Sex (of person filling out the survey)					
Female	61%	55%	51%	58%	51%
Age (of person filling out the survey)					
under 35	26%	23%	30%	30%	31%
35—44	19%	23%	18%	18%	16%
45—54	20%	18%	20%	20%	19%
55—64	20%	32%	19%	19%	16%
65+	15%	5%	13%	13%	18%
Highest level of education completed (of person filling out the survey)					
Other	29%	18%	59%	25%	60%
College, CEGEP, some university or other non-univ. diploma	34%	9%	22%	37%	22%
University degree (Bachelor)	27%	64%	14%	26%	14%
Graduate or professional degree	11%	9%	5%	12%	5%
Household income (pre-tax)					
Less than $40,000	17%	18%	26%	15%	25%
$40,000 to $59,999	22%	9%	19%	21%	19%
$60,000 to $89,999	29%	32%	24%	28%	24%
$90,000 to $124,999	24%	27%	17%	25%	17%
Greater than $125,000	9%	14%	14%	12%	15%
Residence ownership					
Own	76%	68%		78%	69%
Rent	24%	32%		22%	31%
Residence type					
Detached House	62%	46%	54%	67%	62%
Attached House (e.g. townhouse, duplex, triplex, etc.)	15%	5%	23%	15%	17%
Apartment	21%	50%	21%	16%	20%
Mobile Home	2%	0%	2%	2%	1%

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 9: Geographical representation of the Canadian survey sample by postal code (n = 1754, full map: http://goo.gl/l55BtA)



Mainstream NVOS interview sample

To complement the NVOS survey, interview participants were drawn from survey respondents residing in the Metro Vancouver region of British Columbia, which includes a group of cities and municipalities near the city of Vancouver with a combined population of over 2.4 million. We followed a purposive selection process with the aim of accessing the experiences of as wide of an array of new vehicle buying households as possible, including a range of ages and incomes. As well, early interviews indicated that access to a reliable home parking space was critical to participants' abilities to conceptualize PEV charging scenarios; we consequently limited participation to those with an assigned home parking space for one or more of their vehicles.

The interviews were conducted between August 2013 and February 2014. Each interview was between 1 and 2 hours long and attended by two researchers. All interviews were conducted in the participants' homes except in one case where the interviewee opted to meet in a local café. When possible, we conducted interviews with all members of the household who would likely be involved in decisions regarding the technologies discussed in the interview (e.g. vehicles, electricity generation, utility controlled charging). In total we interviewed 31 individuals – 17 women and 14 men – representing 22 households. An audio recording was made of each interview to be transcribed later using a professional transcription service.

Table 15 describes the distribution of NVOS survey and interview participants. In terms of the distribution of British Columbia-specific demographic data, the group of interview participants tended to be of higher income than the Census population, slightly older than the NVOS sample and significantly more highly educated than both the Census population and the NVOS sample. It can also be noted that participants came from a variety of cultural and ethnic backgrounds.

5.2. PEV Pioneer Sample (PEVOS)

To collect data from actual PEV owners in British Columbia for the PEVOS, we recruited respondents from three sources. We detail each source's membership base here:

- Clean Energy Vehicle for BC Program participants were PEVs owners living across British Columbia who received a rebate for the purchase of their vehicle or home charging station. In total, the program had 950 participants; our survey invitation was sent to a sub-set of approximately 340 participants.
- Vancouver Electric Vehicle Association (VEVA) members were primarily PEV owners (and some non-PEVs owners) who live in and around Metro Vancouver. Survey invitations were sent to VEVA's 180 members via its mailing list. A link to the survey invitation was also posted on the VEVA webpage.
- The British Columbia Emotive Campaign members were individuals with Facebook accounts who 'follow' Emotive on Facebook; the majority of its 1, 800 members reside in British Columbia. A brief description of the survey and a link to the invitation were posted several times on the Emotive Facebook page in October of 2014.

Invitations to participate in the PEVOS were provided to participants and members of the groups described above. These invitations outlined the multi-phased survey process and provided details on study objectives, eligibility, confidentiality and compensation. Eligible participants registered for the survey directly using a link provided in the invitation. Once registered, participants were sent a link to Part 1 and were asked to complete the survey within three weeks.

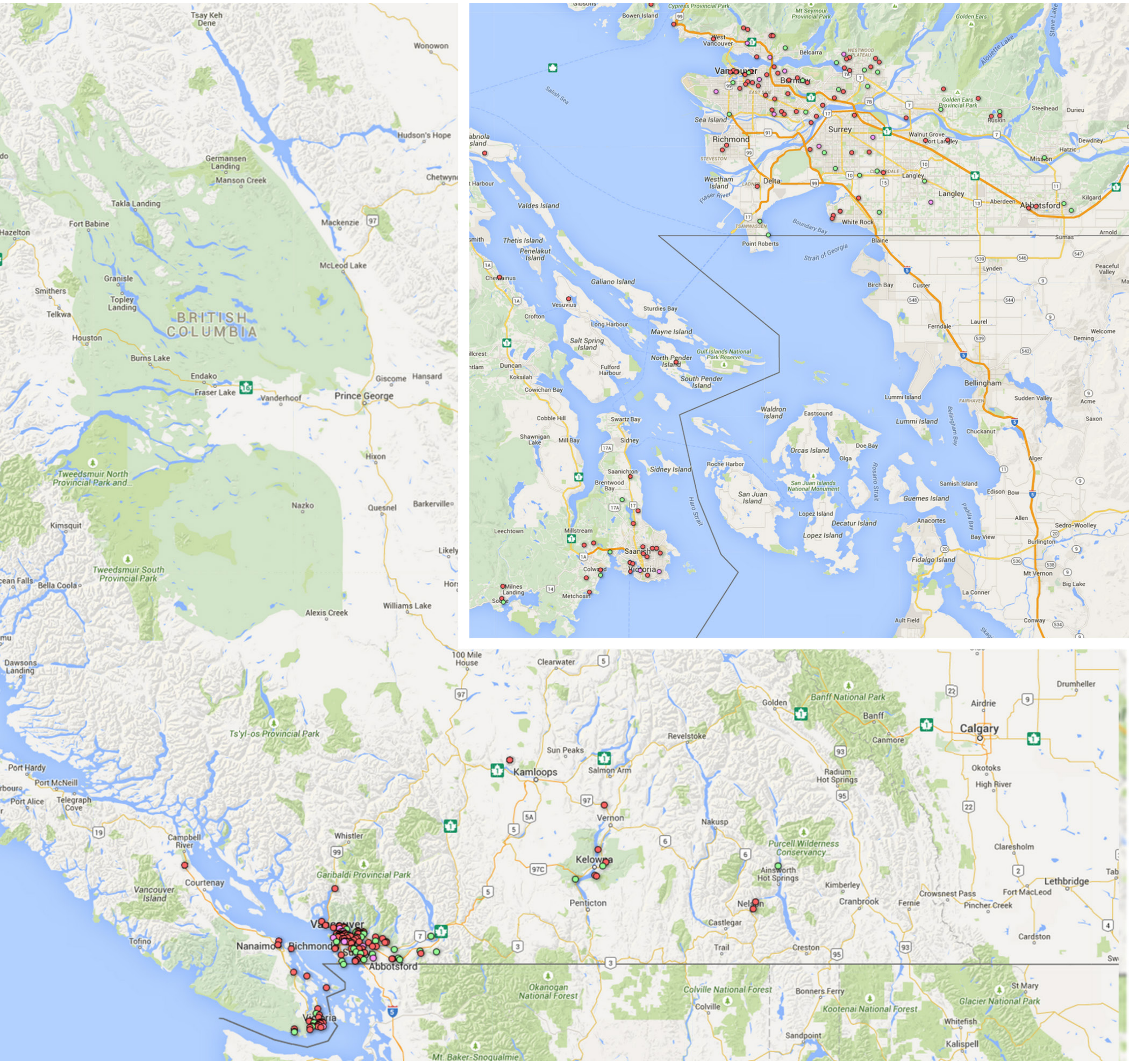
To participate in the survey, participants had to be a resident of British Columbia and own a commercially available PEV; owners of aftermarket PEV vehicle conversions or owners of 2-wheeled electric vehicles (e.g. bikes or scooters) were not part of our target population. In total, 94 respondents completed all three parts of the survey, with 157 completing Part 1 and 110 completing Part 2. To maximize the value of these data, we draw on different subsets (i.e. participants of Part 1, Part 2 or Part 3) of the total sample throughout out this report—as key demographic distributions are nearly identical across respondents of Parts 1, 2 and 3. Our PEVOS sample represents just over 10% of the total number of British Columbian residents that purchased a PEV up to 2015.

Table 16 compares PEV Pioneer (PEVOS) respondents with Mainstream (NVOS) respondents from British Columbia. Based on similar studies of PEV owners in other jurisdictions, we expected our sample to differ substantially from both the Mainstream sample and the general population (Tal and Nichols, 2013; ICF, 2012; CCSE, 2014). Comparing PEVOS data to the corresponding British Columbia NVOS data, we find that:

- **Education:** PEVOS respondents are more likely to have a higher education;
- **Income:** PEVOS respondents tend to have higher incomes;
- **Home ownership:** PEVOS respondents are more likely to own a home, and are more likely to live in detached (single family) homes; and
- **Gender:** PEVOS respondents are more likely to be male.

The geographic distribution of Part 1 participants is illustrated in Figure 10.

Figure 10: Geographical representation, by postal code and vehicle type, of respondents to Part 1 of the PEVOS (n = 157, full map: http://goo.gl/DfUysx)



Coloured dots represent different vehicle makes and models: Nissan Leafs (pink), Chevrolet Volt (green), Tesla Model S (purple), Other Brands (yellow). Combined, the Nissan Leaf, Chevrolet Volt and Tesla Model S represent 82% of the sample.

Table 16: Pioneer (PEVOS) and Mainstream (NVOS) British Columbia sample demographics

British Columbia Samples			
	Pev Pioneer		Mainstream
	Survey (Part 1)	Interview	Survey (Part 3)
Sample Size	157	19	538
Household Size			
1	8%	0%	15%
2	39%	38%	42%
3	19%	31%	19%
4+	34%	31%	24%
Sex (of person filling out the survey)			
Female	18%	37%+	61%
Age (of person filling out the survey)			
under 35	11%	21%+	26%
35—44	24%	16%+	19%
45—54	26%	21%+	20%
55—64	29%	32%+	20%
65+	10%	10%+	15%
Highest level of education completed (of person filling out the survey)			
Other	20%	16%*	29%
College, CEGEP, some university or other non-univ. diploma	22%	15%*	34%
University degree (Bachelor)	28%	23%*	27%
Graduate or professional degree	30%	46%*	11%
Household income (pre-tax)			
Less than $40,000	17%	0%	17%
$40,000 to $59,999	5%	0%	22%
$60,000 to $89,999	11%	8%	29%
$90,000 to $124,999	24%	46%	24%
Greater than $125,000	43%	46%	9%
Residence ownership			
Own	92%	85%	76%
Rent	8%	15%	24%
Residence type			
Detached House	79%	77%	62%
Attached House (e.g. townhouse, duplex, triplex, etc.)	12%	15%	15%
Apartment	8%	8%	21%
Mobile Home	1%	0%	2%

\+ Age and sex distributions include all interview participants, not just the participant who completed the survey (n = 19)

* Education levels for interview participants are only known for person filling out survey (n = 13)

PEVOS Vehicle Ownership

Of the 157 respondents that completed Part 1 of PEVOS, total ownership of PEVs was 164; seven participants owned more than one PEV. Figure 11 depicts the percentage of PEV participant ownership by vehicle make and model. About 80% of PEV ownerships is accounted for by three models: the Nissan Leaf (46%), Chevrolet Volt (24%) and Tesla Model S (10%). This is reflective of Canada-wide PEV ownership, where these three models account for just over 70% of all PEV sales (as of 2015).[10]

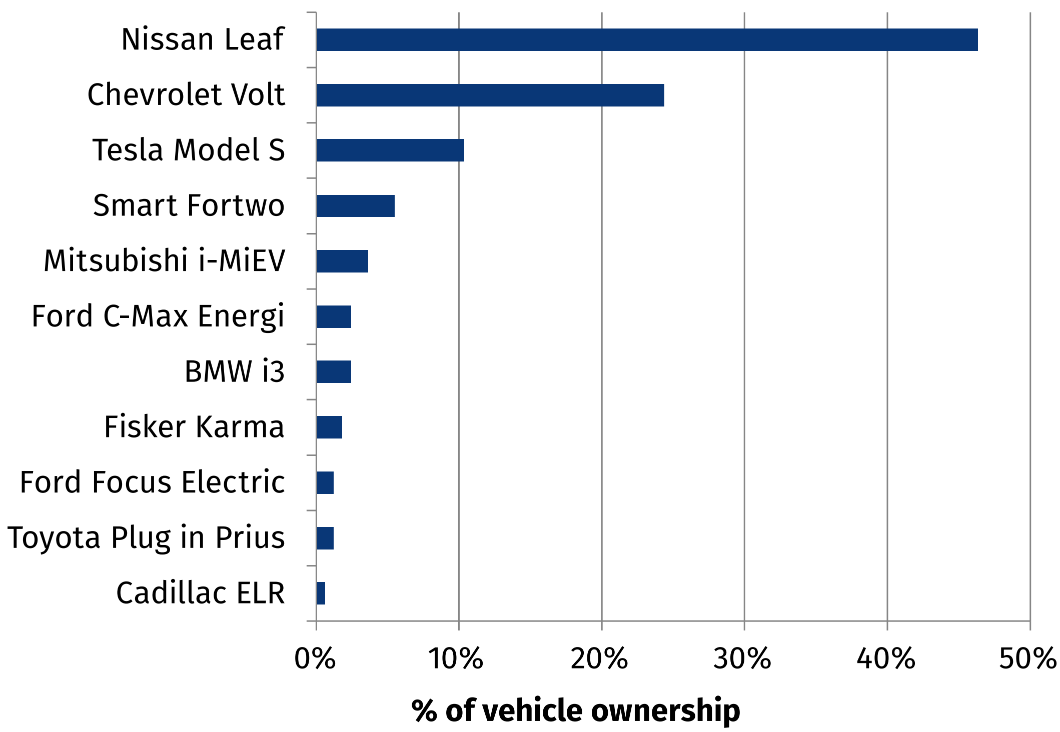
Table 17 presents selected demographic data for our three largest owner groups, the Nissan Leaf (herein the Leaf), the Chevrolet Volt (herein the Volt) and the Tesla Model S (herein the Tesla). While we have identified several differences between NVOS and PEVOS respondents, there are also interesting differences among PEV owners when broken down by PEV model, including:

» **Education:** Tesla owners are most likely to have higher education levels, followed by Leaf and Volt owners.

» **Income:** Tesla owners report significantly higher income levels, followed by Volt and Leaf owners.

» **Age:** Tesla owners are most likely to be between the ages of 55—64, while Leaf buyers are more likely to be under the age of 45.

Figure 11: PEVOS Participant PEV ownership, by vehicle type (n = 164)



10. Market share data were derived from sales data in the "Canadian EV Sales" spreadsheet maintained by Matthew Klippenstein for GreenCarReports. Available at www.tinyurl.com/CanadaEVSales.

Table 17: Volt, Leaf and Tesla owner group demographic data

British Columbia PEV Pioneer Sample	Volt (n = 38)	Leaf (n = 74)	Tesla (n = 16)
Sample Size	38	74	16
Highest level of education completed (of person filling out the survey)			
Other	31%	12%	13%
College, CEGEP, some university or other non-univ. diploma	19%	26%	6%
University degree (Bachelor)	17%	36%	31%
Graduate or professional degree	33%	26%	50%
Household income (pre-tax)			
Less than $40,000	5%	18%	13%
$40,000 to $59,999	0%	7%	0%
$60,000 to $89,999	16%	11%	0%
$90,000 to $124,999	32%	22%	19%
Greater than $125,000	47%	43%	69%
Age (of person filling out the survey)			
under 35	15%	10%	0%
35—44	17%	34%	27%
45—54	39%	29%	33%
55—64	22%	21%	40%
65+	8%	6%	0%
Other non-PEV vehicles			
0	11%	19%	6%
1	63%	65%	69%
2	24%	14%	13%
3 or more	3%	3%	13%

PEV Pioneer PEVOS Interview Sample

We conducted interviews with a subsample of PEVOS respondents that completed all three sections of the PEVOS. As of March 2015, 13 household interviews have been completed (19 participants), with an expected total of 16—21 interviews by the summer of 2015.

Participants were recruited for the interviews using the same purposeful selection method, as was done for the NVOS interviews. Accordingly, the PEV owner sample was selected to contain participants that varied by characteristics such as income, age, and household size. The PEVOS interview sample was also selected to include a variety of PEV models (i.e. Chevrolet Volt, Nissan Leaf, and Tesla Model S). All participating households resided in Metro Vancouver. Where possible, each interview included all members of a household that were involved in the purchase of the PEV, or regularly used the PEV.

Table 16 compares the PEVOS interview sample to the larger PEVOS sample and British Columbia Census data. The distribution of socio-economic and demographic variables is fairly similar between the two samples.

5.3. Comparing Market Segments in British Columbia

Here we compare our insights into PEV Pioneer (as indicated by our PEVOS sample) demographics, lifestyles and values to potential Early and Late Mainstream PEV buyers (as indicated by our NVOS sample). We categorize the NVOS sample into Early or Late Mainstream PEV buyers according to respondents' vehicle design in Part 3 of the survey. Respondents that selected some sort of PEV design in the lower price scenario of the design space exercise in Part 3 are categorized as the "potential Early Mainstream" PEV buyers, while the remaining respondents are categorized as "potential Late Mainstream" PEV buyers. It is important to distinguish between these three groups, as such differences can hold important implications for outreach efforts and the design of policy to support PEV deployment.

Table 18 and Table 19 summarize these three segments according to variables measuring demographics, lifestyle and values (from our British Columbia samples). In terms of demographics, PEV pioneers report the highest levels of household income (especially above $150k), education (especially at the graduate level) and are the most likely to live in a single family detached home that they own. In contrast, the Early and Late Mainstream PEV segments are fairly similar to one another. The two segments report similar incomes and home ownership rates; however, the Early Mainstream is slightly younger, more educated, and less likely to live in an apartment than the Late Mainstream.

Table 18: Demographic profiles of PEV Pioneers, Early Mainstream and Late Mainstream (British Columbia samples only)

British Columbia Samples			
	PEV Pioneer (Part 1)	**Early Mainstream** (Part 3)	**Late Mainstream** (Part 3)
Sample Size	157	215	323
Age (of person filling out the survey)			
under 35	11%	30%	26%
35—44	24%	20%	19%
45—54	26%	20%	20%
55—64	29%	18%	20%
65+	10%	12%	15%
Highest level of education completed (of person filling out the survey)			
Other	20%	24%	32%
College, CEGEP, some university or other non-univ. diploma	22%	34%	34%
University degree (Bachelor)	28%	30%	24%
Graduate or professional degree	30%	12%	10%
Household income (pre-tax)			
Less than $100,000	31%	77%	77%
$100,000 to $124,999	20%	13%	14%
$125,000 to $150,000	18%	5%	5%
Greater than $150,000	31%	5%	4%
Residence ownership			
Own	92%	78%	74%
Rent	8%	22%	26%
Residence type			
Detached House	79%	65%	59%
Attached House (e.g. townhouse, duplex, triplex, etc.)	12%	16%	14%
Apartment	8%	17%	24%
Mobile Home	1%	2%	2%

We also compare the three samples according to engagement in different lifestyles, environmental concern, life liminality (or openness) and values – we measured participant engagement in Part 1 of the survey using a lifestyle and attitude-based assessment and a condensed version of the New Environmental Paradigm (NEP) scale. Table 19 compares results where each construct uses a different scale. While the average score for one segment is not meaningful, the comparison of average scores across segments is interesting.

Table 19: Lifestyle and values for PEV Pioneer, Early Mainstream and Late Mainstream (British Columbia samples only, average scores for each question scale)

British Columbia Samples	PEV Pioneer (Part 1)	Early Mainstream (Part 3)	Late Mainstream (Part 3)
Sample Size	157	215	323
Lifestyle Engagement			
Technology Orientation (0—25)	17.0	13.8	12.9
Environmental Orientation (0—25)	15.4	13.2	11.8
Attitudes			
Liminality/Openness (-18 - +18)	0.8	1.1	0.9
Environmental Concern (-16 - +16)	8.0	6.5	5.4
Values			
Traditional Values (0—12)	9.7	10.2	10.3
Egoist Values (0—12)	5.5	6.9	6.9
Biospheric Values (0—12)	9.5	9.4	9.1
Altruistic Values (0—12)	9.9	10.1	10.0

As with the demographic variables, we find that Pioneer respondents are distinct from Mainstream respondents in that they have the:

- Highest average engagement in an environment-oriented lifestyle (using the lifestyle scale from Axsen et al. (2012)),
- Highest average engagement in a technology-oriented lifestyle (using the lifestyle scale from Axsen et al. (2012)),
- Highest average level of concern about the environment (using the New Ecological Paradigm scale from),
- Lowest, only slightly, traditional values and egoistic values on average.

Other studies have also found that PEV Pioneers tend to be more pro-technology and pro-environmental than other consumers (Axsen and Kurani, 2013a). For most of these technology and environmental variables, the "Early Mainstream" respondents tend to have scores that are higher than those of the "Late Mainstream" respondents. Interestingly, scores are fairly similar across all three segments in terms of lifestyle liminality (openness in lifestyle), biospheric values and altruistic values.

In summary, we find that there are important differences among these segments in terms of demographics, lifestyle and values. These differences are likely to translate into different motivations and interests relating to PEVs and green electricity. Section 8 provides further analysis of different motivations among the Mainstream and PEV Pioneer samples.

6. PEV Awareness

Research Highlights for Section 6

According to the reflexive theory, consumers develop preferences as they learn about new products and technologies. We thus assess the initial awareness of Mainstream and PEV Pioneers to compare each samples' understanding of (or confusion with) PEV technologies. Through this comparison, we see significant differences in the level of technological awareness between the two samples.

Among Mainstream (NVOS) respondents in British Columbia we find that:

» PEV understanding is low, with a minority correctly identifying how to fuel the Toyota Prius (18%), the Chevrolet Volt (29%), and the Nissan Leaf (31%).

» None of the respondents interviewed (n = 22) had direct experience with a BEV, and only a few had direct experience with a PHEV (as either a passenger or driver).

» Most Mainstream respondents did not know that PHEVs existed, and had trouble understanding the "dual fuel" concept.

Among PEV Pioneer (PEVOS) respondents we find that:

» PEV understanding is considerably higher, with the vast majority knowing how to fuel a Chevrolet Volt and Nissan Leaf.

As noted in Section 3, consumers develop preferences as they learn about technologies, which can also translate to purchase intention. Previous research indicates that new vehicle owners are generally unfamiliar with PEVs and tend to be confused about their attributes (Caperello and Kurani, 2012; Kurani et al., 1994). Thus, consumers might not be able to develop preferences or interest in a new technology if they are unaware of it, or if they are confused about its basic functions.

In this section we investigate consumer awareness of PEVs among our British Columbia sample of Mainstream new vehicle owners (NVOS) and PEV Pioneers (PEVOS). In this analysis we explore participants' pre-existing or initial awareness of PEV technologies and brands — that is, before learning about PEVs in Parts 2 and 3 of the survey. We also derive further insight into PEV awareness and confusion from Mainstream interview participants.

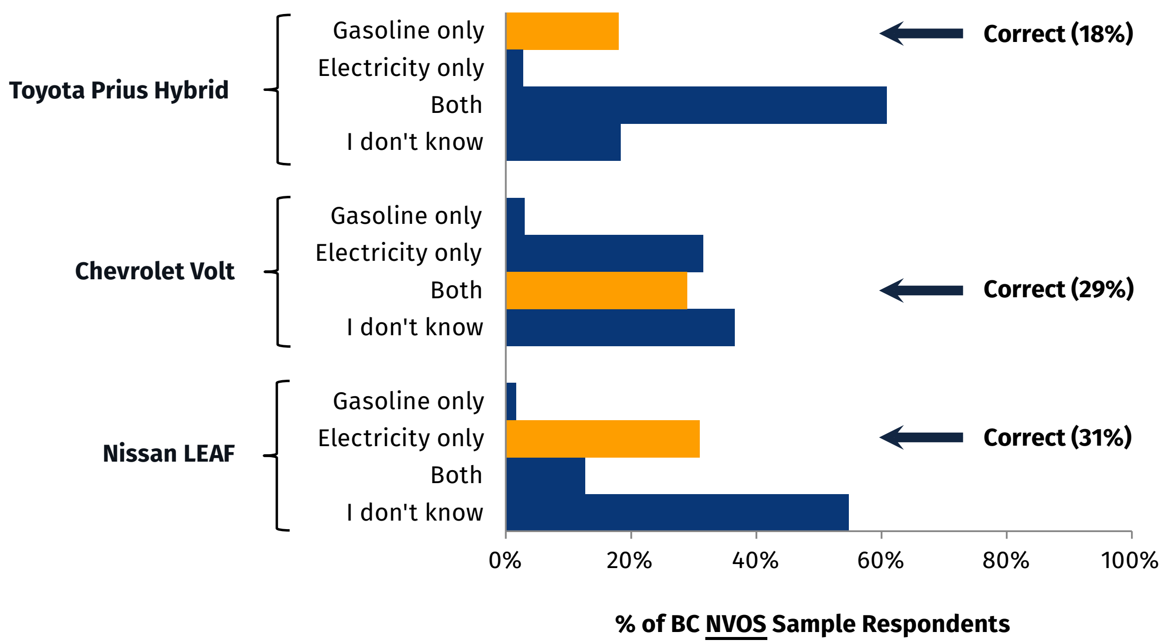
6.1. Mainstream PEV Awareness

In this section we assess pre-existing knowledge of PEV brands and technologies among our British Columbia sample of Mainstream respondents. Survey questions related to awareness were answered before respondents were provided with information about PEVs in Parts 2 and 3 of the survey. As described in Section 4, educational material (i.e. the "Buyer's Guide") was provided to each respondent before eliciting vehicle preferences. To determine PEV awareness, Part 1 of the NVOS survey assessed:

- Respondent **familiarity with three different vehicle models**: the Toyota Prius (HEV), the Chevrolet Volt (PHEV), and the Nissan Leaf (BEV)
- Respondent **knowledge of how each vehicle is fuelled**, that is, if it can be fuelled by gasoline only, by electricity only (by plugging in), or by either gasoline or electricity.

Most respondents indicated that they were at least somewhat familiar with the Toyota Prius (78%) and the Chevrolet Volt (55%), and less familiar with the Nissan Leaf (37%). When asked about how the vehicle types can be fuelled, the majority (>68%) of respondents demonstrated confusion with each of the three vehicle models (Figure 12). Only 18% successfully indicated that the (conventional HEV) Prius can be fuelled only by gasoline, and less than one third successfully describe the Volt (as a PHEV) and the Leaf (as a BEV). This clear lack of knowledge with PEV technology supports our present methodology—where we educate respondents about PEVs before eliciting their interests and preferences.

Figure 12: Mainstreams' responses to question: "How do you think each of the following vehicles can be fuelled?" (British Columbia sample, n = 538)

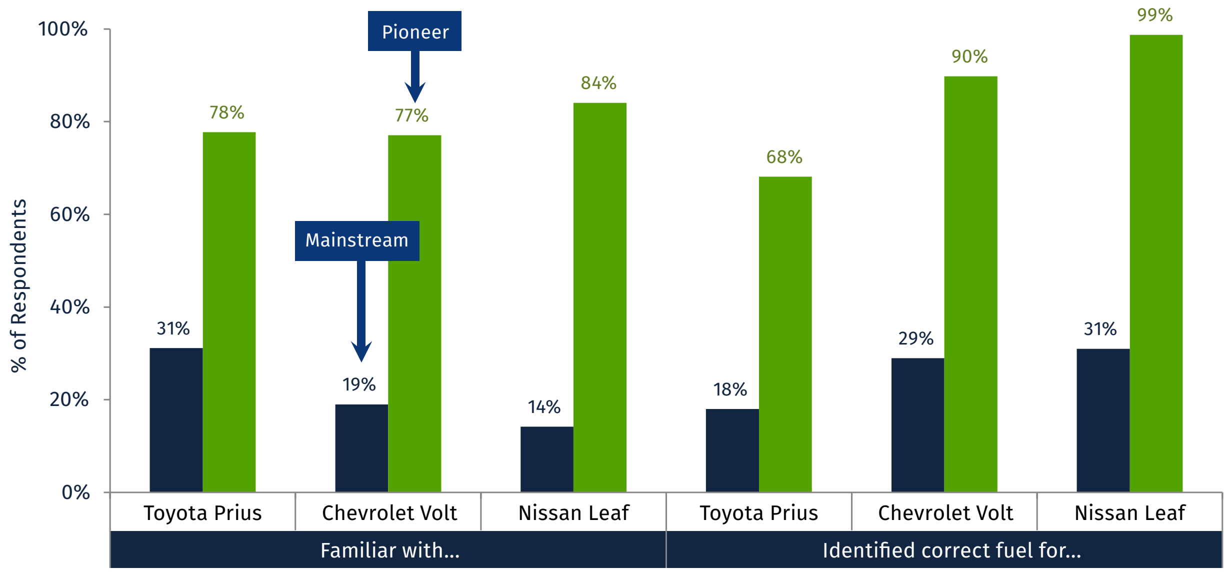


6.2. PEV Pioneer PEV Awareness

As expected, PEV Pioneer respondents were much more familiar with PEV technologies and models relative to Mainstream respondents. Figure 13 compares pre-existing PEV awareness of the two samples in terms of familiarity and knowledge of refuelling. Respondents that described themselves as "familiar" or "very familiar" are classified as "highly familiar". Among PEV Pioneer respondents, 77—84% were "highly familiar" with each of the three PEV models compared to only 14%-31% of Mainstream respondents. In particular, we see the biggest difference in familiarity between the two samples with the Nissan Leaf: 84% of PEV Pioneer respondents were highly familiar with the Leaf, compared to only 14% of Mainstream respondents.

In terms of knowledge about vehicle refueling, recall that less than 31% of Mainstream respondents were correctly able to identify how each vehicle was fuelled. In contrast, the vast majority of PEV Pioneer respondents (90—99%) were able to correctly identify how a Chevrolet Volt or Nissan Leaf was fuelled. However, more than one third of PEV Pioneer respondents incorrectly described refuelling for the Toyota Prius, indicating that there is still some confusion in regard to HEV technology (though not nearly as much as observed among Mainstream respondents).

Figure 13: Comparison of PEV familiarity and refueling between Mainstream (NVOS, n = 538, blue bars) and PEV Pioneer (PEVOS, n = 157, green bars) respondents from the British Columbia samples



6.3. Insights from NVOS Interviews: PEV Knowledge and Confusion

Knowledge of vehicle technologies was also assessed in the NVOS interviews. Much like the survey, interview participants were first asked to discuss their understanding of the different vehicle technologies (HEV, PHEV and BEV) and were then provided with an explanation before completing the vehicle design exercises (see NVOS interview protocol in Section 4.4). Although all interview participants had completed the NVOS and read the PEV Buyer's Guide, confusion about vehicle technologies remained, especially for PHEVs and to a lesser extent for HEVs. Participants' PEV technology knowledge was assessed according to their:

- **Awareness** of the technology's existence;
- **experience** with the technology (direct or indirect); and
- **demonstrated** understanding of how the vehicle functioned (refueling and operating).

Using these parameters, we group participants into three knowledge categories based on their level of experience and understanding of HEVs, PHEVs, and BEVs (Table 20):

- **Basic PEV knowledge** – Experience with, but misinformed understanding of HEVs. No experience or understanding of PHEVs or BEVs;
- **Moderate PEV knowledge** – Experience with, and moderate understanding of HEVs. No experience or understanding of PHEVs or BEVs;
- **High PEV knowledge** – Experience and understanding of HEVs and PHEVs. No experience and limited understanding of BEVs.

Table 20: Interviewed NVOS households categorized by knowledge of vehicle technology (n = 22)

<table>
<tr><th rowspan="2">Category of electric-drive vehicle knowledge</th><th rowspan="2">Households</th><th colspan="3">Knowledge of vehicle type</th></tr>
<tr><th>Hybrid-electric vehicles (HEV)</th><th>Plug-in hybrid vehicles (PHEV)</th><th>Battery electric vehicles (BEV)</th></tr>
<tr><td>Basic knowledge</td><td>Fay
The Mathews
Andreas
The Chens
Lei
Violet
Veronica
The Parks
The Morrettis
Christine
Al
The Dimirovics
Margaret
Clair</td><td>Experience, but low familiarity</td><td rowspan="2">Not aware that this type of vehicle exists</td><td rowspan="3">No experience, but aware that this type of vehicle exists</td></tr>
<tr><td>Moderate knowledge</td><td>The Youngs
Sandra
Omar
Kevin
The Nicolovs</td><td rowspan="2">Experience and familiarity</td></tr>
<tr><td>High knowledge</td><td>Daryl
Liz
The Fengs</td><td>Experience and familiarity</td></tr>
</table>

All 22 households were aware that BEVs existed; in other words, they knew that there are vehicles on the market which can be plugged-in and run on electricity rather than gasoline (via an internal combustion engine). However, participants from all three categories had only an abstract idea of BEV technology. No households had direct experience with a BEV – none had ridden in a BEV and only one participant (Omar) reported having a cursory conversation about this vehicle type with a BEV owner. Moreover, 10 households thought they could recall having seen a BEV, but this recollection was often uncertain. For example, Mr. Chen thought he had seen a Nissan Leaf (a BEV), but asked, “Is the Leaf electric or is it hybrid?” These types of uncertainties and misconceptions varied, but overall, perceptions of BEVs amongst the 22 households were not based on direct experience.

Participants in the “**Basic Knowledge**” category are differentiated by their confusion regarding hybrid-electric vehicles (HEVs). Specifically, all 14 of these households had the impression that an HEV can be recharged using external electricity or that an HEV has separate extended electric drive capabilities like a PHEV. One participant, for example, expressed that seeing her friend’s Prius C (an HEV model) has made her think that she would like to buy an HEV of her own, but noted “a common problem that I’ve noticed is… the charging part… it’s kind of inconvenient sometimes.” Similarly, Mr. Mathew’s was concerned that “there might be a little bit of difficulty in recharging things if you’re going on a long journey.” Others from the “Basic Knowledge” category seemed to believe that driving an HEV entailed having some extended electric range followed by "gas back-up". As Fay remarked, "if you run out of electricity, you've got the gas anyway." All 14 of these households had some experience with HEVs (typically rides in a taxi or a friend's or neighbour's Toyota Prius) but they did not understand how this type of vehicle was operated. Because of their misconceptions regarding the operation of HEVs, these 14 households were not aware of plug-in hybrid electric vehicles as distinct from HEVs.

The "**Moderate Knowledge**" category consists of five households who were more familiar with HEVs, yet still unaware of the existence of PHEVs. These participants had experiences with HEVs similar to those in the "Basic Knowledge" category (e.g. riding in one as a passenger), but had a better understanding of how an HEV was operated. Omar, for example, had considered buying an HEV and discussed how this technology would be preferable to a BEV because he would not need to worry about charging or range limitations. Rather than confusing PHEVs with HEVs, participants in this category were simply not aware that PHEV technology existed. When asked about PHEVs, participants in this category gave responses similar to Mrs. Nicolov who commented: "I know there are electrical, hybrid, and gas, but no, not this [a PHEV]."

The "**High Knowledge**" category consists of three households who had experience with PHEVs and were the only participants who were aware of PHEVs as distinct from HEVs. All three participants had at least a basic understanding of how a PHEV is refuelled and recharged, as well as how propulsion occurs in the two distinct modes. In fact, all three had ridden in a Chevrolet Volt – Daryl and Mr. Feng had ridden in PHEVs owned by an acquaintance as passengers, while Liz had test driven a Volt on a visit to a Chevrolet manufacturing plant. These three households were clearly familiar with how a PHEV was distinct from an HEV and one household (Daryl) was an HEV owner.

Previous familiarity with HEVs was an important influence on how easily participants learned about PHEVs as the interviews progressed. As described in Section 4.4, after the participants' initial knowledge of the different vehicle types was established, the interviewers provided basic explanations of electric-drive technology to facilitate further discussion. The five "Moderate Knowledge" households (who understood how an HEV operates) were able to easily grasp how having the ability to plug in a PHEV would allow the vehicle to be powered by external electricity for some range, followed by HEV-like operation once the battery is depleted. However, this elementary understanding of a PHEV was more of a challenge for the 14 "Basic Knowledge" households – all participants in this category required more information to understand the differences between PHEVs and HEVs, over the basic explanation of the different vehicle types initially provided.

For example, Clair at first appeared to grasp the contrasts between the varying types of electric drive but later asked, "[W]hat's the deal here? You don't plug this in, the hybrid?" Similarly, when discussing how the different vehicle options would work with her household's lifestyle, Mrs. Park expressed some uncertainty regarding PHEVs, saying "So just to clarify… let's say I didn't have time to charge it and I still had to drive it, it would still drive because it would just default to gas?" It seems that without having established an understanding of what HEVs are and how they are propelled, these households found it difficult to understand how a PHEV would operate.

7. Charger Access and Awareness

Research Highlights for Section 7

PEV charging infrastructure is an important aspect of PEV deployment; however, it is unclear what kind of charging infrastructure is needed to best support PEVs. As a first step, we explore potential access and use of home charging and public charging among the Mainstream and PEV Pioneer sample, highlighting key differences in charging availability.

Among Mainstream (NVOS) respondents in British Columbia we find that:

- Two-thirds presently have Level 1 charging access at home, and 35% have the potential to install Level 2.
- One-third have seen at least one public (non-home) charger, and 7% have seen two or more.

Among PEV Pioneer (PEVOS) respondents we find that:

- 97% have some form of home access, with 75% having installed a Level 2 charger.
- The majority of PEV Pioneers paid $500 to $1500 to install their home Level 2 charger.
- Prior to purchasing their PEV, most (86%) were aware of at least one public (non-home) charger, and 70% knew of two or more.
- Reported usage of any specific public charging locations tends to be infrequent (once per month or less).

PEV charging infrastructure is an important aspect of PEV deployment. It is unclear what kind of charging infrastructure is needed to best support PEVs, including charging speed and location types. As a reminder, we describe the three different levels of chargers mentioned in Section 2.1:

- **Level 1** chargers (or cordset chargers) use 110/120V outlets, which are common in North American households.
- **Level 2** chargers (or charging stations) use 220/240V circuits, and can recharge a battery three to six times faster than a Level 1 charger.
- **Level 3** chargers (or DC fast chargers) provide much faster charging, where typically a BEV's battery can be recharged up to 80% in 30 minutes.

Chargers can also vary by location. A PEV driver might use a Level 1 or 2 charger at their home or workplace. Other non-home locations might have a Level 2 or Level 3 charger. Presently we define a "public" charger as any charger other than a home charger, including locations such as workplaces.

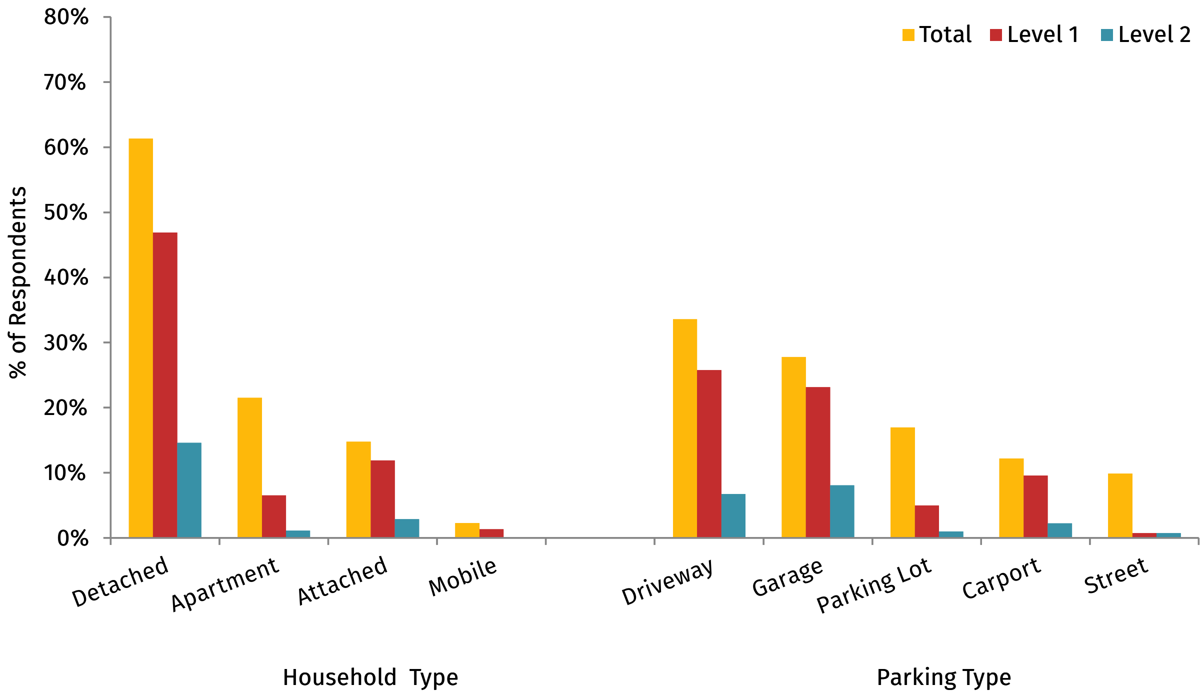
Each type of charging has its advantages and functions. For example, home charging allows PEV owners to plug-in every night and wake up with a fully charged battery. There is some evidence that the uptake of PEVs may depend on the availability of home charging infrastructure. Among American PEV owners in 2012, more than 80% of vehicle charging occurred at home (Smart, 2013). Home recharging can also be an important factor for those considering potential PEV ownership. A survey of 508 new vehicle buying households in San Diego, California in 2011 found that interest in PHEV and BEV designs was much higher among respondents whom had identified recharge potential at their home (Axsen and Kurani, 2013). Public charging, on the other hand, allows PEV owners to travel longer distances and some suggest may even increase awareness of PEV technologies (Community Energy Association, 2013), but less is known about how important its role is in PEV deployment (we further explore this in Section 9). In this section we investigate home and public recharging availability in British Columbia, looking at potential and actual home recharging access of our Mainstream and PEV Pioneer samples.

7.1. Home Charging Access among Mainstream Respondents

Here we present results from our British Columbia Mainstream (NVOS) sample; results for the full Canadian new vehicle owner sample are presented in Bailey et al., (2015a). To assess potential recharge access, we analyzed data collected from the Home Recharge Assessment (Part 2 of NVOS). 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 and Kurani (2012c), we consider a respondent to have "home recharge access" to Level 1 or Level 2 charging if they had 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 British Columbian Mainstream respondents currently have Level 1 access at home, while 19% have Level 2 access at home. Furthermore, we also identified that 35% of respondents have the potential to install a Level 2 charger. Figure 14 shows Levels 1 and 2 access for the British Columbia Mainstream sample by housing type and type of parking space. Recharge access is proportionally higher among respondents living in detached and attached homes, and those parking their vehicle in a garage, driveway, or carport. These results are similar to results observed using a similar survey instrument, which was implemented in San Diego, California (Axsen & Kurani, 2012b). Compared to the rest of Canada, the British Columbia Mainstream 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).

Figure 14: Mainstream respondents' residential Level 1 and 2 access by housing type and parking space (British Columbia only, n = 528)



7.2. Home Charging Access among PEV Pioneer Respondents

For PEV Pioneer respondents (PEVOS), we assessed respondent recharge access throughout the background survey (Part 1). To elicit respondent home recharge access, participants were asked about the type of home charger they had (e.g. Level 1, Level 2 or no charging). We also asked several follow-up questions including:

» their reasons for installing a Level 2 (if one was installed);

» why they did not install a Level 2 (if they had no home recharge access or a Level 1); and

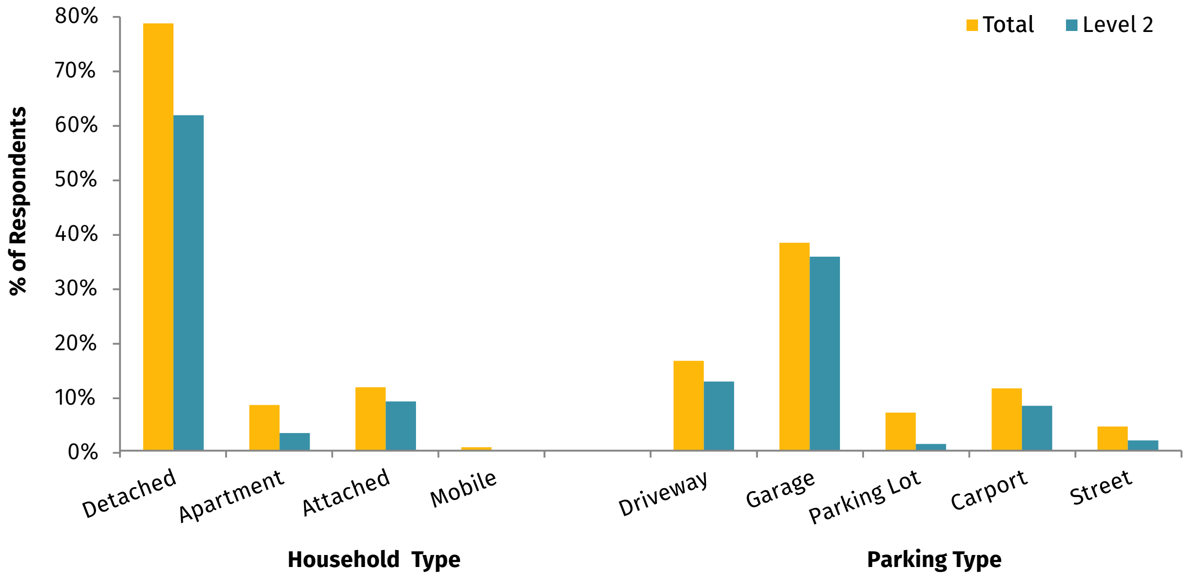
» what they paid to install their Level 2 (if one was installed).

Almost all PEV Pioneer respondents reported having some form of home recharge access (97%), with the majority having installed a Level 2 charger (75%). Figure 15 depicts PEV Pioneer respondent Level 2 charging access by dwelling and parking type. As with the Mainstream sample, respondents with charging access were more likely to live in single family detached homes (80% of sample) and to have access to a reliable parking spot (e.g. garage, driveway or carport). Only 8% of PEV Pioneer respondents reported living in an apartment, whereas about 20% of Mainstream respondents reported living in apartments.[11] For the few respondents living in apartments, only 3% had access to Level 2 charging, indicating that multi-unit dwellings can be problematic in offering home recharge access.

11. The 2006 Canadian Census also reports that 21% of British Columbian residents live in apartments. See Table 15 for a complete breakdown of population by dwelling type.

The Level 2 adoption rates reported in this study are slightly higher than those reported in the California Center for Sustainable Energy's Plug-in Electric Vehicle Owner Survey (CCSE, 2014). Among PEV Pioneer respondents, there was no significant difference in Level 2 installation between BEV and PHEV owners. This is in contrast to the findings of Tal and Nichols (2013) that identified higher installation rates among BEV owners. In our study, the 3% of respondents with no home charging access were BEV owners. These differences, however, may in part be explained by the fact that many participants were recruited from the British Columbia Government's Clean Energy Vehicle program – meaning they received a rebate for the purchase of their vehicle and/or home charger.

Figure 15: PEV Pioneer respondents' residential Level 2 access by housing type and parking space (excludes other categories, n = 154 & 156)

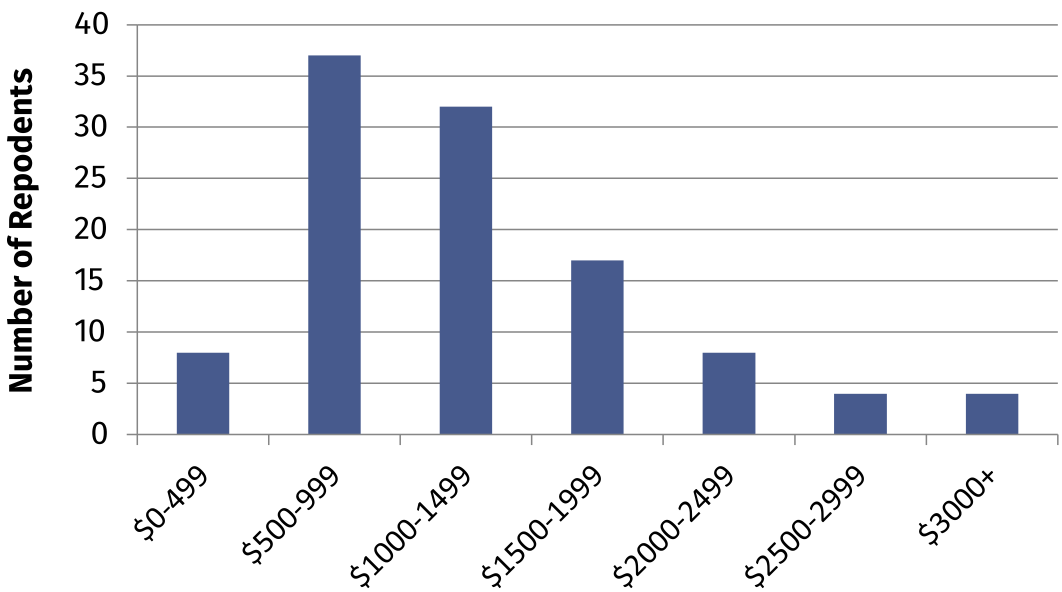


As follow up to the home recharge access question (i.e. what type of home charger do you have: Level 1, Level 2 or no access), we asked respondents why they installed (if they indicated Level 2 access) or did not install (if they indicated Level 1 or no access) a Level 2 home charger. When respondents with Level 2 access (116 participants) were asked, "which factors were important in your [their] decision to install a Level 2 dedicated home charger", the most frequently cited factor was "faster recharge time" (70%). Conversely, when the 41 respondents without Level 2 access were asked , "why have you [they] not yet installed a Level 2 dedicated home charger?", the most frequently cited reasons were having "no need" (60%) and "high costs" (40%); only 20% reported interest in installing a Level 2 in the near future.

Reported total installation costs (charger unit and installation) for PEV Pioneer respondents that had installed a Level 2 charger at home ranged from under $100 to just over $4000 (Figure 16).

Average total installation costs were $1235, with the majority (80%) of participants reporting costs between $500—2000. Of the respondents reporting installation costs, 73% received a rebate for the purchase and installation of their Level 2 charger.[12] Higher costs may be attributed to obstacles encountered in the installation process, such as expensive electrical panel upgrades or retrofits. Lower installation costs, especially those under $500, are likely linked to self-installations by PEV owners who also received the full $500 LiveSmart BC rebate. Insights from the interviews reveal that some participants installed their own charging units and received the rebate (mainly electricians and engineers). Out of the 13 interviewed households, at least two indicated that they had installed their charging units themselves.

Figure 16: Distribution of Level 2 charger total installation costs among PEV Pioneer participants (n = 110)



7.3. Public Charging Awareness among Mainstream Respondents

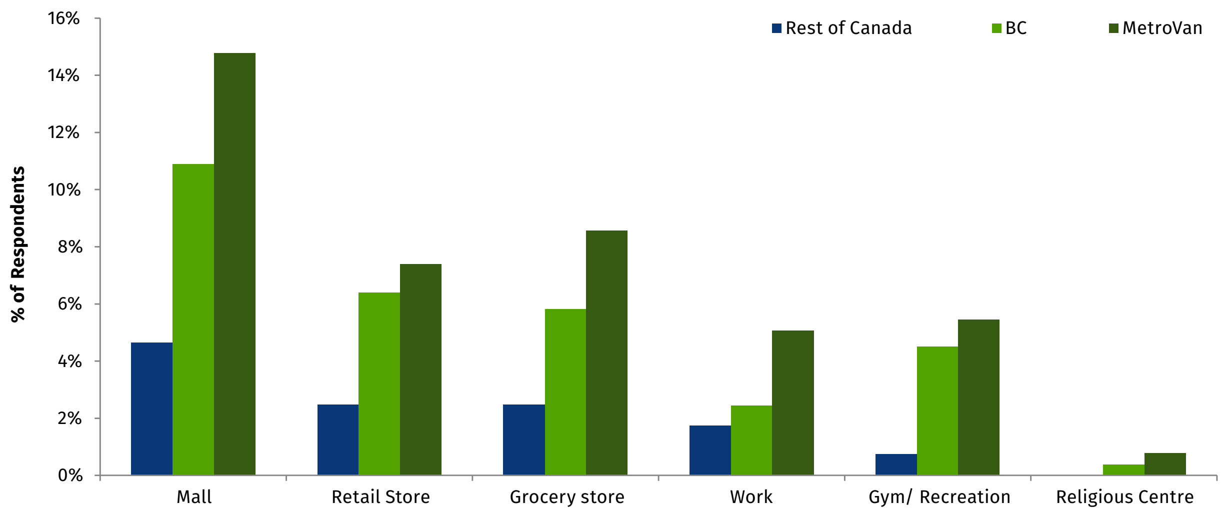
The NVOS survey instrument also assessed respondents' awareness of "public" chargers (which we presently define as any non-home based chargers). Part 1 of the survey presented respondents with a description of different types of public chargers and then asked if they had ''seen any electric vehicle recharge stations at the following parking spots or spaces you use?". The list of recharge locations provided to respondents included grocery stores, retail stores, shopping malls, gyms or recreation centres, religious or spiritual centres, workplaces, parking lots, as well as a user-defined ''other''.[13]

12. The residential charger subsidy was a $500 rebate offered by the BC Government via the LiveSmart BC program from December 2011 to March 2014. Details available at: http://www.livesmartbc.ca/incentives/transportation/

13. Because we focus on of chargers that the respondent could actually use, we excluded any responses that specified sightings at locations other than these categories (e.g. sightings in other countries, on the internet, outside of the respondent's province, etc.

Respondent charging awareness varied by both frequency and location (Figure 17). Overall, 31% of Mainstream respondents reported awareness of at least one public charger and 7% were aware of two or more. Compared to the rest of Canada, awareness in British Columbia was significantly higher. Only 13% of respondents in the rest of Canada reported having seen at least one charger. This level of awareness is likely a consequence of the Clean Energy Vehicle Program initiated in 2011, which drastically increased the number of public chargers across British Columbia. Awareness also varied by type of charger location. The most frequently cited locations among British Columbian respondents were shopping malls (11%), followed by retail and grocery stores (about 6% for each). Awareness of chargers in all locations was especially high for the sub-sample of British Columbian Mainstream respondents living in Metro Vancouver, where respondents reported seeing an average of 2% more chargers per location.

Figure 17: Mainstream respondents' public charger awareness by location categories; rest of Canada (n = 1207); British Columbia (n = 536) and Metro Vancouver (n = 257); Source: Bailey et al., 2015.



7.4. Public Charging Awareness among PEV Pioneer Respondents

The PEVOS survey instrument (Part 1) elicited respondents' perceptions of public charger awareness before and after the purchase of their PEV. Specifically:

» 1. To elicit pre-purchase data, we asked respondents to "think back to the time when you first decided to purchase your [their] PEV" and to indicate which charging opportunities they were aware of from a list of charging locations (e.g. malls, parking lots, etc.).

» 2. To elicit post-purchase data, we asked several questions about the *specific* public chargers (up to five) that participants used most frequently, including location type, address/location, frequency of use, duration of charge and awareness prior to purchase.

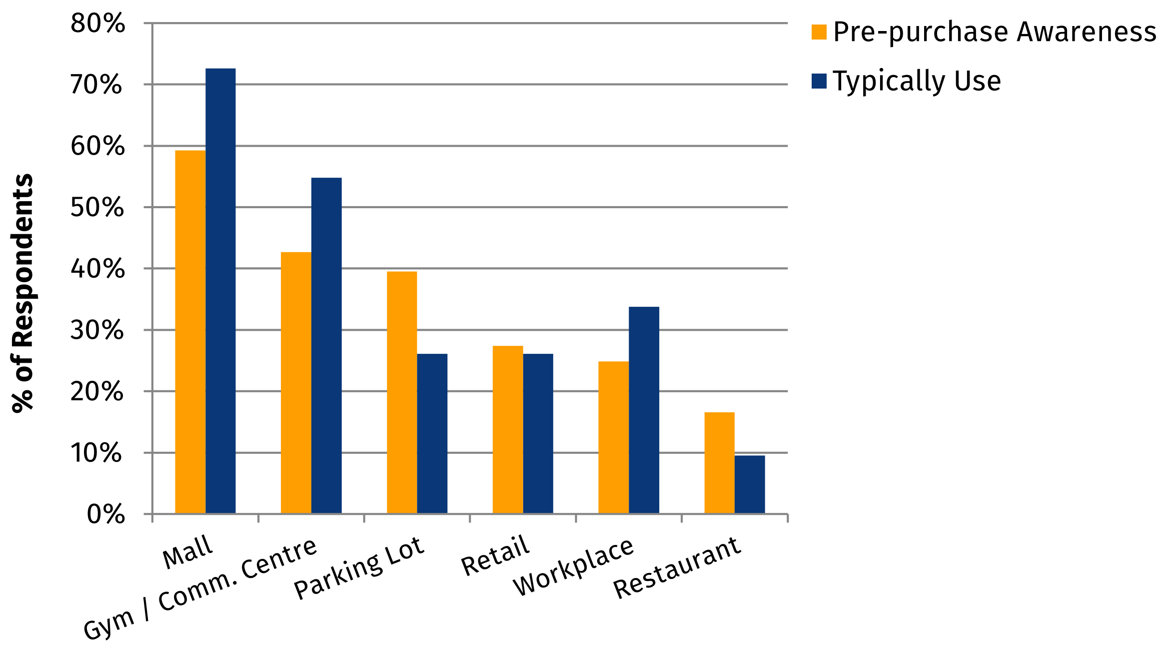
Combined, the data collected from these questions provided us with a comprehensive dataset to assess public charger awareness and stated use among our PEV Pioneer respondents.

Prior to purchasing their PEV, 86% of PEV Pioneer respondents were aware of at least one charger and 70% were aware of more than one. The most frequently cited charging location types were malls, followed by gym/community centres and parking lots (Figure 18). When asked "how important was it to know about potential charging opportunities other than your home [prior to purchasing the PEV]", 65% of respondents stated that public charging was "important" or "very important." At that time, respondents, on average, expected to use public chargers 28% (12% workplace, 16% other) of the time, and home chargers for the remainder of their PEV charging. This may suggest that public charging is important to some owners before they purchase a PEV, although actual usage may be relatively low compared to home-based charging.

After PEV Pioneer respondents purchased their PEV, almost all respondents (90%) reported using public chargers. Figure 18 compares pre-purchase awareness to reported usage of specific chargers by location type. Reported usage data were collected from questions related to the specific charging locations (up to five) respondents indicated using most frequently. Over 50% of the public charging locations respondents reported to use most frequently were known before their PEV purchase. The most frequently used charging location types also tended to be the locations that PEV Pioneer respondents were more likely to be aware of prior to the vehicle purchase –with malls and gyms/community centres as the most popular. We provide additional analysis of actual charger use in Section 11 where we assess participants' charging patterns from a five-day driving diary.

When asked about the frequency – daily, weekly, monthly, annually – at which these specific charging locations were used, reported usage was quite infrequent. Most PEV Pioneer respondents reported using each public charger monthly or annually (~40%); however, overall use of public charging, in general, tends to be somewhat higher (as discussed in Section 11.3).

Figure 18: Comparison of pre-purchase public charger awareness and reported use in Part 1, by charging location type



8. PEV Demand and Motivation

Research Highlights for Section 8

Interest in PEVs and valuation of PEV attributes may help us understand the motivations of PEV pioneers and potentially identify the next likely segment of PEV buyers, the Early Mainstream. We find interesting differences between these two samples in terms of PEV interest, valuations and motivations.

Among Mainstream respondents (NVOS) in British Columbia and Canada we find that:

» About one-third expressed interest in some form of PEV, and most selected a PHEV over a BEV design (89—93%); we define this subsample as the "Early Mainstream".

» Resistance to PEVs included range limitations (especially for BEVs), reliability concerns, and aesthetic concerns (i.e. PEVs look "strange").

» Although perceived as a limitation, the NVOS choice model indicated that most respondents are unable to value PEV driving range (not significant at a 95% confidence level).

» Motivations for PEV interest included driving flexibility (for PHEVs), fuel savings, and pollution reduction.

Among PEV Pioneer (PEVOS) respondents we find that:

» Almost all would buy another PEV (96—100%). 50—70% selected a BEV over a PHEV design, with 20—38% selecting the longest range BEV (320km).

» Average willingness to pay was very high for PHEVs and BEVs and their attributes, including fuel savings, driving range, and Level 2 charging at home.

» Just over half reported that they would not have purchased their vehicle without a purchase rebate.

» The number and type of symbols and images associated with their vehicles varied significantly between owner groups (Volt, Leaf, Tesla).

» Motivations for BEV interest included improved driving experience, environmental benefits, independence from oil companies, and technological superiority.

In this section we investigate PEV interest by examining participants' preferences for vehicle technologies and features. According to the reflexive lifestyle approach (detailed in Section 3.1), consumers construct their interests and preferences as they learn about PEV technology. Previous research indicates that Mainstream vehicle owners are generally unfamiliar with PEVs and tend to be confused about their attributes (Caperello and Kurani, 2012; Kurani et al., 1994). Therefore, we educated our respondents before eliciting their PEV interests by providing them with information about different vehicle technologies and features in the Buyer Guide (see Section 4.2 for more details). In this section we report results on respondents' PEV interests and motivations, including results from the design space exercises (8.1), discrete choice experiment (8.2), as well as other survey responses and interview questions (8.3 and 8.4).

8.1. Who Wants What Type of PEV in British Columbia?

In Part 3 of both survey instruments (NVOS and PEVOS) we elicited participants' vehicle preferences using design space exercises where respondents were asked to design their preferred next vehicle—either a CV, HEV, PHEV or BEV. Participants completed two design game exercises, one at a "higher price" to represent current prices and one at a "lower price" to reflect prices after subsidies (or cheaper batteries) (see Table 8). For illustration, in the higher price scenario it would cost an additional $9000 to "upgrade" a conventional compact car to a BEV-120km (similar to the Nissan Leaf), but only an additional $4500 in the low price scenario. This reduction of ~$4500 is similar to the current $5000 dollar incentive in British Columbia provided by the Clean Energy Vehicle Program. A more in-depth description of this tool is provided in Section 4.

Through these exercises, respondents indicated their interest in PEVs (i.e. by selecting a PEV), providing us with data on the types and designs of PEV that "Early Mainstream" buyers may want.

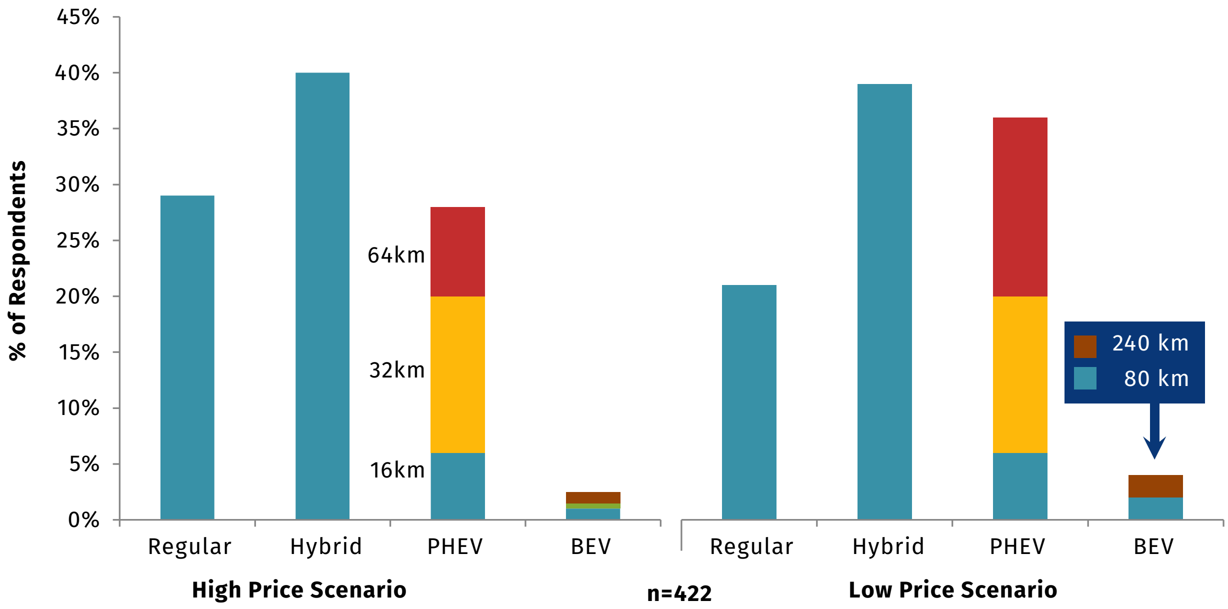
The Early Mainstream

Overall, about one-third of Mainstream NVOS respondents selected some type of PEV design (Figure 19). As described in Section 3.3 and throughout this report, respondents that selected a PEV design in the lower price scenario are categorized as the "Early Mainstream." These participants (36% of the British Columbia NVOS sample) are considered to be the most likely next wave of potential PEV buyers and are thus the focus of many analyses in this report. The "Late mainstream" (those that designed a CV or HEV in the lower price scenario), on the other hand, are not likely to purchase a PEV in the near term. Consequently, there is less focus on this sample throughout the report.

In both price scenarios, the highest proportion of respondents designed and selected some form of HEV (40 to 38%), with minorities selecting a PHEV (28 to 34%) or a conventional vehicle (28 to 21%). A BEV was designed by only two to four percent of survey respondents. This gravitation of respondents to PHEV designs (not BEV designs) has been observed in previous surveys of new vehicle owners in San Diego, California (Axsen and Kurani, 2013b), and across the U.S (Axsen and Kurani, 2013a).

Interest in PEVs is influenced, to some extent, by price (or subsidies). In the lower price scenario, demand for PHEVs increases by 20% 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 BEV designs doubles in the lower price scenario—although BEVs still represent around only five percent of the total market.

Figure 19: PEV designs selected by Mainstream respondents
(NVOS British Columbia only, n = 442, higher and lower price scenarios)



PEV Interest among Pioneer Respondents (PEVOS)

PEVOS respondents also completed a high and low price design exercise. The design and application of these exercises was almost identical to that used in the NVOS; however, the PEVOS included an additional option for BEV range, a 320km BEV with an upgrade cost of $19,000—40,000, depending on body type and scenario (see Table 12 on p. 66). With that in mind, readers should be careful in directly comparing NVOS and PEVOS results.

In both price scenarios, almost all participants selected some type of PEV (96—100%), with only 4% selecting either a CV (2%) or HEV (2%) and only in the higher price scenario (Figure 20). The selection of PEV type was influenced by price. In the higher price scenario, the split between PHEVs and BEVs was almost equal (45% and 51%), whereas the lower price scenario yielded more interest in BEVs (71%) than PHEVs (29%). This result, to some extent, may be a function of PEV owners selecting the same vehicle type as what they currently own when prices were closer to their current vehicle's purchase price. For reference, ownership among our PEV Pioneer respondents was 70% BEVs and 30% PHEVs (Figure 21).

Respondent selection of electric battery range also varied between the price scenarios (Figure 21). The PHEV-64 (like the Volt) was the most frequently selected vehicle in the higher price scenario (41% of all designs), while the BEV-320 was the most popular in the lower price scenario (38% of all designs). These results indicate a stronger desire for longer range BEVs among PEV Pioneer respondents (PEVOS) compared to Early Mainstream respondents (36% of NVOS in British Columbia). Interestingly, however, only 9% of PEV Pioneer respondents designed a BEV with a range equivalent to the Nissan Leaf, which is owned by 46% of the PEV Pioneer sample.

Figure 20: PEV designs selected by PEV Pioneer respondents (PEVOS n = 94, higher and lower price scenarios)

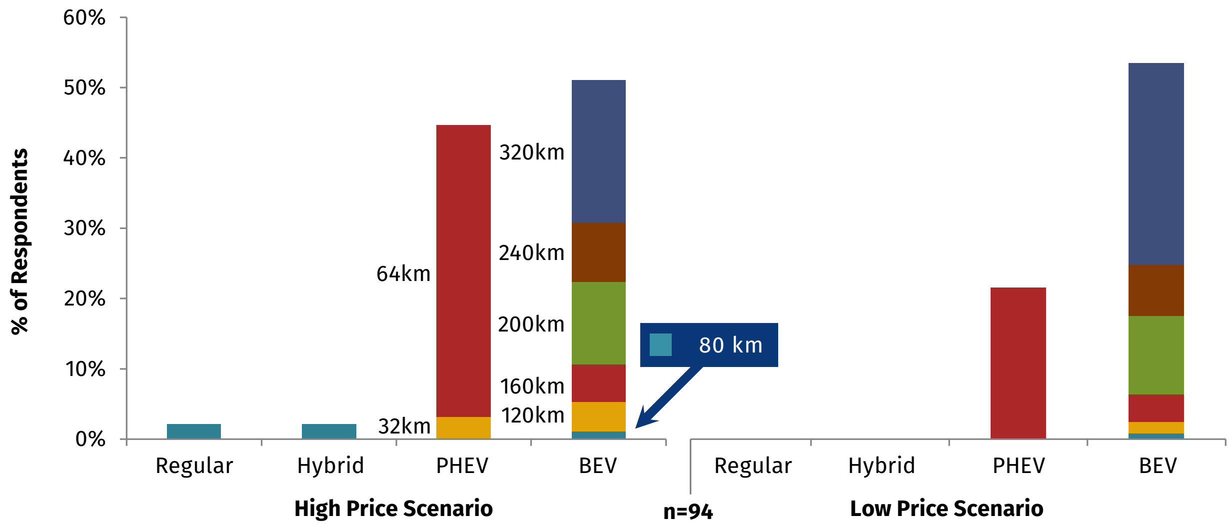
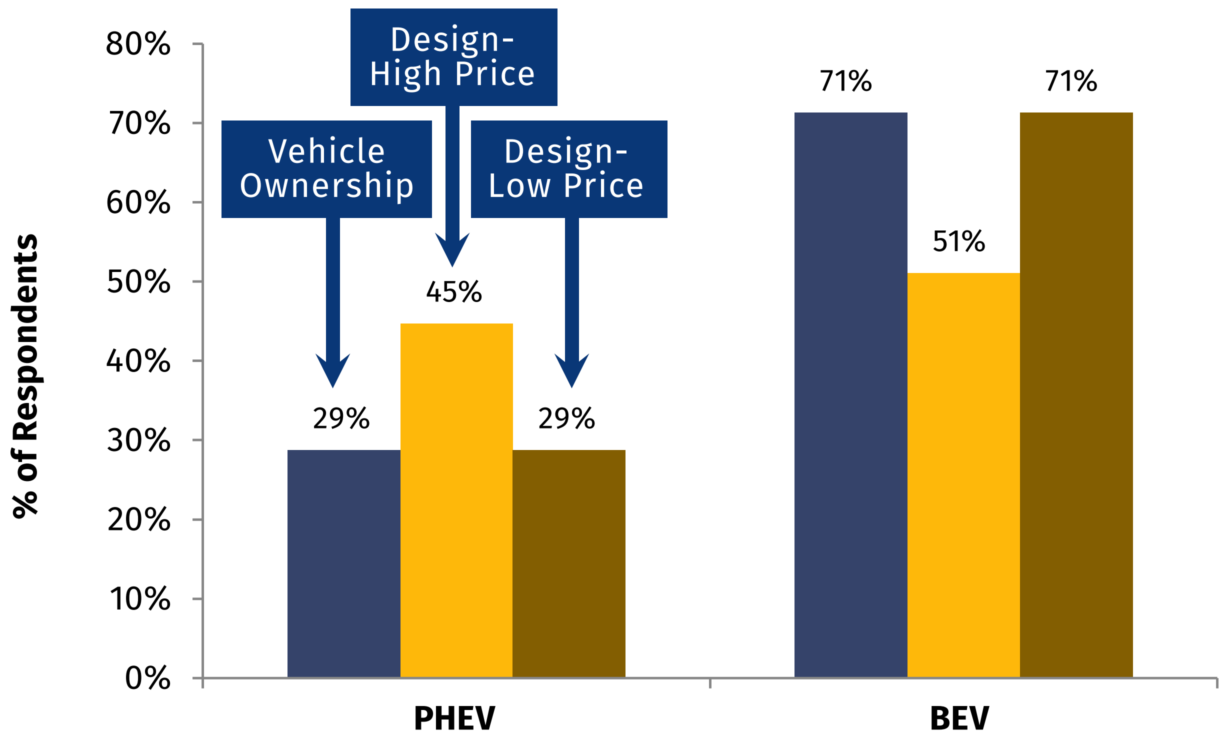


Figure 21: PEV Pioneer vehicle ownership and design in the higher and lower price scenarios (n = 94)



8.2. Valuation of PEV Attributes

Both the NVOS and PEVOS surveys included a PEV discrete choice experiment in Part 3. Rather than ask the respondent to select their ideal vehicle design, the discrete choice experiment collects consumer choices over a variety of attribute combinations (price, fuel cost, range, and home recharge access), then quantifies the relative value that respondents place on each attribute. A more in-depth description of this tool is provided in Section 4.

Table 21 portrays a simple choice model estimated using a multinomial logit analysis from the Canadian NVOS and British Columbia PEVOS data. The coefficients in the model can be interpreted by their sign—where positive coefficients indicate that respondents want more of that attribute, and negative coefficients represent undesirable attributes. For example, vehicle price and fuel costs 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.

In addition to determining the coefficients, we can also estimate the average "willingness to pay" (WTP) for certain attributes in the experiment (which we only estimated for values that were significant at a 95% confidence level or greater). Overall, PEV Pioneer respondents express a higher WTP for every attribute in Table 21. While the electric range coefficients for PHEVs and BEVs are not statistically significant among Mainstream respondents, they are for PEV Pioneer respondents who (according to this model) are willing to pay a substantial amount for 1km of additional range – $544 per extra km for PHEVs and $235 for BEVs. These values are quite high and could be a function of the simplicity of our model. One simple explanation for this apparently large difference in willingness to pay for driving range is that Mainstream respondents generally have not experienced operation of a PHEV or PEV, whereas PEV Pioneer respondents have such experience and are also generally less price sensitive.

The attribute for Level 2 charging at home is interacted with the vehicle types (PHEV or BEV). For example, the existence of Level 2 charging has a greater effect in increasing demand for BEVs than for PHEVs (in both samples), as indicated by the magnitude of the coefficient estimate. The average Mainstream respondent is willing to pay an extra $1,295 for a PHEV if they could have a level 2 charger at home. This value increases to $3,311 for a BEV. Both values are about an order of magnitude higher among PEV Pioneer respondents ($10,974, and $21,518, respectively).

In the NVOS model, the alternative specific constants for HEVs, PHEVs and BEVs are statistically significant and positive for HEVs and PHEVs but negative for BEVs. 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 of these drawbacks might include safety concerns, symbolic values, or perceived inconveniences. The "base" vehicle here is a CV, indicating that all else held constant (e.g. price, fuel cost, range, and charger access), the HEV is more desirable than the CV, the PHEV even more so, and the BEV least desirable for Mainstream respondents. PEV Pioneer respondents, on the other hand, are willing to pay much higher premiums for PEVs than

Mainstream respondents. In fact, PEV owners are willing to pay an additional $27,000 and $33,000 for a BEV and PHEV, respectively, above the price of a CV. In contrast, Mainstream respondents would have to be compensated over $10,000 (relative to the price of CV) to purchase a BEV and would only be willing to pay an additional $744 for a PHEV (relative to the price of CV).

Table 21: Discrete choice model (NVOS Canadian sample, n = 1754 & PEVOS British Columbia Sample, n = 94)

Attributes	NVOS (2013) Canadian sample	PEVOS (2015) BC sample
Alternative Specific Constants		
HEV constant	0.205 ***	-0.232
PHEV constant	0.126 **	1.073 ***
BEV constant	-1.850 ***	0.889 **
Base = Conventional Vehicle		
Vehicle price (CAD$)	-0.0002 ***	-0.00003 ***
Fuel cost (CAD$/week)	-0.008 ***	-0.008 **
PHEV range (km)	-0.0001	0.017 ***
BEV range (km)	0.0009	0.008 ***
PHEV × Level 2 charging at home	0.219 ***	0.352 **
BEV × Level 2 charging at home	0.559 ***	0.690 ***
Implied willingness-to-pay[a]		
Saving $1000/year in fuel	$2,313	$12,974
HEV	$1,215	
PHEV[b]	$744	$33,456
BEV[b]	($10,956)	$27,711
1km PHEV range		$544
1km BEV range		$235
PHEV with Level 2 charging	$1,295	$10,974
BEV with Level 2 charging	$3,311	$21,518
Model		
Number of observations	10524	564
Number of individuals	1754	94
R-square	0.148	0.367
Log-likelihood	-12425	-495

* Significant at 90% confidence level

** Significant at 95% confidence level

*** Significant at 99% confidence level

a We only depict willingness-to-pay calculations where the coefficient estimates are significant at a 95% confidence level or greater.

b Because the coefficient estimate for PHEV and BEV range are not statistically significant, our willingness-to-pay calculations for PHEV and BEV are not based on the range of a given PHEV or BEV (e.g. PHBEV-16 vs. PHBEV-32).

8.3. Insights into Mainstream (NVOS) Motivations

As noted in Section 6.3, interviews can provide additional context to survey findings and are complementary to quantitative survey data because they allow researchers to gather more in-depth information about participant responses. In the NVOS interviews, PEV interest was elicited through a design space exercise similar to that completed in Part 3 of the survey. Results from these interviews provide additional insight into participants' PEV interests and preferences. We identified three categories of PEV interest among the 22 households:

- **High PEV interest** – households that selected a PHEV or BEV in the design game (11 households)
- **PEV open** – households that did not select a PEV but were not opposed to the technology and expressed consideration of PEVs in the future (9 households)
- **PEV opposed** – households that did not select a PEV and expressed opposition to the technology (2 households)

This categorization of PEV interest corresponds with the rows in Table 22. Subsequent columns indicate the number of households in each category, which includes initial level of PEV knowledge (following the Basic, Moderate, and High Knowledge groupings described in Section 6.3), and perceived benefits and drawbacks shaping interest in PEVs.

In Section 6.3 we described how initial knowledge of PHEVs was low; at the beginning of the interviews only three households were aware of PHEVs as a distinct vehicle type. Nonetheless, nine households selected a PHEV in the interview design exercise ("High PEV interest"), and another nine households indicated their 'openness' to PHEV adoption in the future ("PEV open") (Table 22). It is clear that for many participants, an initial lack of awareness was not a barrier to developing interest in the technology—once the basic concept of PHEV was explained. However, individual motivations for PHEV preference varied somewhat between both PEV interest categories and households.

For the nine "High PHEV Interest" households shown in Table 22 (as well as all nine of the "PEV Open" households), the preference for PHEVs over BEVs was consistently associated with the differences in range. For example, when asked why her household preferred a PHEV to a BEV, Mrs. Moretti cited the "range extension" attribute, saying, "[You get] the best of both worlds... You could still go on longer trips, and ... on a daily basis we don't travel very far, so we'd really be running on electricity." To further illustrate the importance of range perceptions, both of the "High BEV Interest" households selected vehicles with 80km ranges, expressing that although this range imposed some limitations, it was sufficient for their needs. In Kevin's words, "80 [km] would be good because if I ever did need to go out of town, I'd rent a vehicle... 80 [km] is a good range for local driving."

For four of the High PHEV Interest households, the preference for a PHEV over a BEV was also based partly on the feeling that the "unestablished technology" drawback of electric drive was less of a concern when the vehicle also had a gasoline engine. Veronica explained that with the PHEV "if the battery fails, you still have the gasoline option whereas [with a BEV], when it fails, it fails." For Veronica and the Mathews the concern about PEVs being "strange" was also alleviated by having the familiarity of an internal combustion engine. Referring to both of these issues of PEV novelty, Mr. Mathews told the interviewers that his preference for a PHEV over a BEV was partly because, in his words, "Maybe I'm just traditional enough that I don't like to be putting all my eggs in the electric basket."

The motivations behind "High Interest" in PEVs in general (both PHEVs and BEVs) included both environmental and private benefits, or more specifically, benefits to the environment via less pollution and benefits to the individual via home charging, fuel savings, and PHEV gasoline backup. However, the relative importance of these different types of benefits varied amongst participants in the "High Interest" category. For Liz, the perceived environmental benefit of less pollution was so important that other benefits such as fuel savings were not significant influences. Yet for the Fengs, recognized environmental benefits had essentially no impact on their desire to adopt a PEV. Instead, this household was focused on saving money through lower operating costs and, to a certain extent, having the option to refuel (i.e. charge) at home and not a gas station. For others in this "High Interest" category both environmental and private benefits were seen as significant motivators – as Fay put it, "I save gasoline, and I save the environment, and if I can kill two birds at the same time, why not?"

While the households listed as "PEV Open" in Table 22 were influenced by a number of perceived drawbacks, hesitance to adopt a PEV in the design game was particularly based on concerns about unknown maintenance costs or the perception that electric-drive technology is unestablished. For example, when asked what might increase his household's interest in adopting a PEV, Mr. Chen replied, "I'd have to look into it more [to determine if] the savings in terms of the fuel would balance out... whatever maintenance costs are associated." Similarly, Omar told the interviewers, "I think if we were gonna make that decision, we'd want to know that the price per kilometre, whatever the metric is, is significantly lower when you're buying electric vs. buying gas. And I don't know that it is."

Only 2 households would not consider adopting a PEV under any reasonable scenario. These participants placed essentially no importance on pro-environmental attributes of the technology. Both stated that climate change was not anthropogenic and directly stated that they were not "green" people (in Mr. Young's words he is "not a nature type or a dirt muncher"). Both of these households also seemed to be strongly influenced by the perception that PEVs are 'strange'. As Sandra put it, "the electric, to me, just seems a bit out there". In fact, for Sandra, this perceived drawback was so important that no other aspects of PEVs were significant influences.

Table 22: Explaining PEV interest according to knowledge, perceptions, and motivations, by NVOS households (n = 22)

				Number of households								
				Influential perceived PEV drawbacks					Influential perceived PEV benefits			
PEV interest	**Preferred design**	**Total House-holds (of 22)**	**Initial Electric-drive Knowledge**	**BEV Range**	**Tech un-established**	**Tech too "strange"**	**Charging incon-venient**	**Unknown main-tenance costs**	**Home Charging**	**PHEV Range**	**Save fuel money**	**Less pollution**
High Interest	BEV	2	Basic (1) Mod (1)	0	0	0	0	0	2	0	2	2
	PHEV	9	Basic (6) High (3)	9	4	2	0	0	1	9	8	8
Open	BEV	0		-	-	-	-	-	-	-	-	-
	PHEV	9	Basic (7) Mod (2)	9	5	4	5	5	0	9	9	0
Opposed	-	2	Mod (2)	1	1	2	1	0	0	0	0	0

8.4. Insights into PEV Pioneer (PEVOS) Motivations

PEVOS Survey Results

The PEVOS survey provides additional insights into PEV Pioneers' motivations from those that have actually purchased a PEV. In Part 1 of the survey, we directly asked participants about the factors that influenced their PEV purchase. Specifically, we asked about:

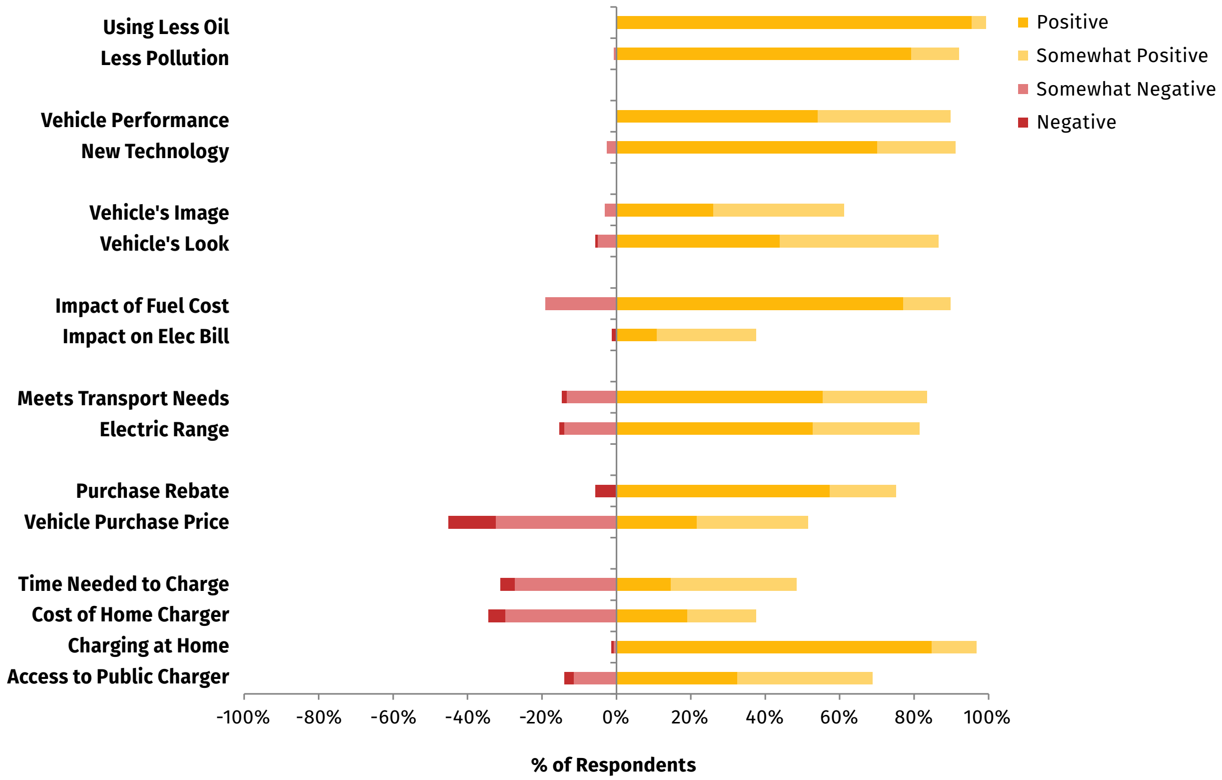
- **The perceived benefits and drawbacks of their PEV purchase.** Participants were asked to rate the degree of influence, negative or positive, a range of factors had on their purchase.
- **Purchase incentives that the respondent may have received.** Participants were asked about the types of incentives received as well as their influence on the PEV purchase. As explained in Section 2.2, in December of 2011 the British Columbia Government introduced its Clean Energy Vehicle Program to support the adoption of PEVs in British Columbia, including a point-of sale rebate of up to $5000 for PEV purchase, and up to $500 on the installation of a Level 2 home charger.
- **The symbolic aspect of the PEV purchase.** Participants were asked about the "images" they associate with their vehicle (e.g. environmental, intelligence, sporty, powerful).

Given that all PEV Pioneer respondents had already purchased a PEV, and likely perceived sufficient benefit to justify the purchase, it is not surprising that survey responses tended to emphasize the positive aspects of PEV ownership (Figure 22). The most frequently cited positive factors (by 70—95% of respondents) included:

- ability to charge at home,
- refueling costs,
- the ability to explore new technologies,
- using less gasoline, and
- reducing pollution.

Despite this emphasis on the positive aspects of PEV ownership, some respondents did indicate some drawbacks or factors that negatively influenced their purchase decision. The most frequently mentioned drawbacks included vehicle purchase price (45%) and the challenges of charging, including time to charge, access to public infrastructure and costs of home charger installation (14—34%). Interestingly, however, less than 20% of respondents mentioned vehicle electric range as a drawback, with the remaining sample perceiving it as a benefit.

Figure 22: Factors influencing the PEV purchase decision



As mentioned above, a point-of-sale vehicle and home charger rebate were available to many participants, and not surprisingly, the majority of PEV Pioneer respondents reported receiving both incentives – 64% for the vehicle purchase rebate and 60% for the home charger rebate (Table 23). However, rebate participation varied significantly among owner groups, with higher vehicle rebate participation rates for Tesla (88%) and Volt owners (82%) relative to Leaf owners (49%). When asked about the influence of these incentives, the majority of respondents reported that the point-of-sale vehicle rebate and charger rebate had a “moderate” to “major” influence, 78% and 57% respectively, on their PEV purchase. Additionally, a slight majority (54%) indicated that they would not have purchased their PEV if the vehicle rebate had not been available. However, this varied substantially among owner groups, with the rebate having a greater influence on Volt and Leaf owners than Tesla owners; 86% of Tesla owners reported that they would have purchased their PEV regardless. Conversely, the home charger rebate was not as influential on purchase decisions, with 87% of respondents reporting that they would have purchased their PEV without the rebate. The charger rebate had a larger influence on the installation of a Level 2 at home, as discussed in Section 7.2.

Table 23: Influence of British Columbia Government rebates on PEV Pioneers and owner groups

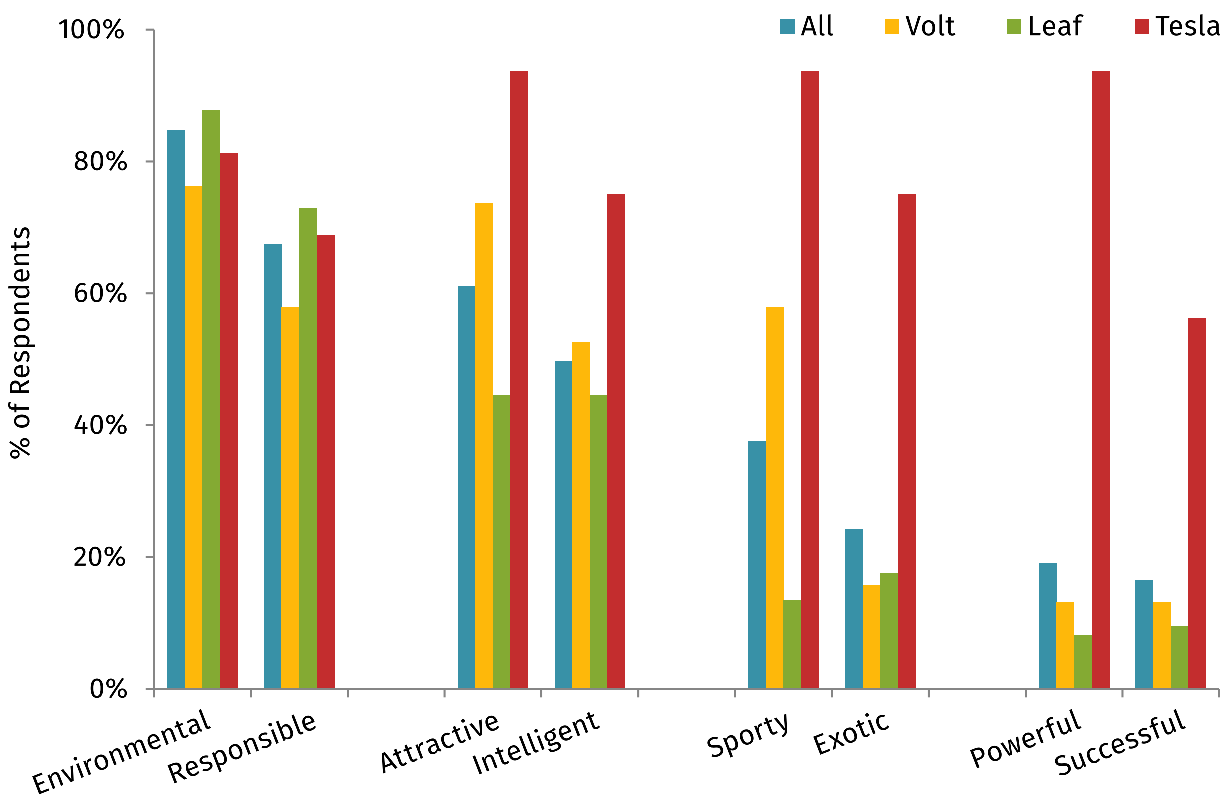
	CEVforBC™ Point-of-Sale Vehicle Rebate				LiveSmart BC Residential Charging Rebate			
	Volt	**Leaf**	**Tesla**	**All**	**Volt**	**Leaf**	**Tesla**	**All**
Received Subsidy								
Number of owners	31	36	14	101	29	44	7	94
% of sample	82%	49%	88%	64%	76%	59%	44%	60%
Influence on purchase decision								
Moderate	29%	14%	29%	25%	31%	30%	57%	30%
Major	52%	61%	36%	53%	24%	27%	14%	27%
Would have purchased vehicle without incentive?								
No	61%	53%	14%	54%	10%	11%	0%	13%

In addition to the functional attributes and benefits mentioned above (e.g. price, technological performance, environmental, emissions reductions), symbolic benefits can also be an important factor in the vehicle purchase decision—as discussed in Section 3.2. PEVs can provide symbolic benefits, conveying "different social meaning" than previous products (Hirschman, 1981). A portion of an individual's purchase decision can be explained by the images or symbols they associate with a vehicle because these images are intrinsically linked to one's self-image, interests, beliefs, values and social status.

To elicit symbolic value or benefit, PEV Pioneer respondents were asked to identify the images that would be associated with their PEV. We depict the most frequently selected images, broken down by owner group in Figure 23. Overall, most respondents indicated some pro-social symbolic association with their PEV, with many associating their vehicle with 'supporting the environment' (86%) and 'being responsible' (66%), as well as more private images such as being attractive (60%). There was also substantial heterogeneity among owner groups with respect to the number and type of image associations:

- Volt and Tesla owners were more likely to associate their PEV with a larger number of "images" relative to Leaf owners.
- Relative to Leaf owners, Volt owners were more likely to associate their vehicle with images relating the vehicle's attractiveness and sportiness.
- Relative to Volt owners, Leaf and Tesla owners were more likely to associate their vehicle with being pro-environmental and responsible.
- Tesla owners were by far the most likely to associate their vehicle with images relating to attractiveness, intelligence, sporty, exotic, powerful and successful.

Figure 23: Reported vehicle image associations, by owner group



PEVOS Interview Insights

Interviews were also conducted with 13 households (9 BEV, 3 PHEV, and 1 BEV+PHEV households) that participated in all three parts of the PEV owners survey (PEVOS). Similar to the NVOS interviews, participants were asked about their interest in and perceptions of PEVs through discussion of vehicle ownership rather than the design exercises used in the NVOS interviews (see the PEVOS interview protocol in Section 4.3.1 for more details). Findings from the interviews reveal important insight about vehicle preferences and purchase influences.

PEVOS interviews (n = 13) reveal that current PEV owners are generally satisfied with their vehicles. Driving experience or vehicle performance was a positive purchase influence for a majority of both BEV and PHEV owners. Eight of the thirteen households interviewed emphasized how the PEV driving experience makes conventional vehicles feel outdated in comparison. For example, one participant explained that “once we did the test drive, it was sort of game over at that point. That was the first electric car that either of us had driven, and just the whole experience ... is totally different”. Or as another participant put it more bluntly: “you just can’t beat the driving experience of [electric motors]”. The most commonly cited benefits associated with driving experience were torque, regenerative braking, and lack of noise.

While all participants noted positive benefits from the PEV driving experience, perceptions of other PEV attributes varied by interest in (and ownership of) PHEVs and BEVs. Similar to the PEVOS survey respondents, BEVs were generally preferred over PHEVs among the interviewees, and all but one household (12 of the 13) indicated interest in purchasing (or continuing to own) a BEV. By comparison, only five households expressed a similar interest in PHEVs and none expressed interest in CVs or HEVs.

Exploring the motivations behind BEV preferences (especially relative to PHEVs), three general themes emerged: (1) conservation of the environment, (2) independence from oil companies, and (3) technological superiority. We elaborate on each below.

The first theme relating to BEV interest was environmental conservation. Nine households with BEV interest (9/12) attributed their vehicle preference to environmental benefits. One participant explained that with BEVs "we can have our cars and not be wrecking everything, and we can have the electricity we want and not be causing huge damage because of that." Further, five BEV interested households highlighted the environmental shortfalls of PHEVs. As one participant stated, "I never considered a [plug-in] hybrid … I think it's sort of halfway there to where we need to get to". Elaborating on this idea, another respondent explained that they "didn't like the concept of the hybrid because you've got two engines … I didn't want to have a car that had two engines … I'm still buying gas, so even though you're buying half the gas, you're still buying gas. So obviously it's not going to be zero emission".

The second theme was independence from oil companies. Seven households indicated that the BEV provided an opportunity to gain independence from oil companies. One respondent explained that their reliance on oil was frustrating, mentioning that the recent fall in oil prices was "just a temporary blip in the whole oil world…this is a manufactured thing by the [Middle East]…they're just causing this whole thing to disrupt the scale of oil in the world." A few respondents took the idea of independence further to include other forms of energy. Fascinated by the idea of installing solar panels and producing their own energy, one participant stated that "the whole idea of decentralized power production is only a rational choice … I think having a social and economic unit that's small – and that includes energy production and use as well – makes sense to me."

The third theme was technological superiority. Seven households indicated a strong preference for the technological aspects of BEVs. The perceived technological advantages of BEVs reported by these households included: the driving experience, reduced maintenance, and efficiency of an electric motor. One respondent explained that the use of an internal combustion engine means trying to mitigate "wasted energy … Noise, heat, dealing with fuel that doesn't burn efficiently and goes out the tailpipe…it's all this waste, so it seems pointless". One respondent explained that "just the efficiency of the electric motor and the energy storage and the whole design of the [BEV] from an engineering standpoint just seemed so much better". Another five households were more explicit about their preference, stating that PHEVs were technologically inferior to BEVs, e.g. "[with a PHEV] you don't get the benefit of a more simplistic system", or "[the PHEV's] mechanical complexity…kind of just seems silly".

9. Does Awareness of Public Chargers Matter?

Research Highlights for Section 9

There is some evidence that the uptake of PEVs may depend on the availability of home charging infrastructure; however, it is not clear if the visibility of public charging stations actually has an impact on PEV demand. Looking at the correlations between public charging visibility, PEV interest and other factors, such as PEV readiness and socio-demographics, produces interesting findings about what actually influences the Mainstream's PEV interest.

Among Mainstream (NVOS) respondents in Canada we find that:

» Public charger awareness has a weak or non-existent relationship with PEV interest, although being aware of chargers at multiple locations may be a slightly better predictor of interest.

» According to our analysis, having PEV charger access at home is the most significant predictor of PEV interest.

NOTE: This Section is based on a full peer-review publication that is available here: http://www.sciencedirect.com/science/article/pii/S1361920915000103

Full Citation: Bailey, H., A. Miele, and J. Axsen (2015a). Is awareness of public charging associated with consumer interest in plug-in electric vehicles? *Transportation Research Part D: Transport and Environment*, 36, 1—9.

9.1. Background and Analysis

There is some evidence that the uptake of PEVs may depend on the availability of home charging infrastructure (Smart, 2013; Axsen and Kurani, 2013b). Policymakers often seek to increase the visibility of PEV chargers in public locations in effort to build familiarity and interest in PEVs. However, it is not clear if the visibility of public charging stations actually has an impact on PEV demand. The purposes of the present study are to:

» 1. Assess the current levels of visibility for public PEV charging infrastructure within Canada, and

» 2. identify whether or not a statistically significant relationship exists between consumer awareness of public charging infrastructure and interest in purchasing a PEV.

We perform this analysis with our sample of Mainstream vehicle buyers (NVOS data). Specifically, we assess the current levels of visibility for public PEV charging infrastructure within Canada (as summarized in Section 7.3) and identify if there is a statistically significant relationship between awareness of public charging infrastructure and consumer interest in purchasing a PEV. We explore the importance of two unique concepts of charger awareness: perceived charger existence as having seen a public charger in at least one location type, and perceived charger abundance as having seen PEV chargers in at least two location types, e.g. at a workplace and in a mall. In this section, we present a brief summary of results from this analysis.

Data for this analysis were collected from all three parts of the NVOS survey, including:

» questions about public charger visibility in Part 1 (see public charging awareness in 7.3);

» the home recharge assessment questionnaire in Part 2 (see home charging access in Section 7.1); and

» the vehicle design games in Part 3 (see Section 8).

Data were analyzed in two stages. First we assessed charger awareness from public charging visibility data in Part 1. Second, we combined data from all three survey components mentioned above to investigate the relationship between charger awareness and PEV interest. We developed our investigation using binary logistic regression to control for socio-demographics and variables relating to respondent readiness for a PEV. Socio-demographic variables included income, age, education, household size, and geographic location. PEV-readiness variables included home charger availability because this has previously been shown to be influential in PEV preferences (Axsen and Kurani, 2013b).

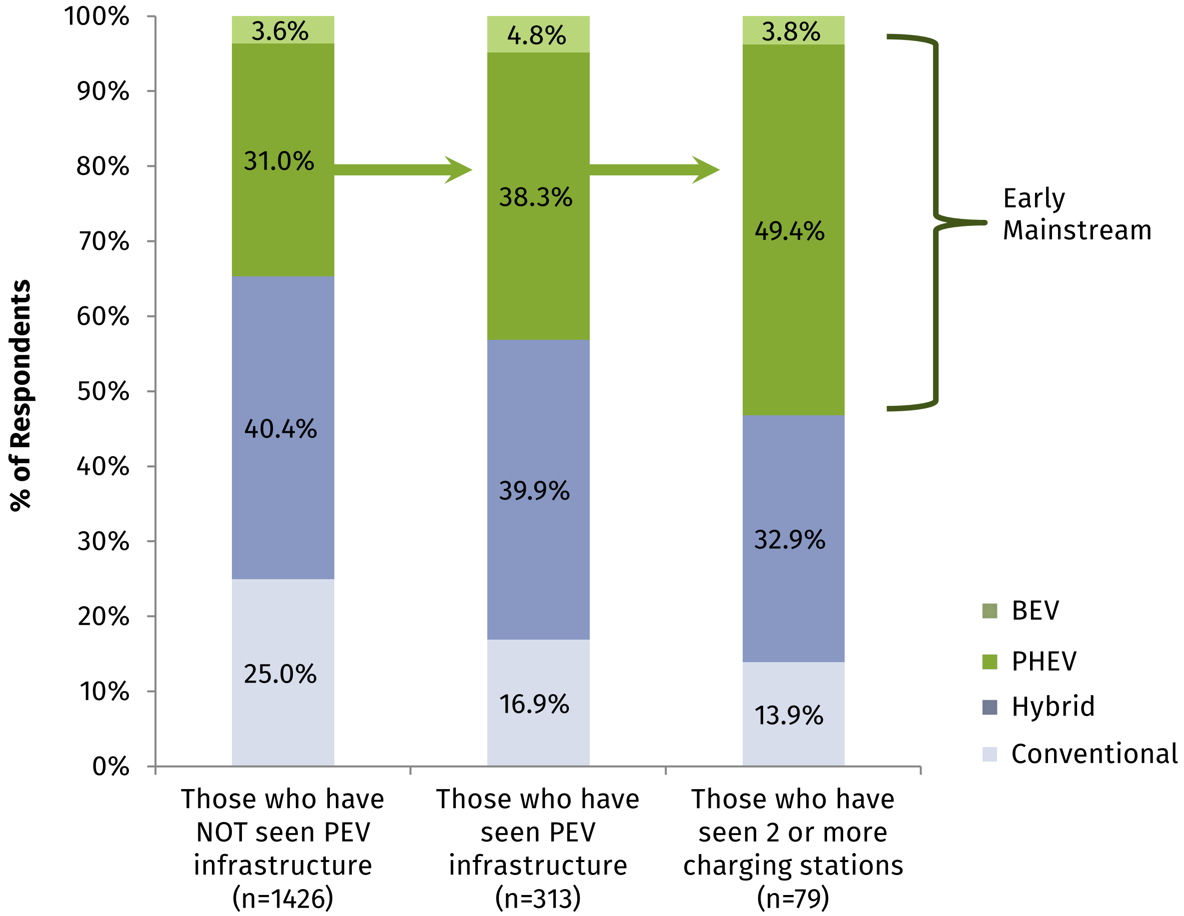
In our regression, we also controlled for respondents having prior interest in PEVs, as individuals with prior interest may be more likely to notice and remember PEV infrastructure. In other words, any significant relationship we observe between charger awareness and PEV interest might be spurious if pre-existing PEV interest is the true explanation. To test for this particular pattern, we attempted to control for ‘‘pre-existing PEV interest’’ with two different explanatory variables: prior research into one of two specific PEV models (Leaf and volt) and stated familiarity with either of these PEV models.

9.2. Results

Section 7.3 already summarizes overall Mainstream respondent awareness of chargers, by frequency and location in British Columbia (Figure 17). Overall, 31% of British Columbia respondents reported awareness of at least one public charger and 7% were aware of two or more. Compared to the rest of Canada, awareness in British Columbia was significantly higher, where only 13% of respondents reported having seen at least one charger in the rest of Canada.

According to our bivariate analysis, the level of PEV interest is associated with awareness of public chargers at a 99% confidence level. Figure 24 compares stated PEV interest (i.e. designed a PEV in Part 3) among respondents with different levels of charger awareness. About 43% of respondents with perceived public charger existence stated PEV interest, compared to 35% of those with no public charger awareness. However, this analysis does not control for other potentially important explanatory variables.

Figure 24: Vehicle designs among Mainstream respondents according to public charger awareness (n = 1739)



To explore the relationship between consumer interest in PEVs and awareness of charging locations we performed binary logistic regression analysis, allowing us to control for the explanatory variables noted above. We estimated the five regression models shown in Table 24:

i. with charger awareness variables (perceived existence and abundance) only,

ii. with all socio-demographic variables and "PEV research" as the proxy variable for pre-existing PEV interest,

iii. a reduced version of model (ii).

iv. with all socio-demographic variables and "PEV familiarity" as a proxy variable for pre-existing PEV interest, and a reduced version of the model (iv).

Table 24: Regression models summarizing influence of PEV readiness and socio-demographics on interest in PEVs (Mainstream NVOS sample)

		"PEV research" as proxy		"PEV familiarity" as proxy	
	Public charger awareness variables only (i)	Full (ii)	Reduced (iii)	Full (iv)	Reduced (v)
PEV Readiness					
Perceives public charger "existence"	0.180	0.004		-0.076	
Perceives public charger "abundance"	0.700 ***	0.454 **	0.488 **	0.311	0.349
"Has researched" a Volt or Leaf (or both)		0.542 ***	0.567 ***		
"Familiar with" a Volt or Leaf (or both)				0.293 **	0.304 **
Has Level 1 (110/120-volt) access at home		0.807 ***	0.857 ***	0.792 ***	0.825 ***
Has Level 2 (220/240-volt) potential at home		0.156		0.093	
Socio-Demographics					
Resident of British Columbia (Base = other)		0.373 ***	0.359 ***	0.220 **	0.204
Resident of urban location (Base = other)		-0.041		-0.043	
Bachelor's degree (Base = < Bachelor's)		0.173		0.200	
Graduate Degree (Base = less than Bachelor's)		0.402 **	0.333 **	0.439 **	0.352 *
Income \$50—99k/yr (Base = < \$50k/yr)		-0.038		0.019	
Income \$100—149k/yr (Base = < \$50k/yr)		-0.079		-0.010	
Income >\$149k/yr (Base = < \$50k/yr)		-0.034		-0.099	
# in Household (continuous)		0.106 *	0.137 ***	0.092	0.114 *
Age < 35 years(Base = >54 years)		0.508 ***	0.392 ***	0.484 ***	0.409 **
Age 35—54 (Base = >54 years)		0.185		0.126	
Constant	-0.635 ***	-1.995 ***	-1.920 ***	-1.274 ***	-1.203
-2 Log likelihood	2283.7	2182.9	2189.2	1628.8	1632.5
Nagelkerke R square	0.009	0.085	0.080	0.076	0.072

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

In our multiple-regression results, perceived charger existence was only determined to have a statistically significant association with interest in PEV uptake when we used a single independent variable (not shown). Perceived charger abundance however, was significant in models (i), (ii) and (iii). Perceived abundance was estimated to be a significant predictor at the 95% confidence level in both models where we used "PEV research" as a proxy to represent prior interest in PEVs. In contrast, perceived abundance was not estimated to be a significant predictor in models (iv) and (v), where we used the "PEV familiarity" as a proxy for prior interest in PEVs.

Across all four models that control for socio-demographic factors, PEV interest is higher for residents of British Columbia, respondents with a graduate degree, and for younger individuals. Also, individuals that exhibited prior interest in PEVs by either proxy were more likely to be interested in PEVs. We also see that access to Level 1 charging at home is a reliable and highly significant predictor of PEV interest.

Thus, when controlling for other explanatory factors through regression analysis, we find that perceived charger existence did not have a statistically significant relationship with consumer interest in PEVs. Perceived charger abundance had a statistically significant relationship with PEV interest in some models, but this association was weak at best, and non-existent in the other models. Thus, our measures of public charger awareness did not serve as robust predictors of PEV interest. The significant associations we saw in the bivariate analyses may actually be spurious, as the relationships diminish or disappear when other explanatory factors are introduced. Though, we do demonstrate that our distinction between perceived public charger existence and abundance provides a unique perspective on the potential association with PEV interest relative to previous studies (Carley et al., 2013; Krause et al., 2013). Indeed, the notion of "abundance" might be more likely to serve as a significant factor in PEV interest, which should be further tested and refined in future research.

In terms of PEV readiness, respondents with Level 1 (110/120-volt) charger access at home and respondents whom have previously researched PEV technology are more likely to be interested in PEVs - which also supports previous findings in Germany (Hackbarth and Madlener, 2013). In particular, Level 1 charger access seems to be a key predictor of interest in PEVs, being a significant predictor at a high significance level (99%) in all regression models. This finding suggests that policies aimed at investment in home recharge accessibility could have a greater impact on PEV adoption than those that focus on public charging infrastructure—such as subsidies for home charger installation or building regulations that require or facilitate charger installation. Development of home charging availability may be particularly effective among residents of apartment buildings and in housing situations where respondents are less likely to already have some form of home charger access.

10. Heterogeneity in Consumer Interests and Motivations

Research Highlights for Section 10

Among Mainstream (NVOS) respondents:

- There is substantial heterogeneity according to PEV preferences and motivations.
- Preference-based segments differ in PEV interest and willingness-to-pay.
- The "PEV-enthusiast" class (representing 8% of Mainstream respondents) expresses very high valuation of PEVs, similar to our model of PEV Pioneers (in Section 8.2).
- Lifestyle-based segments differ in motivations for PEVs, including interests related to the environment and technology.

Among PEV Pioneer (PEVOS) respondents:

- There is also substantial variation in motivations for PEV interest, including environment- and technology-oriented motives.

NOTE: This Section includes analysis from a manuscript that is currently in peer review.

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Consumer Heterogeneity

It is intuitive that consumers vary in their tastes and preferences for new products and technologies. One consumer might be wildly enthusiastic about PEVs, a second consumer shows cautious interest, while a third completely rejects the concept. Consumers can be segmented according to these stated or revealed preferences for new technology, where these preferences are often quantified in terms of willingness-to-pay.

Consumers also vary in the motivations that underlie their preferences. For example, two consumers might demonstrate the same enthusiasm (and willingness-to-pay) for a PEV, but one wants to drive a pro-environmental symbol while the other is excited about owning a cutting-edge technology (Heffner et al., 2007). Arguably, effective characterization of consumer heterogeneity should address variations in consumer motivations as well as overall preferences. This study aims to explore both aspects of heterogeneity among Mainstream (NVOS) and Pioneer (PEVOS) respondents.

Understanding heterogeneity can be important in the anticipation of demand for emerging technologies with potentially pro-environmental attributes, such as alternatively-fuelled vehicles, solar panels, and energy efficient appliances. Such products are complex in that they can offer a mix of private, symbolic and pro-societal benefits to the consumer (Brown, 2001; Heffner et al., 2007).

In this section we segment Mainstream respondents first based on preferences, and then based on lifestyles. Section 10.3 then looks at how PEV Pioneers vary in terms of perceptions, based on PEVOS interview data.

10.1. Preference-based Segments (Latent Class)

Methodological Approach

Here we apply a preference-based approach to explore key differences in consumer preference and to identify groups of participants with PEV interest. Most previous research into consumer demand for alternative-fuel vehicles has focused on preferences, typically estimating some form of discrete-choice model using empirical consumer data to quantify consumer valuation of technology (e.g. a PEV), or its attributes (e.g. one extra km of electric battery range) (e.g., Bunch et al., 1993; Potoglou and Kanaroglou, 2007). In that vein, we apply a latent-class discrete choice model as a way to identify consumer segments that primarily differ according to overall preferences (Swait, 1994). Latent-class choice modeling is an approach that has infrequently been applied to PEV demand, other than a few recent studies (e.g., Hidrue et al., 2011). A latent-class model, divides a sample into a given number of classes (or segments) and estimates separate sets of coefficients for each class (Greene and Hensher, 2003; Shen, 2009; Zito and Salvo, 2012).

Part 3 of the survey instrument included a stated choice experiment that we used to estimate a discrete choice model (described in Section 4.2). Discrete choice models quantify consumer preferences and are based on random utility theory, assuming that overall consumer utility for a product is based on components that are observable and unobservable. The most common choice modeling technique is the simple multinomial logit (MNL) which estimates a single set of coefficients for the entire sample (which we implemented in Section 8.2). To quantify heterogeneity in consumer preferences, in this analysis we estimate a latent-class choice model which divides the sample into a predefined number of classes (or segments) and estimates separate sets of coefficients for each class (Greene and Hensher, 2003; Shen, 2009; Zito and Salvo, 2012). The latent-class model assumes that individual preferences can be discretely grouped according to different patterns of preferences. This approach can be designed to use individual characteristics to facilitate the formation and interpretation of class membership, e.g. demographic and psychographic characteristics (Strazzera et al., 2012). The estimation of coefficients for a given class can use an MNL or any other discrete model.

We estimate a latent class choice model using data collected via the stated choice experiments in the survey instrument (Part 3). As explained in Section 4.2, every respondent indicated the make, model, purchase price and fuels cost of their next anticipated new vehicle purchase (which initially we asked them to limit to being a conventional vehicle). This information was then used to present six customized vehicle choice sets to the respondent. Each choice set presented four different vehicles: a conventional vehicle (CV, their next anticipated vehicle purchase), and a hybrid (HEV), plug-in hybrid (PHEV) and pure electric version (BEV) of that vehicle.

We estimated the latent-class choice model with Latent Gold version 5.0 (Vermunt and Magidson, 2013). Although there are statistical diagnostics that are commonly used to determine the optimal number of classes, we emphasize that our present focus is on improving our understanding of heterogeneity in consumer preferences and motivations—not just maximizing the predictive performance of the model.

Thus, we consider several criteria when selecting the number of classes to include in our model, ordered here from most important to least: 1) maximizing the interpretability of the solution, 2) avoiding solutions with proportionally large classes (e.g. greater than 50% of sample) or very small classes (e.g. less than 5% of sample), 3) avoiding solutions where two or more classes are essentially identical, and 4) if consistent with the above objectives, maximizing statistical measures of quality and parsimony, namely the Akaike information criterion (AIC) and Bayesian information criterion (BIC) (Louviere et al., 2000). We calculate WTP values for each class using coefficient estimates that are statistically significant at a 95% confidence level.

Results

Table 25 shows our latent class model based on a five class solution and depicts the coefficient estimates for the discrete choice model in each class, the calculations for willingness-to-pay, and the demographic and lifestyle characteristics that are associated with respondents in each class. We focus on the five class solution because it reveals clear and interpretable differences in respondent classes according to alternative specific constants (A.S.C.'s), attribute coefficients, and individual characteristics.

Across all five classes, all the vehicle price and fuel cost coefficient estimates are significant and of the expected sign. Most of the constant terms (representing overall interest in an HEV, PHEV, or BEV) are significant and half of the PEV constant interactions with Level 2 access at home are significant (the latter indicating that WTP for a PHEV or BEV is higher if faster charger speed is available at the respondent's home).

The five classes differ most obviously according to respondent interest in vehicle technologies (i.e. their alternative specific constants):

1. The "PEV-enthusiast" class (representing 8% of the sample) place very high value on HEV, PHEV and BEV designs relative to a CV. This group has high interest in PHEVs and BEVs, but places no significant value on fuel savings.
2. The "PHEV-oriented" class (25% of the sample) has positive and significant constant estimates for HEV and PHEV designs, and a negative and significant constant for BEV designs. This group has high interest in PHEVs and is very conscious of fuel savings.
3. The "HEV-oriented" class (16% of sample) has a significant and positive HEV constant, a significant and positive but relatively smaller PHEV constant, and a significant and negative BEV constant. The group prefers HEVs to other vehicle types.
4. The "HEV-leaning" class (27%) only has a positive constant for HEVs, which is smaller than the "HEV-oriented class." This group has some interest in HEVs.
5. The "CV-oriented" class (23%) has negative constants for all three vehicles, though the BEV estimate is not significant. The group has no interest in any other vehicle but a CV.

Table 25: Latent-class results 5-class solutions (Canadian Mainstream NVOS sample, n = 1754)

Class label	PEV-enthusiast	PHEV-oriented	HEV-oriented	HEV-leaning	CV-oriented
Probability of Membership	**8.0%**	**25.4%**	**5.9%**	**27.7%**	**23.0%**
Discrete choice model					
HEV constant	0.64 **	2.30 ***	2.65 ***	0.88 ***	-2.91 ***
PHEV constant	2.09 ***	3.22 ***	-1.37 ***	-0.11	-4.72 ***
BEV constant	2.14 ***	-1.16 **	-5.07	-3.10 ***	-2.15
Vehicle price (CAD$)	-0.00002 ***	-0.0002 ***	-0.0002 ***	-0.0006 ***	-0.0003 ***
Fuel cost (CAD$/week)	0.0002	-0.0407 ***	-0.0079 ***	-0.0387 ***	-0.0197 ***
PHEV range (km)	-0.0035	-0.0033	0.0118 **	0.0065 **	0.0039
BEV range (km)	-0.0017	0.0038	0.0003	0.0057 **	-0.0195
PHEV × Level 2 charging at home	0.11	0.51 ***	1.04 ***	0.51 ***	-0.20
BEV × Level 2 charging at home	0.62 ***	1.20 ***	3.67	0.26	-1.08
Implied willingness-to-pay[a]					
Saving $1000/year in fuel		$3,781	$670	$1,258	$1,126
HEV	$41,245	$11,090	$11,692	$1,493	-$8,637
PHEV[b]	$135,026	$15,568	-$6,028		-$14,021
BEV[b]	$137,794	-$5,612		-$5,246	
PHEV with Level 2 charging		$2,444	$4,602	$856	
BEV with Level 2 charging	$39,981	$5,805	$670	$1,258	
Class membership model [relative to base]					
Constant	-6.0 ***	-1.9 ***	-0.5	[Base]	1.2 ***
Household size (number of people)	0.17 *	0.10	-0.15 **		-0.22 ***
$50,000 to $99,999 [Base = "<$50,000]	0.18	-0.28 *	-0.29 *		-0.20
$100,000 to $150,999 [Base = "<$50,000]	0.36	-0.21	0.15		0.15
$150,000 or more [Base = "<$50,000]	-0.05	-0.28	0.15		0.12
Bachelor's degree [Base = "less than Bachelor's]	0.43	0.15	-0.30 *		-0.54 ***
Graduate degree [Base = "less than Bachelor's]	0.12	-0.03	-0.38 *		-0.94 ***
Live in Alberta [Base = "rest of Canada"]	1.14 **	0.28	0.45 *		-0.17
Live in British Columbia [Base = "rest of Canada"]	1.42 ***	0.42 **	0.59 **		-0.11
Live in Ontario [Base = "rest of Canada"]	0.75 *	-0.04	0.03		-0.23
Technology-oriented lifestyle score	0.10 ***	0.02	-0.01		-0.04 **
Environment-oriented lifestyle score	0.10 ***	0.09 ***	0.02		0.02
Environmental concern (NEP score)	0.06 ***	0.04 ***	0.03 *		-0.04 ***
Liminality score	0.02	0.00	0.04 **		0.03 *

* Significant at 90% confidence level

** Significant at 95% confidence level

*** Significant at 99% confidence level

a We only depict willingness-to-pay calculations where the coefficient estimates are significant at a 95% confidence level or greater. As of February 12, 2015, $1.00 CDN is equivalent to $0.80 USD and €0.70 EUR

b Because the coefficient estimate for PHEV and BEV range are not statistically significant, our willingness-to-pay calculations for PHEV and BEV are not based on the range of a given PHEV or BEV (e.g. PHEV-16 vs. PHEV-32).

Table 25 also presents the willingness-to-pay for all classes. The PEV-enthusiast class has the highest WTP values for HEVs, PHEVs and BEVs, indicating that even if fuel costs are equivalent to that of a conventional vehicle, the average respondent in this class would pay over $40,000 extra for an HEV, or pay more than $130,000 extra for a PHEV or an BEV (and an extra $40,000 more for a BEV if Level 2 charging were available at their home). These WTP values seem inflated and probably should not be interpreted in a literal sense, but at least indicate a strong level of enthusiasm for these technologies (hence the "PEV- enthusiast" label). Also note that the PEV-enthusiast class has similar valuation of PEVs as the discrete choice model estimated with Pioneer (PEVOS) respondents (Section 8.2). The PHEV-oriented class generally prefers PHEV designs, and is on average willing to pay an extra $15,000 for such a design. The HEV-oriented, HEV-leaning, and CV- oriented classes do not have positive WTP values for any PEV designs.

The class membership model (lower half of Table 25) provides further description of the respondents in each identified class. The HEV-leaning class is used as the "base" or reference point for the other classes. PEV-enthusiast and PEV-oriented respondents are the most likely to engage in environment-oriented lifestyles and to have high levels of environmental concern. PEV-enthusiast respondents are unique in being the most likely to also engage in technology- oriented lifestyles. These findings support the notion that PEV (and HEV) interest is associated with a higher degree of environmental concern and lifestyle as indicated by previous choice modeling studies (e.g., Ewing and Sarigollu, 2000; Hidrue et al., 2011) and also supports exploratory research suggesting that PEV interest can be associated with engagement in a technology-oriented lifestyle (Axsen et al., 2012). The classes generally do not differ according to household income, but we do see regional variations, where membership in PEV-interested classes is associated with residence in the Province of British Columbia.

10.2. Lifestyle-based Segments (Cluster Analysis)

Methodological Approach

To quantitatively explore heterogeneity in consumer motivations, we also construct consumer segments based on "lifestyle theory"—which describes consumer behaviour as at least partially motivated by the need to engage in coherent patterns of lifestyle that represent aspects of self-identity (Axsen et al., 2012; Giddens, 1991). Lifestyle theory postulates that a consumer is more likely to purchase and use a new technology like a PEV if it fits into a lifestyle that they currently engage in or want to engage in, such as an environment- or technology-oriented lifestyle. We identify lifestyle-based consumer segments using a cluster analysis method, and then estimate separate discrete choice models for each segment.

Our lifestyle-based segmentation approach also uses data collected from Mainstream respondents. First, we identify the subset of our sample that we call the Early Mainstream respondents—those that selected a PEV design in the PEV design space exercise. The design space exercises are further described in Section 4.2, and overall NVOS results are portrayed in Section 8.1. Each respondent completed two PEV purchase exercises, each allowing the respondent to design and select an HEV, PHEV or BEV version of their selected CV.

We then quantified consumer heterogeneity within this Early Mainstream subsample using cluster analysis, a method that identifies relatively homogeneous clusters (or segments) of respondents according to some combination of variables. We used the same four variables utilized by Axsen et al. (2012) to construct lifestyle-based clusters (which we also found to be associated with PEV preferences in our latent class model in Table 26): engagement in environment-oriented lifestyle, engagement in technology-oriented lifestyle, lifestyle liminality, and environmental concern (using the New Ecological Paradigm scale). Specifically, we used K-means cluster analysis in SPSS 14.0, based on standardized data from these four question scales. As with latent-class modeling, K-means cluster analysis allows the researcher to specify the number of clusters used to segment the sample (Horn and Huang, 2009; SPSS Inc., 2004). Our selection of the number of clusters is based on our goals of finding a solution that: 1) is interpretable, 2) avoids proportionally large clusters (e.g. greater than 50% of sample) or very small clusters (e.g. less than 5% of sample), and 3) has at least the number of clusters where inter-cluster variability exceeds intra-cluster variability (a measure indicating that clusters substantially differ from one another).

Our analysis then characterizes these clusters of respondents by comparing: lifestyle engagement, environmental concern, biospheric (pro-environmental) values, PEV interest and familiarity, and demographic characteristics. We look for statistically significant differences between the Early Mainstream clusters using chi-square tests of association. To quantify preferences within each cluster, we estimated discrete choice models for each cluster, using the same vehicle attribute variables as the latent-class model (MNL models using the LIMDEP software package). WTP values are calculated for each lifestyle-based cluster using coefficient estimates that were significant at a 95% confidence level.

Results

We used the K-means clustering method to identify a six-cluster solution for our “Early Mainstream” sub-sample based on the four cluster variables noted above (Table 26). This solution was found to be interpretable and largely consistent with the five lifestyle-based clusters identified by Axsen et al. (2012). For convenience of interpretation, we further divide the six clusters into two broad categories based on the K-means results: pro-environmental and non-environmental.

Table 26: PEV lifestyle-cluster descriptions and center values (NVOS Early Mainstream, n = 635)

	Pro-environmental			Non-environmental		
Variable	**Strong**	**Tech-enviro**	**Concerned**	**Techie**	**Open**	**Unengaged**
Discrete choice model						
Environmental concern (NEP)	1.01	-0.80	0.92		-0.50	-0.50
Environment-oriented lifestyle	0.98	1.26	-0.22	-0.27	-0.48	-0.48
Technology-oriented lifestyle	0.47	0.93	-0.86	0.75	-0.15	-0.15
Liminality (openness to change)	1.04		-0.61	-0.48	0.92	0.92
Sample size	107	74	119	107	112	112
% of PEV designing sample	17%	12%	19%	17%	18%	18%

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. Only cluster centers greater than 0.15 and less than -0.15 are depicted.

In Table 27 we compare the six clusters with a chi-square test of association according to lifestyle, values, attitudes, PEV-related details, and demographics. For reference, we also show the corresponding values for the 67% of respondents that designed a CV or HEV (non-PEV buyer segments or the "Late Mainstream"). Based on our analysis of Table 27 we observe significant differences between the six potential Early Mainstream PEV buyer segments:

Respondents in the "Strong" pro-environmental cluster...

- have the highest biospheric values and environmental concern, and high engagement in pro-environmental lifestyle;
- are the most likely to perceive climate change and air pollution as "serious" threats;
- are likely to see a variety of PEV information sources as important, including news providers, car dealers, friends and government;
- are the most likely to have researched the Toyota Prius or Chevrolet Volt; and
- are the second most likely to be female (64%).

Respondents in the "Tech-enviro" pro-environmental cluster...

- have the highest levels of engagement in environment- and lifestyle-oriented lifestyles;
- are the most likely to have designed an BEV in the design space exercise (18%);
- are relatively likely to have researched the Toyota Prius, Chevrolet Volt, or Nissan Leaf;
- are also likely to see a variety of PEV information sources as important ; and
- have the highest education levels.

Respondents in the "Concerned" pro-environmental environmental cluster...

- have a high NEP-score and are the most likely to see climate change and air pollution as "serious" threats;
- are not much more likely to engage in pro-environmental lifestyles relative to non-PEV buyers segments;
- are the least likely to engage in a technology-oriented lifestyle, even compared to non-PEV buyer segments;
- are the most likely to be female (71%), and tend to have the lowest education level;
- are the least likely to have researched the Prius, Volt or Leaf; and
- are the least likely to perceive any PEV information sources as important.

Respondents in the "Techie" non-environmental cluster...

- have the highest engagement in a technology-oriented lifestyle;
- are the most likely to have previously researched the Nissan Leaf; and
- are the most likely to be male (55%).
- Respondents in the "Open" cluster:
- are the most likely to be over the age of 54; and
- are relatively unconcerned about air pollution, climate change, or the environment more generally.

Respondents in the "Unengaged" non-environmental cluster...

- are the least likely to engage in environment- or technology-oriented lifestyles— even lower than the conventional vehicle buyer segment;
- have the least liminal lifestyles;
- have the lowest levels of biospheric values and environmental concern;
- are the least likely to be concerned about climate change or air pollution; and are the least likely to have selected an BEV in the design space exercise (4%).

Table 27: Comparing lifestyle-based segments by characteristics (Canadian Mainstream NVOS sample, n =1754)

	Potential Early Mainstream (n = 634)						Late Mainstream (n = 1120)	
	Pro-environmental PEV segments			Non-environment PEV segments				
Variable	Strong (n = 107)	Tech-enviro (n = 74)	Concerned (n = 119)	Techie (n = 106)	Open (n = 112)	Unengaged (n = 116)	Designed HEV (n = 708)	Designed CV (n = 412)
Lifestyle, values and attitudes								
Environment-oriented lifestyle (mean score 0 to 25)***	17.2	18.3	12.3	12.1	11.2	10.1	12.1	11.5
Technology-oriented lifestyle (mean score 0 to 25)***	16.0	18.0	10.2	17.3	13.3	10.9	13.1	12.4
Lifestyle liminality (mean score -16 to +16)***	5.9	1.2	-1.6	-1.0	5.3	-2.4	0.5	-0.7
Environmental concern (NEP) score -16 to +16)***	11.5	2.3	11	6.2	3.8	2.1	5.4	4.2
Biospheric values (mean score 0 to 12)***	11.2	9.5	10.1	9.1	8.9	7.9	9.1	9.0
Climate change is "serious problem." (%)***	68.2	40.5	66.4	31.1	21.4	12.9	29.9	24.3
Air pollution is "serious problem." (%)***	67.3	47.3	71.4	37.7	33.9	26.7	37.9	32.5
PEV-specific details								
Vehicle designed (%)*								
Designed PHEV-16	8.4	14.9	19.3	9.4	11.6	16.4	0.0	0.0
Designed PHEV-32	29.9	31.1	26.9	35.9	28.6	33.6	0.0	0.0
Designed PHEV-64	48.6	36.5	43.7	41.5	51.8	45.7	0.0	0.0
Designed BEV (80km to 240km)	13.1	17.6	10.1	13.2	8.0	4.3	0.0	0.0
Importance of PEV information source (1 to 4)								
Magazines***	2.0	2.7	1.4	2.0	1.5	1.4	1.6	1.6
News***	2.8	2.9	2.1	2.6	2.4	2.1	2.4	2.1
Dealers***	2.6	2.7	1.8	2.1	2.1	1.9	2.0	1.8
Friends***	2.9	2.9	2.2	2.4	2.5	2.2	2.5	2.2
Government***	2.4	2.7	1.5	2.0	1.8	1.6	1.9	1.7
Researched Toyota Prius (%)***	26.2	24.3	5.9	21.7	11.6	6.9	10.5	6.3
Researched Chevrolet Volt (%)***	21.5	17.6	3.4	17.9	6.3	4.3	5.7	7.3
Researched Nissan Leaf (%)***	13.1	12.2	2.5	15.1	5.3	1.7	2.8	3.9
Demographics								
Female (%)***	63.6	47.3	70.6	45.3	56.3	59.5	57.3	60.9
Age (%), ns								
<35	32.7	35.1	27.7	45.3	37.5	35.3	27.7	25.7
35—54	39.3	40.5	43.7	35.9	28.6	38.8	41.8	30.6
>54	28.0	24.3	28.6	18.9	33.9	25.9	30.5	43.7
Income (%), ns								
<50k	19.0	19.1	22.0	28.3	24.3	23.2	23.6	28.1
50—99k	52.6	55.9	52.3	39.4	44.7	50.0	49.7	46.3
<100k	28.4	25.0	25.7	32.3	31.1	26.9	26.8	25.6
Bachelor's degree***	22.4	42.5	20.3	30.5	31.3	30.2	28.1	19.4
Grad***	22.4	27.4	9.3	13.3	8.0	12.9	12.1	9.3
Live in detached house (%), ns	72.9	71.6	62.2	70.8	63.4	68.1	63.1	65.3

Note: Differences indicated among 6 clusters;

ns not significant

* Significant at 90% confidence level

** Significant at 95% confidence level

*** Significant at 99% confidence level

Table 28: Comparing respondent clusters by preferences and willingness to pay (Canadian Mainstream NVOS sample, n =1754)

	Potential Early Mainstream PEV buyers (n = 634)						Other (n = 1120)	
	Pro-environmental PEV segments			Non-environment PEV segments				
Variable	**Strong (n = 107)**	**Tech-enviro (n = 74)**	**Concerned (n = 119)**	**Techie (n = 106)**	**Open (n = 112)**	**Unengaged (n = 116)**	**Designed HEV (n = 708)**	**Designed CV (n = 412)**
Constant								
HEV	1.12 ***	0.83 ***	0.73 ***	1.45 ***	0.71 ***	1.15 ***	1.05 ***	-1.70 ***
PHEV	2.16 ***	1.90 ***	1.71 ***	2.01 ***	1.12 ***	1.60 ***	0.033	-2.23 ***
BEV	0.17	0.426	-0.97	1.01 *	-1.95 **	-1.69 **	-2.35 ***	-3.47 ***
Vehicle price (CAD$)	-0.0002 ***	-0.0001 ***	-0.0002 ***	-0.0002 ***	-0.0003 ***	-0.0002 ***	-0.0002 ***	-0.0003 ***
Fuel cost (CAD$/week)	-0.010 **	-0.008 ***	-0.015 ***	-0.015 ***	-0.036 ***	-0.0082 *	-0.011 ***	-0.011 ***
Range								
PHEV (km)	0.0001	-0.0016	-0.0010	0.0067	0.0089 **	0.0027	-0.0036	0.0003
BEV (km)	0.0019	-0.0018	0.0031	-0.0004	0.0031	0.0057	0.0012	0.0005
Home charging availability								
PHEV × Level 2 charging	0.34 **	0.21	-0.050	0.58 **	0.26	0.43 **	0.27 ***	0.21
BEV × Level 2 charging	0.80 ***	0.67 **	0.55 **	0.17	1.08 ***	1.00 ***	0.65 ***	0.32
Implied willingness-to-pay[a]								
Saving $1000/year in fuel	$1,161	$1,095	$1,712	$1,513	$2,284		$951	$719
HEV	$6,734	$5,631	$4,505	$7,443	$2,365	$5,934	$4,640	-$5,979
PHEV[b]	$13,020	$12,867	$10,535	$10,281	$3,707	$8,272		-$7,857
BEV[b]					-$6,456	-$8,724	-$10,348	-$12,230
PHEV with Level 2 charging	$2,050			$2,950		$2,219	$1,191	
BEV with Level 2 charging	$4,833	$4,533	$3,367		$3,576	$5,139	$2,871	
Model								
Number of observations	642	444	714	636	672	696	4248	2472
R-square	0.210	0.209	0.198	0.207	0.201	0.224	0.251	0.608
Log-likelihood	-700	-484	-790	-696	-741	-746	-4411	-1340

* Significant association at 90% confidence level

** Significant association at 95% confidence level

*** Significant association at 99% confidence level

a We only depict willingness-to-pay calculations where the coefficient estimates are significant at a 95% level or greater.

b Because the coefficient estimate for PHEV and BEV range are not statistically significant, our willingness-to-pay calculations for PHEV and BEV are not based on the range of a given PHEV or BEV (e.g. PHEV-16 vs. PHEV-32).

Table 28 depicts the discrete choice models estimated for each of these six clusters, and the non-PEV respondents. Some patterns are similar across the six Early Mainstream clusters; each has a positive WTP for an HEV ($2,365 to $7,443) and an even higher WTP for PHEVs ($3,707 to $13,020); and WTP for a BEV is either negative (-$6,456 to -$8,724) or not statistically significant. As might be expected, WTP values are higher for clusters that are more likely to engage in environment-oriented lifestyles (Strong and Tech-enviro), and technology-oriented lifestyles (Techie).

Across clusters there is some variation in WTP for saving fuel costs, and for Level 2 charging at home. But for the most part, the six Early Mainstream clusters exhibit preference patterns that are more similar than different—despite have very different motivations as indicated by lifestyle engagement, liminality and environmental concern. For example, respondents in the "Strong Pro-Environmental" and "Techie" clusters have nearly identical WTP values for HEV and PHEV designs as well as the fuel savings attribute—yet cluster members differ substantially by environmental lifestyle engagement, concern about the environment and climate change, biospheric values, and lifestyle liminality or openness to change.

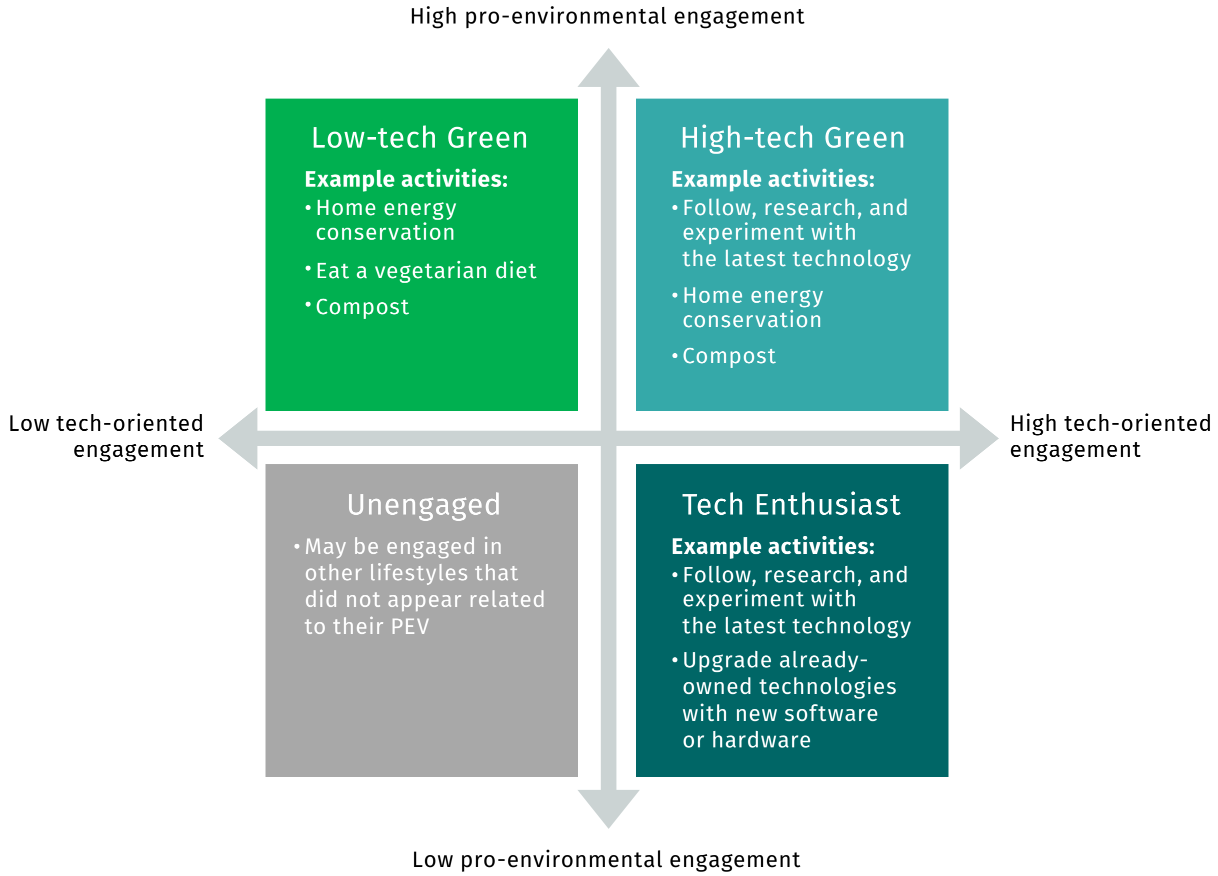
In summary, we provide evidence that heterogeneity can be substantial and important. We also demonstrate that a given approach to heterogeneity will shape the insights that can be discovered. Our preference-based approach identified segments with very different preferences for HEVs, PHEV and BEVs, and their attributes. This preference-based approach also suggests that PEV interest is generally associated with engagement in certain lifestyles and environmental concern. In contrast, our lifestyle-based approach instead identified segments with very different combinations of lifestyle and concern, yet in some cases had very similar PEV preferences. In other words, while our latent-class discrete choice model helped to characterize how consumer choices (outcomes) may differ among respondents, the lifestyle-based cluster analysis served to better characterize how consumer motivations may differ. Both sets of insights can be useful, providing different types of insights into different types of consumer heterogeneity.

10.3. PEVOS Interview Participant Heterogeneity

To complement our analysis of heterogeneity among Mainstream (NVOS) respondents, here we conduct a qualitative lifestyle segmentation analysis of PEVOS interview participants. In this analysis, we segment interview participants based on their engagement in different lifestyles, as indicated in the interviews. As in Section 10.2, we draw from lifestyle theory to identify how interview participants perceive and value PEVs according to their engagement in lifestyles, which reflect self-concept or identity (Giddens, 1991; Axsen et al., 2012).

We constructed lifestyle segments by grouping participants with similar lifestyle engagement related to pro-environmental activities (e.g. energy conservation, composting, low consumption) and technology-oriented activities (e.g. reading technology blogs, frequent technology upgrades). Four lifestyle segments emerged from the PEVOS interviews (depicted as a 2 × 2 diagram in Figure 25), which are further summarized below:

Figure 25: Overview of PEVOS interview lifestyle segments and example lifestyle activities



1. "Tech Enthusiast" PEV owners...

» Make up 5 of the 24 interview participants

» Have the highest levels of engagement in a technology-oriented lifestyle;

» Are critical of PHEVs and perceive them to be technologically inferior to BEVs (e.g. "[The question for manufacturers is] jeez: do you build a pure EV, or do you do something like they did with the Volt ... which I think is the worst of all worlds because you got everything crammed in there. It's jack of all trades and master of none.")

» Are more strongly influenced by technological attributes when purchasing a vehicle

» Likely to be engaged with PEV communities (e.g. VEVA, on-line user groups)

» Most likely to unconditionally support utility controlled charging due to its ability to help optimize the grid

2. "High-tech Green" PEV owners…

- Make up 4 of the 24 interview participants
- Have high levels of engagement in both a technology-oriented and pro-environmental lifestyle
- Are critical of PHEVs and perceive them to be both technologically and environmentally inferior to BEVs (e.g. "so much of [the] car's systems are around mitigating wasted energy … Noise, heat, dealing with fuel that doesn't burn efficiently and goes out the tailpipe. It's all this waste, so it seems pointless to me.")
- Are strongly influenced by both environmental and technological attributes when purchasing a PEV
- Likely to be engaged with PEV communities (e.g. VEVA, on-line user groups)
- Supportive of utility controlled charging for its potential environmental and technological benefits

3. "Low-tech Green" PEV owners…

- Make up 6 of the 24 interview participants
- Have high levels of engagement in a pro-environmental lifestyle
- Are critical of PHEVs and perceive them to be environmentally inferior to BEVs (e.g. "[It] just seems silly … I don't want to burn gas").
- Are strongly influenced by environmental attributes when purchasing a PEV
- Supportive of utility controlled charging for its potential environmental benefit
- More willing to pay to support the development of green electricity

4. "Unengaged" PEV owners…

- Are the largest consumer group in the interviews, consisting of 9 of the 24 participants
- Have the lowest levels of engagement in tech-oriented or pro-environmental lifestyles
- Are most supportive of PHEVs and more likely to see them as a technology that provides the benefits of both a PEV and conventional vehicle (e.g. "it's not 100% electric, but it gives you electric 99% of the time … the only time we burn gas is when we go on a long trip … and it gets rid of 90% of what you need").
- Are not strongly influenced by environmental or technological attributes when purchasing a PEV, but are more likely to be influenced by savings and practicality
- Least supportive of utility controlled charging, and most skeptical of the benefits of such a program

11. Actual and Anticipated PEV Usage

Research Highlights for Section 11

Understanding the actual and potential driving and charging patterns of PEV owners will help us estimate impacts on electricity demand and GHG emissions. As an initial step, we explore the driving patterns of Mainstream and PEV Pioneers in British Columbia, and examine the charging habits of PEV pioneers.

Among Mainstream (NVOS) respondents in British Columbia we find:

- The median driving distance for one “driving day” was 36 km (mean of 54 km).
- Most vehicle travel was 60 km (range of the Volt) or less on 73% of driving days, and less than 125 km (range of the Nissan Leaf) on 90% of driving days.
- 15% arrived home between 5—6PM and 80% were home by 8PM.

Among PEV Pioneer (PEVOS) respondents we find:

- The median driving distance for one “driving day” was 45 km (mean of 59 km).
- Most vehicle travel was 60 km or less on 62% of driving days, and less than 125 km on 94% of driving days.
- Median “driving days” varied across owners of the Nissan Leaf (37 km), the Chevrolet Volt (45 km) and the Tesla (39 km).
- About 63% (521/831) of charging events occur at home, and many of those charging events were overnight where duration was longer than the average time parked at non-home charging locations (average 3.2 hours).
- Interview participants indicated that they increased the number of trips (overall increase in kilometers travelled) they made since purchasing a PEV. Their reasons included: reduced operating costs, increased engagement with the technology, and feeling better about driving.
- Most households interviewed (9 of 13) did not report regular use of public charging infrastructure, instead relying on home or workplace charging.

In this section we investigate anticipated PEV driving patterns drawing from our Mainstream respondents (NVOS) and actual PEV driving and charging patterns from our PEV Pioneer (PEVOS) respondents. To date, few studies have examined the driving and charging habits of these two consumer groups. Early Mainstream driving and potential recharge data have been collected in the US (Axsen and Kurani, 2012c; Axsen and Kurani, 2013b), but not in Canada. Section 11.1 summarizes

Mainstream respondents' driving patterns in British Columbia, while Sections 11.2 and 11.3 look at PEV Pioneer respondents' driving and recharge patterns, respectively. Section 11.4draws from PEVOS interview data to further understand PEV driving behaviour.

11.1. Anticipated Mainstream PEV Usage (NVOS)

Because our Mainstream (NVOS) respondents do not currently own PEVs, we cannot collect data on their actual usage of PEVs. However, we can look at how they use their current conventional vehicles to help anticipate how they might drive PEVs, if they buy them in the future. To do so, we collected driving data from Mainstream respondents using the three-day driving diary in Part 2 of the survey. Prior to analyzing the 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 British Columbia decreased from 538 to 528. In Part 3 of the survey, respondents were shown a summary of their driving data (as they entered in Part 2) and were asked if these patterns were representative of their "typical" driving patterns. 81% reported that their diary data was typical, while 13% stated that they drove significantly less and 5.8% stated they drove significantly more than is typical for them.

Respondents were asked to start their three-day diary on a day when they drove their vehicle for at least one trip. However, some respondents had "zero-trip" days on either 2 or day 3 of their diary. Excluding these zero-trip days, average daily driving distance across respondents was 54 km while the median was 36 km. If these zero-trip days are included, average daily driving distance was 49 km, which would equate to about 17,900 km per year.

The distribution of daily distances driven is shown in Figure 26. We exclude zero-trip days in order to compare our data to the US National Household Travel Survey (NHTS), which is based on a one-day driving diary (and does not include zero-trip days). We find that 63% of diary days were below 50 km and followed a distribution similar to the 2001 US NHTS data (US DOE, 2012).

When comparing daily driving distance to the driving ranges of currently available PEVs, we find that on 73% of diary days, respondents drive less than 60km (the electric range of the Chevrolet Volt) and 90% drive less than 125km (the electric range of the Nissan Leaf). The driving patterns of British Columbia Mainstream respondents are similar to respondents from the rest Canada (respondent driving data for Ontario and Alberta are presented in Section 12).

End of day "home arrival times" (Figure 27) could have important implications for electricity demand, if Mainstream respondents were to drive a PEV in a similar way as their diary vehicle, and if they recharged such a PEV when they arrived at home at the end of the day. For example, data collected from PEV Pioneer respondents' driving diaries indicates that 70% of all final home arrivals involved vehicle charging (see Section 11.2). For Mainstream respondents, the peak arrival time is around 5 PM, where about 15% of respondents arrive between 5—6PM, and most (~80%) respondents arrive home by 8PM. Both findings are similar to 2001 US NHTS data (Tate and Savagian, 2009; Weiller, 2011).

Figure 26: Distribution of daily distance traveled by Mainstream respondents (BC only, n = 528 participants, excluding non-driving days to compare with NHTS data)

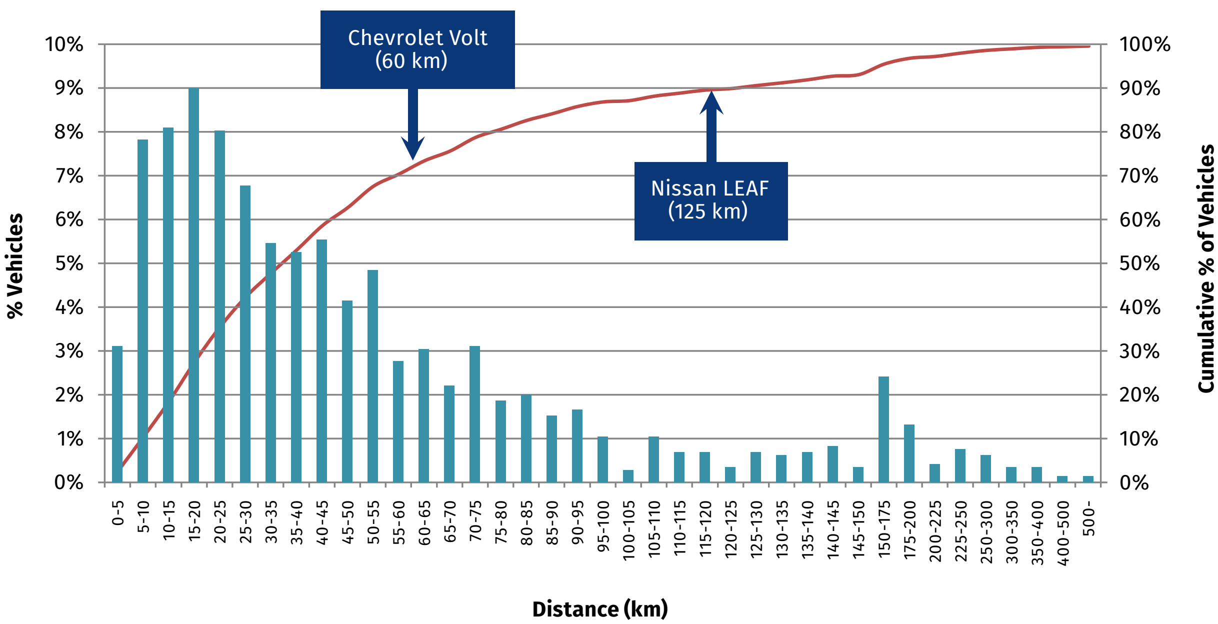
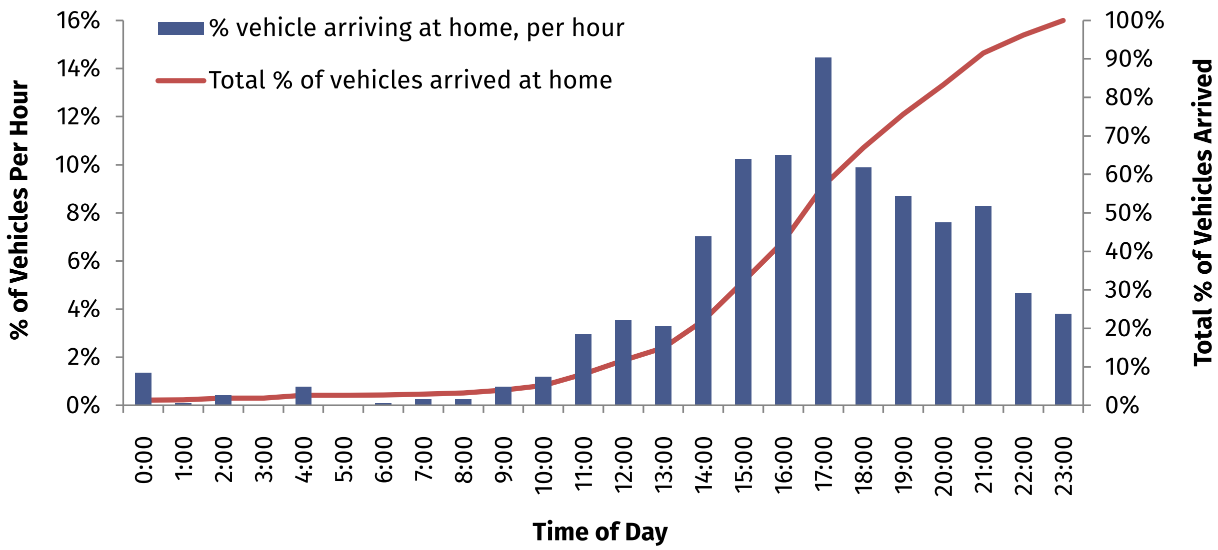


Figure 27: Final home arrival times for Mainstreams' diary vehicle (BC only, n = 528).



11.2. Actual PEV Pioneer Driving Patterns (PEVOS)

Actual PEV driving data were collected from PEV Pioneer respondents using a 5-day driving diary in Part 2 (detailed in Section 4.4). Diary start dates were staggered for each participant to ensure sufficient coverage of weekend and weekdays. Prior to analysis, 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 British Columbia decreased from 631 to 606 diary days: 16 diary days were excluded because the dairies contained missing data or errors, and another 9 diary days were excluded because less than five diary days were submitted. In total, our driving diary analysis covers data from 110 respondents.

Our data indicate that average daily distances are slightly higher for PEV Pioneer respondents relative to Mainstream respondents in British Columbia, but the difference is small (Table 29). Excluding zero-trip days, average daily driving distance was 59 km while the median was 45 km. These values are slightly higher than averages for the Mainstream sample. Including zero-trip days, the average daily driving distance for PEV Pioneer participants was 55 km, which would equate to about 20,150 km per year (compared to 17,900 km per year for the average Mainstream respondent). As portrayed in Figure 28, about 62% of PEV Pioneer vehicles were driven less than the range of a Chevrolet Volt (60 km) on the average diary day, and 92% were driven less than the range of a Nissan Leaf (125 km). These proportions were 73% and 90%, respectively, in the NVOS.

Table 29: Average and median driving distance for the Mainstream and PEV Pioneer British Columbia samples

British Columbia Samples	Mainstream		PEV Pioneers	
Variable	**Non-driving days included**	**Non-driving days excluded**	**Non-driving days included**	**Non-driving days excluded**
Average driving distance (km)	49	54	55	59
Median driving distance (km)	33	36	43	45

Daily driving distances varied across owners of different PEV models (Figure 29). Excluding zero-trip days, the average daily distance driven was shorter for Leaf owners relative to Volt and Tesla owners – 45 km for Leaf owners compared to 54 km for Volt owners and 65 km for the Tesla owners. Additionally, a greater percentage of Leaf owners drove distances less than 50 km per day, with 67% of Leaf owner diary days below 50 km compared to 64% of Tesla owners and 58% of Volt owners. However, few Tesla or Volt owners reported daily distances greater than 125 km despite having higher ranges—the Tesla Model S (85kWh) has an all-electric range of about 425 km and the Chevrolet Volt has a combined gas and electric range of about 600 km. Tal et al. (2013) find similar results among California PEV drivers, where PHEVs such as the plug-in Prius and the Volt have greater average daily distances than BEVs such as the Leaf. These authors find very similar average daily distance values for Leaf owners (45 km) and Volt owners (62 km).

Figure 28: Distribution of daily distance traveled by PEV Pioneer participants (n = 568 driving days, excludes non-driving days)

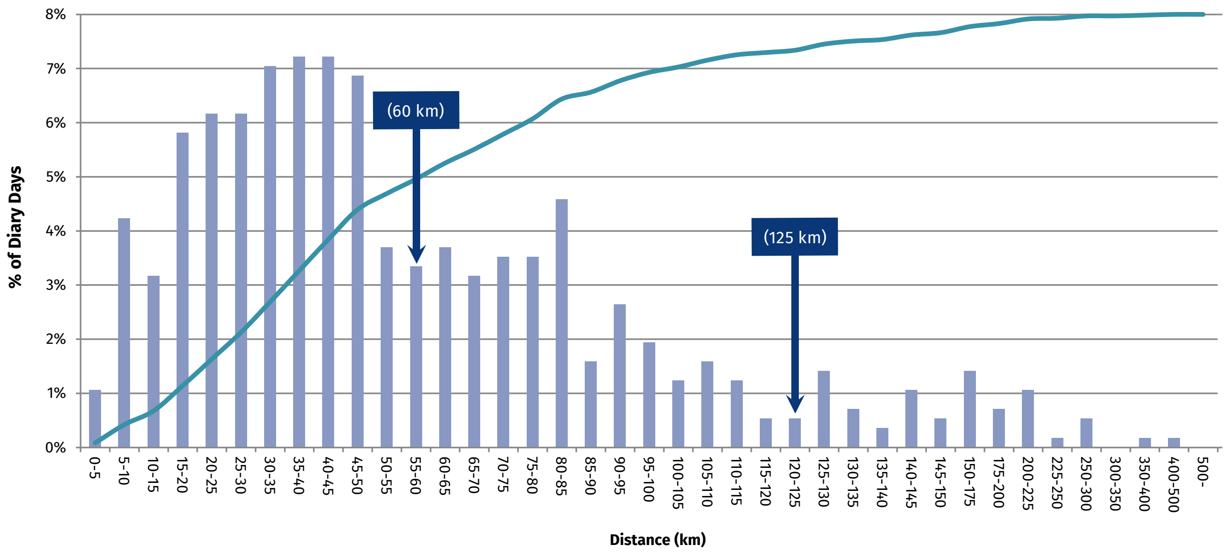
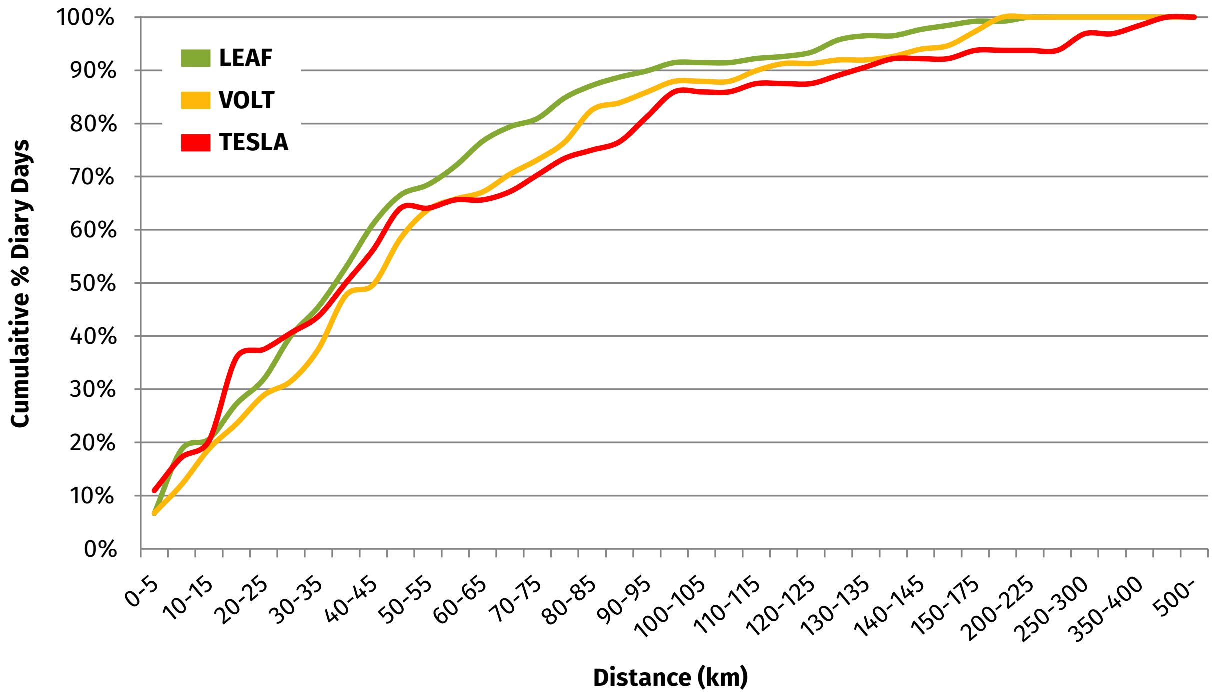


Figure 29: Distribution of daily distance traveled n = 568 (excluding non-driving days) for Leaf, Volt and Tesla drivers

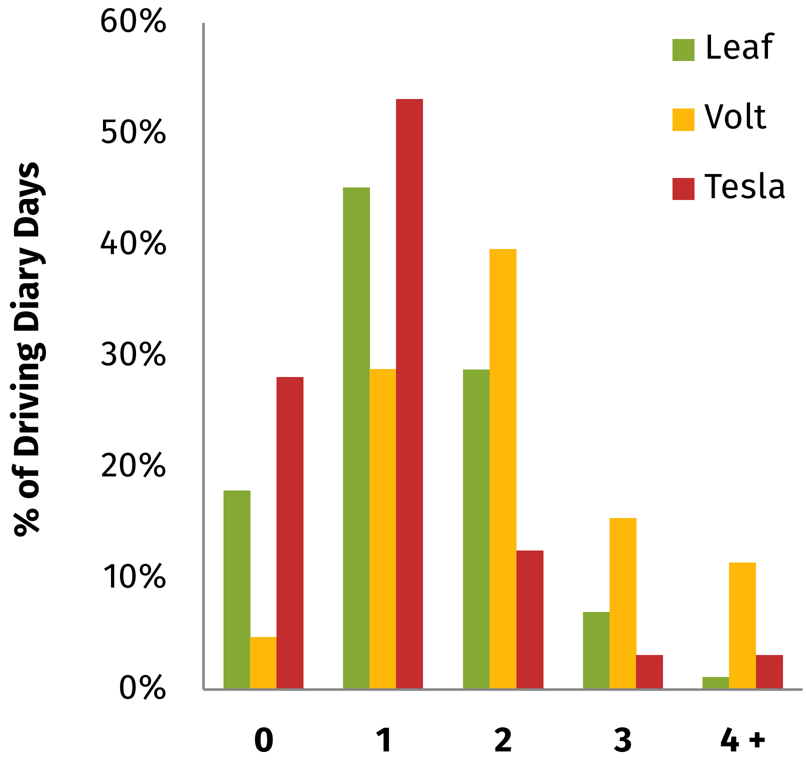


11.3. PEV Pioneer Charging Patterns (PEVOS)

Data on PEV charging behaviour can provide insights regarding charger utilization (for different locations and charging speeds), as well as understanding current patterns of electricity demand and potential electric grid and GHG impacts. The five-day driving diary (in Part 2 of the PEVOS survey) collected information on respondents' charging activity. Participants recorded details about the location, charge speed (Level 1, 2 or DC fast charger) and duration of charging events. Below we present our analysis of charger utilization, leaving the remaining topics for future analyses.

We define a "charging event" as any time a participant indicated being plugged into a Level 1, Level 2 or DC fast charger at any location (home, work or other). The majority of PEV Pioneer respondents (85% or 484/568 of recorded driving diary days) charged at least once a day, with most Leaf (45%) and Tesla owners (53%) reporting one charge a day, and most Volt owners (66%) reporting two or more charging events per day (Figure 30) – likely maximizing electric mode. Across the entire sample, the average number of charging events per day was 1.47 with a median of 1. These results are almost identical to those reported in early analysis of the EV Project in the US (Smart, 2013), where average and median charging events per day were 1.46 and 1, respectively. Furthermore, Smart (2013) also found that Volt owners frequently took opportunities to charge, so that a large portion of their driving used their electric range.

Figure 30: % Total PEV Pioneer respondent charging events per day, excludes non-driving days (Leaf, n = 257; Volt, n = 149; Tesla, n = 64)



In terms of the location of charging activity, the majority of charging events (63%) occurred at home as opposed to work or public charging stations (Figure 31). Workplace and other public charging accounted for 19% and 18% of all charging events, respectively. The proportions of charging locations varied somewhat by type of PEV owned, where Volt owners reported the highest proportion of away-from home charging events (43%).

Most home charging events were overnight, where the average duration was longer than the average time parked at non-home charging locations (average 3.2 hours). Data collected from PEVOS driving diaries indicates that ~70% of all final home arrivals involved vehicle charging. The peak arrival time is around 6 PM (Figure 32), about 1 hour later than the peak time indicated by our Mainstream respondents. About 82% of PEV Pioneer respondents arrive home by 8PM, similar to Mainstream respondents (80%).

Figure 31: % Total PEV Pioneer respondent charge events by location (Leaf, n = 312; Volt, n = 190; Tesla, n = 165)

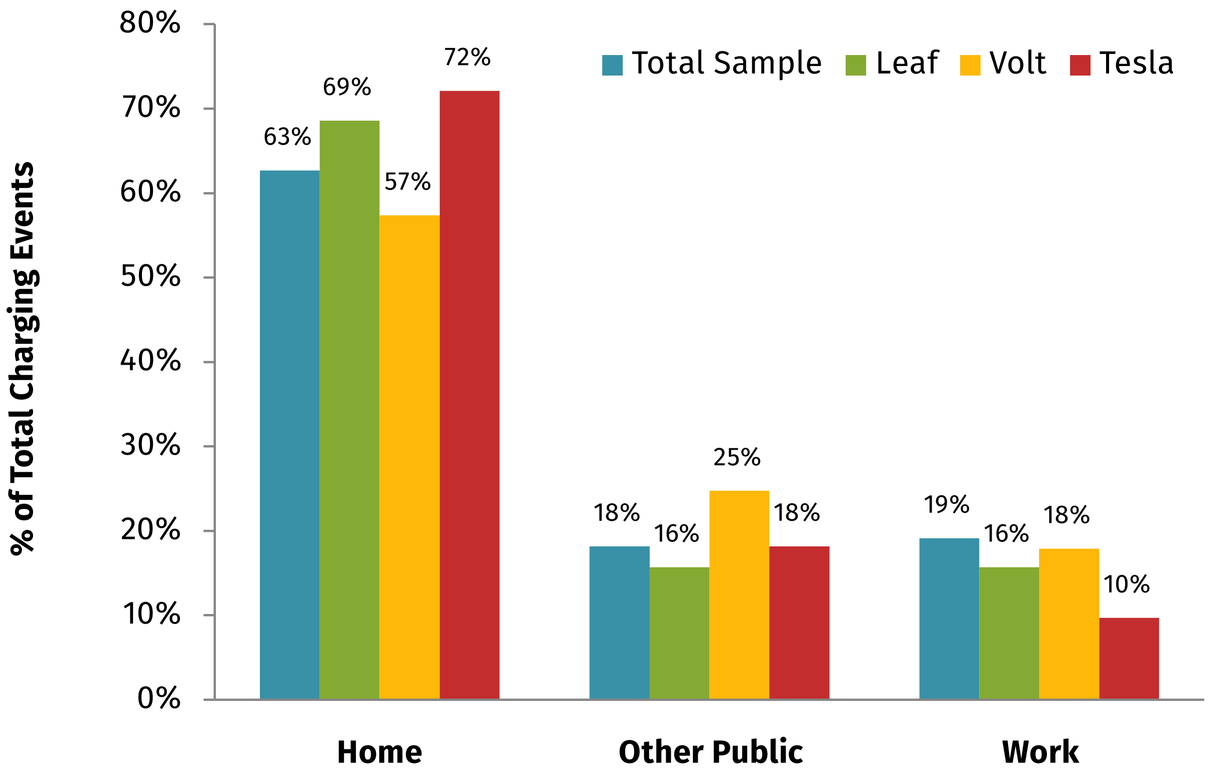
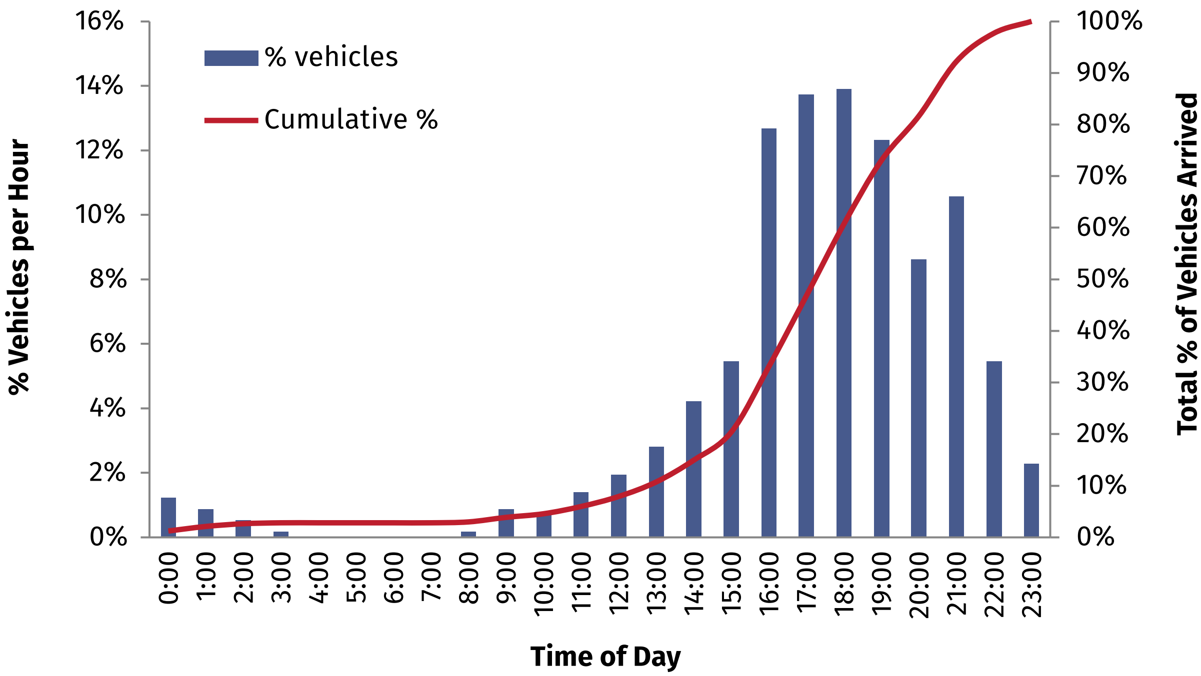


Figure 32: Final home arrival times for PEV Pionners' diary vehicle (BC only, n = 568).



11.4. PEVOS Interview Insights: Driving Behaviour

Analysis of PEVOS driving diaries provides insights into current PEV vehicle use and charging activity. In this section we draw on insights from the PEVOS interviews to shed some light on consumer perceptions and motivations regarding their driving and charging behaviour.

The PEVOS interviews to date (n = 13) have revealed the following themes:

1. PEVs encourage some owners to drive more;
2. electric-range is not perceived as a limitation; and
3. public charging infrastructure is convenient, but not necessarily essential.

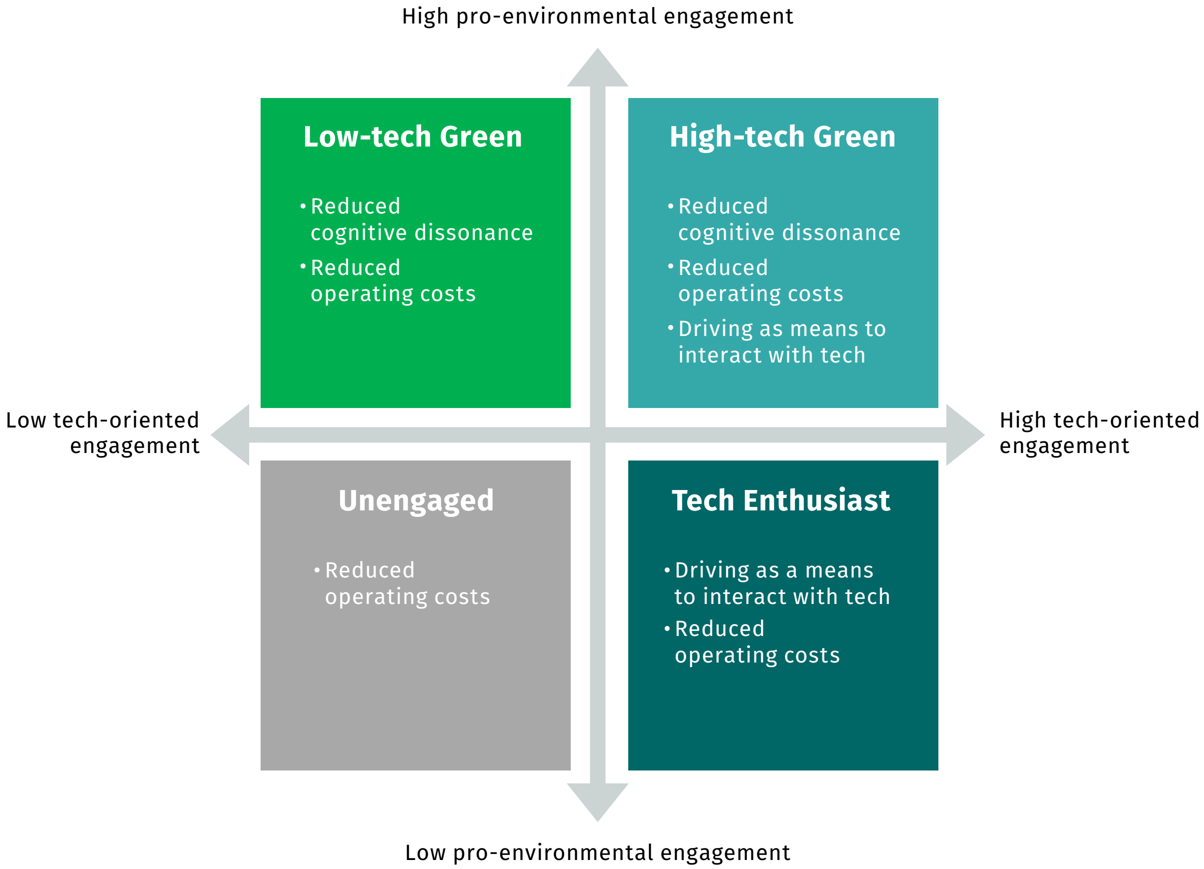
The first theme – PEV owners driving more – was demonstrated by 8 of the 13 households who reported that they are driving more frequently since purchasing their PEV. One household, for example, explained that they will now "not think twice" about having to drive to the grocery store, whereas before they would have postponed such a trip until it became necessary. Figure 33 summarizes different motivations for increased driving according to lifestyle categories introduced in Section 10.3, which include:

» Participants with a **Pro-Environmental lifestyle** (i.e. high- or low-tech greens) may drive more due to the reduced "cognitive dissonance" (associated with feeling guilty when they drive a gasoline vehicle given that they have pro-environmental values) that they previously experienced when driving a conventional vehicle. For example, one participant explains that they now drive to the mountains to go hiking every weekend as they feel less "hypocritical" driving to experience nature.

» **Tech-Enthusiast** and **High-Tech Green** respondents also report driving more because they enjoy having more opportunities to interact with the technology. For example, one participant stated that he will drive his PEV to work in Vancouver rather than take public transportation because he enjoys driving the Tesla and interacting with it.

» Across lifestyle types, some participants drive more due to reductions in operation costs.

Figure 33: Primary motivations by lifestyle type for increased driving



The second theme is that most PEVOS interviewees did not perceive their electric range as a limitation. Only 2 of the 13 households regularly engage in trip planning based on their PEV's range and charger availability—both were Nissan Leaf owners that lacked access to sufficient home charging (i.e. they did not have Level 2 charging at home). By comparison, BEVs owners with Level 2 home charging did not feel the need to plan, and often explained a simple "learning process" that occurred after purchasing their BEV. Two households in particular indicated that some conventional vehicle owners fall victim to "ICE thinking" (or "internal combustion engine thinking"), in believing that the PEV's electric range is a limitation. As one participant explained, "...the unexpected benefits ... of having an electric car is when you wake up in the morning, you got a full tank every day. And now in terms of range, I get more range anxiety when I'm driving the [conventional vehicle]".

The third theme is that public charging is convenient, but not necessarily essential. Seven of the 13 households explained that their selection of leisure activities, and to some extent errands, can be based on the availability of charging stations. One owner explained that he and his partner now go to English Bay in the summer since "there's a pretty good chance we can park at the electric charger ... whereas you'd never even bother taking your car down there in the summer on the weekend before". Another owner (PHEV) explained that "we meet some friends for a movie usually every other Sunday ... and I much prefer to go to SilverCity in Metrotown [rather than Coquitlam] ... I'll drive a little further because I know I can charge, and I can get there and back on electricity". For two households, however, public charging was necessary, as these households lacked sufficient access (i.e. Level 2) to home and work charging.

The remaining households (9/13) explained that they do not regularly use or need public charging infrastructure. Respondents explained that after a brief learning period with a PEV, they discovered that they rarely need to use it. This lack of reliance on public charging seems to depend on the household having charging access at home or work locations. In addition, five interview participants that regularly use charging stations located at their work explained that such access reduced their need for public charging stations.

In summary, these interview findings suggest that current PEV owners tended to quickly adapt to their PEVs after a brief learning period, with some drivers increasing their driving frequency and not regularly using public charging.

12. Anticipating Electricity Demand of Early Mainstream PEV Buyers

Research Highlights for Section 12

Understanding the potential usage of PEVs among future (Early Mainstream) buyers can help utilities and governments to anticipate electricity demand. Here, we use data from Early Mainstream (NVOS) respondents to build a simple of model of potential PEV usage within three Canadian provinces: British Columbia, Alberta, and Ontario.

Among the Early Mainstream in British Columbia, Alberta, and Ontario we find that:

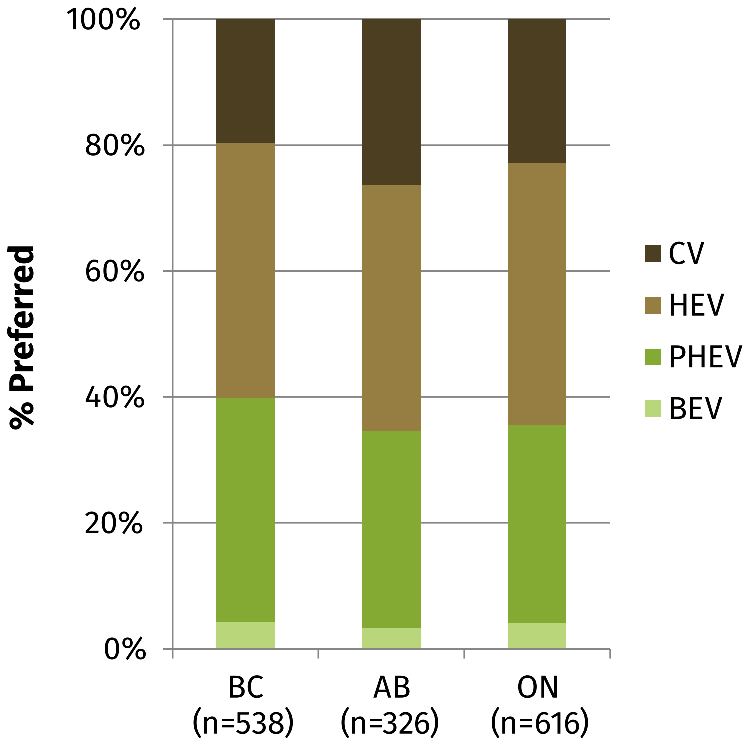
- Average daily driving distances are highest in Ontario (61 km), followed by Alberta (53 km) and British Columbia (49 km).
- With current charging access, modeled average daily electricity demand for PEVs is highest for Albertan respondents (8.7 kWh/day per vehicle), followed by respondents in Ontario (8.0 kWh/day) and British Columbia (6.8 kWh/day).
- With unconstrained charging, PEV electricity demand is expected to peak around 5—6PM (in all three provinces).
- Enhanced workplace charging access could increase the proportion of PHEV km that are powered by electricity (by 21% in British Columbia, 14% in Ontario and 5% in Alberta).
- With the adoption of larger BEVs (240 km range) and increased charging access, daily electricity demand could be substantially higher per vehicle (77% higher in British Columbia, 57% in Alberta, and 79% in Ontario).

As explained in the CPEVS "conceptual framework" in Section 3, this study seeks to understand and anticipate PEV purchase behaviour, as well as potential usage behaviour. In this section, we use data from NVOS to model how "potential Early Mainstream" PEV buyers might use their PEVs, subject to a set of assumptions. We combine three behavioural elements to estimate electricity grid impacts: driving activity (from the driving diary in Part 2 of NVOS), recharge potential (also from Part 2), and vehicle design (from the design space exercise in Part 3 of NVOS).

12.1. Vehicle Usage Patterns

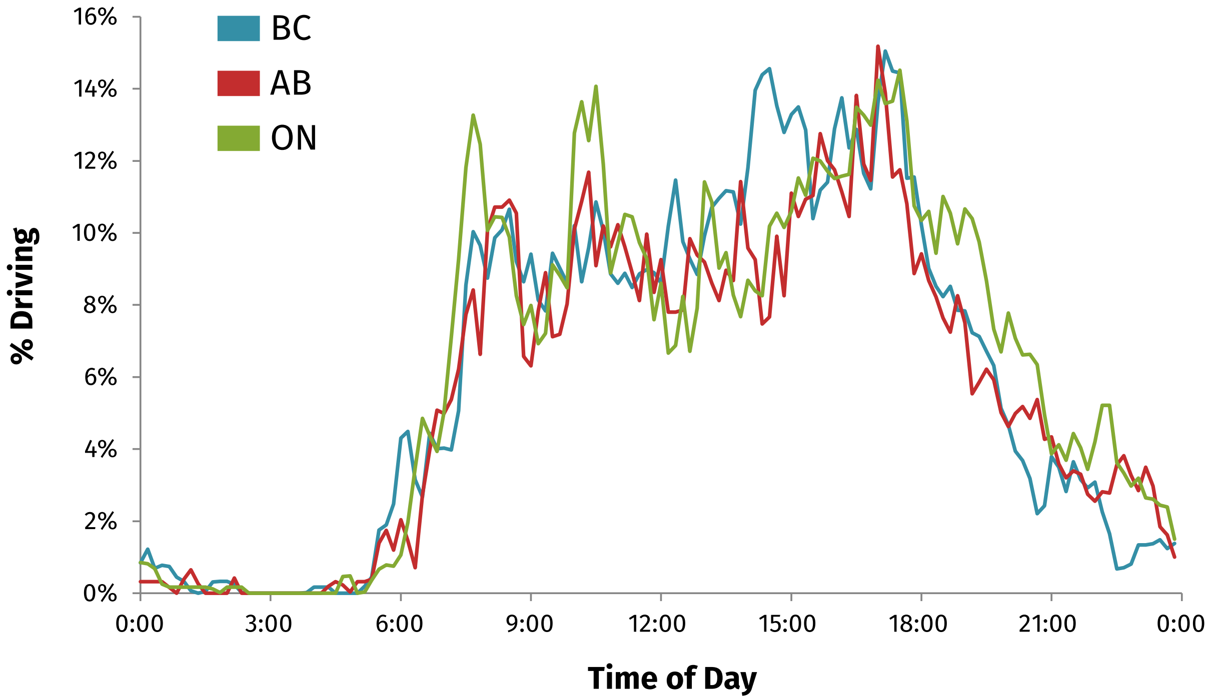
PEV usage patterns are likely to vary by region, as consumers may have different interests in PEV designs, as well as different driving patterns and access to recharge opportunities. In this section, we compare potential PEV usage patterns from respondents in three Canadian Provinces: British Columbia (n = 538), Alberta (n = 326) and Ontario (n = 616). For each of these regions, we identified the Early Mainstream survey respondents as those that designed some form of PHEV or BEV in the lower price version of the vehicle design exercise (depicted by region in Figure 34). The analysis in this section focuses only on the Early Mainstream respondents, which make up about 35—40% of respondents from each province.

Figure 34: Mainstream respondent vehicle design in the NVOS Part 3 low price design game scenario



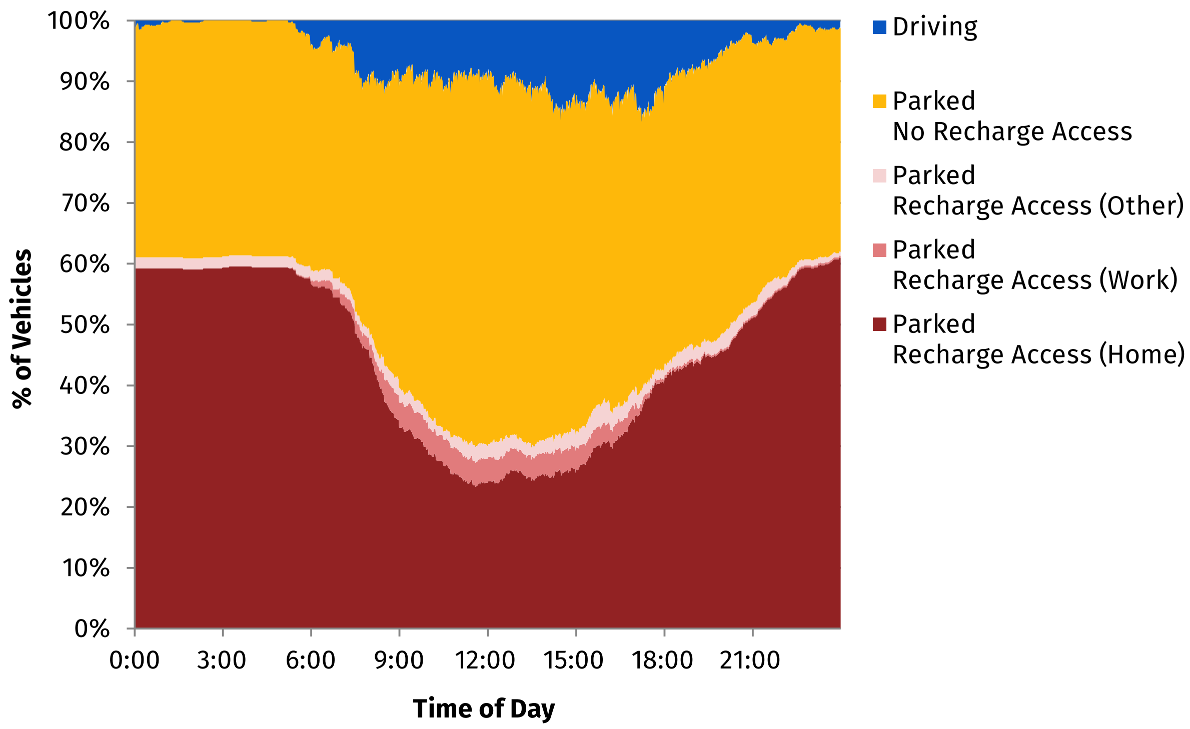
As described in Section 4.2, we collected driving data from Mainstream respondents using a three-day driving diary (Part 2 of the NVOS). Generally, we find that the timing of driving activities for Early Mainstream respondents is similar across the three provinces (Figure 35). Peak end-of-day arrival time is around 5PM in all three provinces and similar to analyses of US drivers using 2001 US NHTS data (Weiller, 2011.). On average, drivers in Ontario arrive home slightly later, with 65% arriving home by 8PM, compared to 71% and 72% in British Columbia and Alberta, respectively. In terms of driving distances, the driving diary data are also similar to previous analyses of the 2001 US NHTS data (Weiller, 2011.). Average daily driving distances are highest in Ontario (61 km), followed by Alberta (53 km) and British Columbia (49 km), and generally align with the 2009 Canada Vehicle Survey (Natural Resources Canada, 2011).

Figure 35: Proportion of Early Mainstream respondents driving by time of day, averaged across weekdays and weekends, by time of day (10-minute moving average) in British Columbia (n = 201 respondents, 603 diary days), Alberta (n = 102 respondents, 306 diary days), and Ontario (n = 194 respondents, 582 diary days). Some respondents are excluded due to incomplete diary data.



Recharge access varies across the day, as demonstrated for British Columbian respondents in Figure 36. Here, we define "recharge access" as occurring when the respondent reported parking their vehicle at a location within 8 metres (25 ft.) of a 120V outlet or an existing PEV charging station. The vast majority of existing recharge opportunities are at home locations (as presented in Section 7.1). Recharge access decreases during the daytime due to a higher proportion of vehicles being driven or being parked away from home, where access to outlets is lower.

Figure 36: Driving activity and recharge access by time of day, British Columbia Early Mainstream respondents only (n = 201, 603 diary days)



12.2. Modeling Potential PEV Usage

To anticipate the potential usage patterns of Early Mainstream NVOS respondents, we created usage scenarios based on survey data. Specifically, we used Microsoft Excel to model PEV usage for each respondent based on their: i) driving, parking and recharge information (summarized above), and ii) their PEV design (presented in Figure 34). We set up three modeling scenarios, which were defined as follows:

- **Scenario 1: "User informed"** is informed by data collected from respondent survey and diary data. Respondents are assumed to drive the vehicles they selected in the PEV design space exercise. Recharge availability is based on the Home Recharge Assessment and driving diary in Part 2 (where respondents indicated access to home and non-home recharging opportunities). Respondents without any home recharge access are assigned Level 1 access at home for the modeling exercise. We assume that respondents drive their designed PEV exactly as they drive their driving diary vehicle, and plug in to recharge immediately whenever they are parked within 8m (25 ft.) of a recharge opportunity.
- **Scenario 2: "User + enhanced workplace access"** is identical to Scenario 1, but also assumes that all workplace locations have Level 2 charging access, and that all respondents use these chargers when they are parked at work.
- **Scenario 3: "BEV-240 + extended access"** models a theoretical "high electrification" scenario where all respondents are driving a BEV-240km and have access to Level 2 charging at all homes and workplaces.

In all three scenarios, we also assume the following:

1. Level 1 chargers recharge PEV batteries at a rate of 1 kW, while the Level 2 charge rate is 6 kW.
2. PEV designs have the usable battery capacities summarized in Table 30.
3. PEV electricity consumption (fuel efficiency) per km travelled is as assumed in Table 31.

Table 30: Usable battery capacity (kWh) for a range of PEV designs and vehicle classes (Adapted from Axsen & 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
BEV-80	13.0	15.0	20.2	23.7
BEV-120	19.5	22.5	30.2	35.6
BEV-160	26.0	30.0	40.3	47.4
BEV-200	32.5	37.5	50.4	59.3
BEV-240	39.0	45.0	60.5	71.2

Table 31: Electricity consumption (kWh/km) by vehicle class (Adapted from Axsen & Kurani, 2013b)

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

Table 32 summarizes the modeled PEV electricity usage by respondents in each province, for each scenario. Average daily electricity demand ranges from 6.9 to 14.3 kWh/day per vehicle. Of the three provinces modeled, British Columbia has the lowest average electricity demand per PEV under all three scenarios, mostly due to the shorter driving distances. Alberta has higher electricity demand per PEV than Ontario under Scenario 1 due to higher existing workplace recharge access.

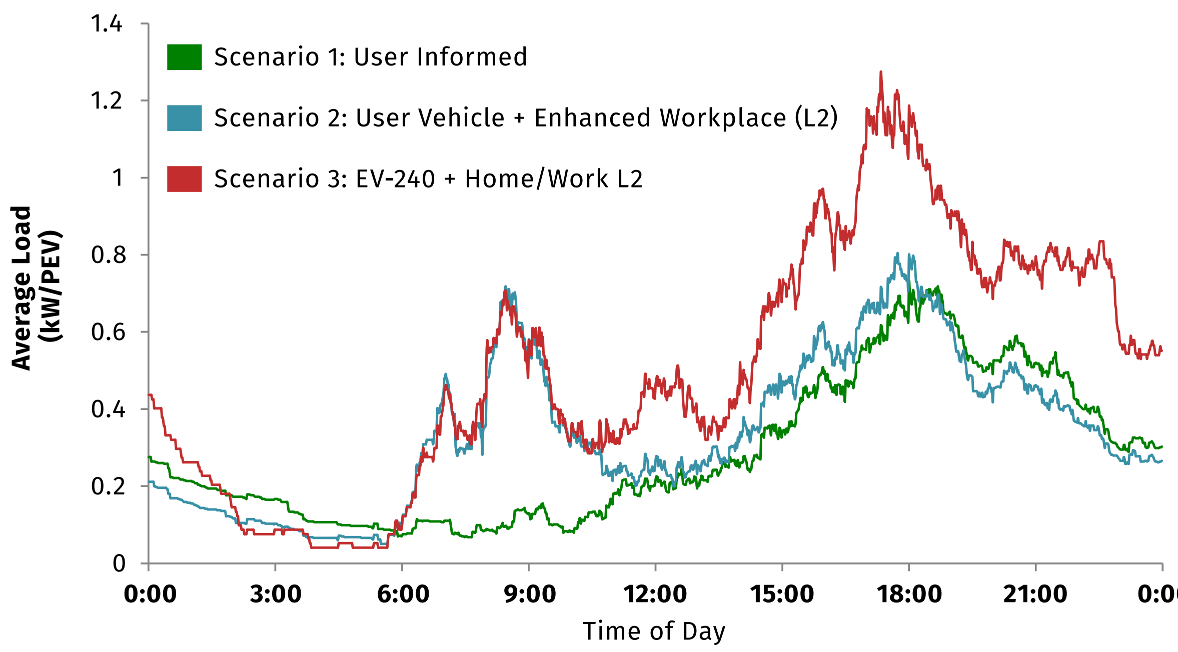
However, in Scenario 3 where all drivers are assigned a 240 km BEV, Ontario's PEV electricity demand exceeds Alberta's because on average, drivers in Ontario drive longer distances daily. Thus more kilometers are switched to electric drive (which were previously gasoline km from PHEVs), subsequently increasing electricity demand. The "electric utility factor" refers to the proportion of total driving distance that is powered by electricity instead of gasoline, where increasing charging access and electric range achieve higher electric utility factors for PHEV designs (whereas BEV designs always have a 100% electric utility factors).

Table 32: Average daily electricity demand, electric utility factor, and morning and evening peak information, by scenario

Scenario	Province	Avg. daily demand (kWh/veh)	Utility factor (across fleet)	Morning Peak Demand		Evening Peak Demand	
				Time	Demand, kW (vs. Scn-1)	Time	Demand, kW (vs. Scn-1)
1	BC	6.9	61%	9:20	0.16	18:00	0.73
	AB	8.7	64%	9:18	0.35	17:55	0.86
	ON	8.0	57%	9:47	0.18	16:46	0.77
2	BC	8.2	74%	8:27	0.72 (+350%)	17:44	0.80 (+10%)
	AB	9.5	67%	8:58	0.68 (+94%)	18:01	0.95 (+10%)
	ON	9.5	65%	8:50	0.84 (+354%)	16:46	0.73 (-5%)
3	BC	12.2	100%	8:26	0.71 (+344%)	17:20	1.27 (+74%)
	AB	13.7	100%	9:00	0.75 (+114%)	18:01	1.37 (+59%)
	ON	14.3	100%	8:50	0.91 (+392%)	18:00	1.27 (+65%)

The three scenarios produce very different time of day demand profiles for PEVs. Figure 37 illustrates the three scenarios using the British Columbia sample. Scenarios 1 and 2 follow similar electricity demand profiles in the afternoon with peaks in the early evening. Due to enhanced workplace access in Scenario 2, there is an additional peak in the morning as vehicles arrive at work—this effect is more pronounced among British Columbia and Ontario respondents due to their presently lower recharge potential. Scenario 3 has a large morning peak and even larger evening peak due to enhanced home recharge access (with universal Level 2 access), and the assumption of universal BEV usage (where electricity powers 100% of all vehicle kilometers).

Figure 37: Electricity demand profiles under three scenarios in British Columbia (n = 201; 603 diary days)



Although this modeling exercise does illustrate the potential impacts of widespread Early Mainstream PEV usage, there are inherent limitations to our approach. In particular, these scenarios did not include the potential impact of delayed charging schemes such as utility-controlled charging (UCC), which could have considerable effects on electricity demand profiles and resulting GHG emissions. Section 15 provides further detail on our efforts to assess willingness to accept a UCC scheme among PEV owners and potential Early Mainstream buyers.

13. Anticipating GHG Impacts from PEV Adoption

Research Highlights for Section 13

One important benefit associated with PEVs is the ability to reduce GHG emissions relative to conventional gasoline vehicles. However, electricity grids in most regions produce some amount of GHG emissions. Ultimately, the GHG impacts of PEV use will depend on the types of PEVs adopted, how they are driven, when they are charged, and what electricity is being generated at the time of charging. We use Early Mainstream NVOS respondent data to build consumer-informed models that represent potential GHG impacts among PEV buyers in British Columbia (a hydro-based grid), Alberta (a fossil-fuel based grid), and Ontario (a mixed grid). Our results focus on estimates of "marginal" emissions, where emissions calculations are based on the power plants most likely to be used at the time of charging.

Our findings show that:

» With Early Mainstream NVOS respondent PEV designs from Part 3 and existing recharge access (the "User-informed" scenario), PEVs can cut emissions by 79% in British Columbia, 44% in Alberta, and 58% in Ontario, relative to conventional gasoline vehicles.

» With enhanced access to workplace charging, which results in more day-time charging (the "User + enhanced workplace access" scenario), GHG emissions reductions are about the same as the "User-informed" scenario.

» With enhanced charger access and universal BEV-240 adoption (the "BEV-240 + extended access" scenario), emissions reductions are even more substantial in British Columbia (98%) and Ontario (70%), but not much different in Alberta (relative to the "User-informed" scenario).

» Estimates of PEV emissions are strongly influenced by our focus on "marginal" emissions values, versus "average" emissions values, which do not represent time of day electricity generation.

13.1. Background

This section uses much of the Mainstream (NVOS) respondent data presented thus far to estimate the potential GHG impacts of widespread PEV adoption and usage in Canada. Transportation accounted for 24% of Canada's total GHG emissions (702 Mt CO2e) in 2011 and light-duty vehicles alone emitted 88 Mt CO2e (12.5%) (Environment Canada, 2013). Several studies have highlighted the importance of transportation electrification in meeting medium and long-term climate targets (Bosetti & Longden, 2013; Kromer, Bandivadekar, & Evans, 2010; McCollum, Krey, Kolp, Nagai, & Riahi, 2013; Williams et al., 2012).

Here we explore the potential GHG impacts of PEV adoption in British Columbia, Alberta, and Ontario, using diary data from Part 2 of the NVOS survey. We consider GHG estimates in the short-term (using the current electricity grid), and leave consideration of the long-term (where the electricity grid develops over time) to future analyses.

The expected GHG impacts of PEV usage depend largely on the assumed GHG intensity of electricity used to charge PEVs (i.e. GHG emissions per km travelled) and the projected overall number of PEVs adopted. In terms of GHG emissions per vehicle, the Pembina Institute conducted a short-term lifecycle analysis of PEVs in British Columbia using the GHGenius[14] model and found that a BEV can reduce GHG emissions by 80% while a PHEV with 50 km of electric range (PHEV-50) can reduce emissions by 55% compared to an average gasoline vehicle[15] (Moorhouse & Laufenberg, 2010).

In Alberta, where electricity is assumed to continue to be dominated by coal, a study by NRCan found that BEVs have 4% higher emissions than conventional vehicles (Ribberink & Entchev, 2013). More generally, a recent analysis by Kennedy (2015) found that PEVs offer no GHG benefits in regions with emissions-intense electricity generation (>600g CO2e/kWh). One limitation of such studies is that they tend be based on the "average" carbon intensity of the region's electrical grid. Instead, a "marginal" perspective looks only at the electrical power plants that would be used to generate the added electricity needed for PEVs. Depending on the region, the marginal grid emissions intensity might be higher or lower than the average intensity. In Alberta for example, marginal emissions will more likely be generated by natural gas plants (~450 gCO2e/kWh), whereas an estimate of carbon intensity across the entire grid would be higher due to a reliance on coal for the base load (~1000 gCO2e/kWh). In addition, longer-term changes to the generation mix over time, such as the increased adoption of renewables, may not be fully captured by short-term analyses.

Another uncertainty is the total number of PEVs that will be adopted over time. Previous studies suggest that overall cumulative GHG reductions in the light-duty vehicle sector are likely to be minimal due to slow uptake (Ribberink & Entchev, 2013). In another study, WWF Canada (2012) used a range of market projections from Deloitte, Boston Consulting Group, and Deutsche Bank to estimate fleet-wide emission reductions from PEVs in 2020 and 2025. The most aggressive penetration scenario assumed a 10.4% new vehicle market share in 2020, where PEVs can reduce fleet-wide light-duty vehicle emissions by only 1% in 2020 and 7% in 2025 compared to business as usual. NRCan's model finds that PEVs may only achieve fleet-wide reductions of 5—12% by 2025 in Ontario and Quebec due to slow turnover of vehicles (Ribberink & Entchev, 2013). In this section, we focus more on the GHG intensity of individual PEVs (GHG per km). Section 14 (next) provides a more detailed model of PEV adoption rate over time—for now we only estimate GHG reductions per PEV adopted.

14 http://www.ghgenius.ca/

15 Baseline fuel efficiency of 10.2L/100km

To better understand the potential GHG emission impacts of PEVs, two perspectives are important: a detailed, static analysis over the short-term and a broader, dynamic analysis over the longer term. Each approach offers its own advantages and limitations:

1. **The short-term (static) perspective** provides a rich and detailed perspective on PEVs using present-day information of PEV usage (based on NVOS data detailed in Sections 8 and 11), and the present-day electrical grid information. We can look at electricity demand and generation on an hourly basis, and also model GHG impacts on a "marginal" basis (based on the electricity generation plants that would be used to recharge PEVs at the time of demand. However, these models do not represent how the electrical system may change over time, which is an important limitation.
2. **The long-term (dynamic) perspective** considers changes to the electricity grid mix and vehicle fleet over the longer term. This is an important perspective because the emissions intensity of electricity supply will change in the future as new, cleaner generation comes online and older power plants are retired. Also, due to their limited uptake, PEVs may only have limited GHG reductions in the near-term, but potentially substantial contributions to emission reductions over the medium to long-term (2035—2050). However, this perspective inevitably includes more uncertainty about the future world (behaviour and technology), and thus more assumptions are required.

At present, we have only completed the short-term analysis, which we summarize below. Future research will integrate these findings into a model that represents long-term dynamics in the transportation and electricity sectors.

13.2. Methodology for Short-term GHG Impacts

We calculate potential PEV emissions in the short-term, using unique information to represent the provinces of British Columbia, Alberta and Ontario. There are a number of different ways to estimate GHG impacts and "attribute" emissions. Emissions attribution refers to how the net change in electricity demand is attributed to specific fuels or technologies used to generate the incremental electricity. In the case of PEVs, we show both the marginal and average grid intensity. The marginal approach is used under the benchmark *Greenhouse Gas Protocol* when quantifying emission reductions from grid-connected projects (World Resources Institute, 2007). Because the electricity demand profile of PEVs varies by time of day and day of the week, we use an hourly marginal emissions factor for electricity in our short-run analysis. We complement this with an estimate using an annual average emissions factor for electricity, which is typically used in the studies cited earlier.

For each province, we construct models of PEV usage using the following information:

- **PEV usage and electricity demand** was modeled using profiles of PEV electricity demand over the course of 24 hours (as described in Section 12), using Mainstream respondent data for each province. Recall from Section 12.2 that we constructed three different PEV usage scenarios:
  - **Scenario 1: "User Informed"** is informed by data collected from the respondents, assuming that respondents drive their designed PEV exactly as they drive their driving diary vehicle, and plug in to recharge immediately whenever they are parked within 8m (25 ft.) of a re-charge opportunity.
  - **Scenario 2:** "User + enhanced workplace access" is identical to Scenario 1, but also assumes that all workplace locations have Level 2 charging access, and that all respondents use these chargers when they are parked at work.
  - **Scenario 3:** "BEV-240 + extended access" models a theoretical "high electrification" scenario where all respondents are driving a BEV-240km and Level 2 recharge access is available at all homes and workplaces.
- **The electricity grid mix** for each province using hourly electricity generation and trade data from:
  - BC Hydro (April 2012-March 2013),
  - Alberta Electric Service Operator (AESO) (April 2011—March 2013), and
  - Ontario's Independent Electricity System Operator (IESO) (April 2012—March 2014).
- **GHG emissions** factors for each electricity source were assumed using values from the IPCC's literature review of lifecycle analyses of electricity emission factors, specifically their median values, available in Table 33 (Moomaw et al., 2014).
- **Marginal GHG emissions** for each region were calculated following a "linear-regression" approach used in Ma et al. (2012) and Siler-Evans, Azevedo, & Morgan (2012). First, we plot hourly generation/demand (MWh, x-axis) against its corresponding hourly GHG emissions (kg, y-axis) for a given hour over the study period (e.g. 3AM over one year). Each point on the plot represents that hour's emission factor (kg/MWh); the slope of the linear regression of a large collection of points is the average marginal emission factor for that data set. For imports from other jurisdictions (e.g. Saskatchewan, United States) we assumed the average generation mix for that region[16].

16 For imports into Alberta from Saskatchewan, we assumed an average intensity of 730g/kWh (Source: Canadian Industrial Energy End-use Data and Analysis Centre, (2014). Energy Use and Related Data: Canadian Electricity Generation Industry 1990 to 2012).

For imports into BC from the US (WECC), we assumed an average intensity of 384 g/kWh (Source: US EPA, 2014. eGRID 9th edition Version 1.0).

For imports into Ontario, we assume the following emission factors: Manitoba (2.8 g/kWh), Minnesota (701 g/kWh –MROW), Michigan (743 g/kWh – RFCM), New York (249 g/kWh – NYUP), Quebec (2.9 g/kWh). Sources: Canadian Industrial Energy End-use Data and Analysis Centre, (2014). Energy Use and Related Data: Canadian Electricity Generation Industry 1990 to 2012; US EPA, 2014. eGRID 9th edition Version 1.0.

Table 33: Lifecycle GHG emissions intensity, by generation type (from Moomaw et al., 2014)

	Emissions intensity ($g\ CO_2e/kWh$)
Coal	1001
Oil	840
Gas	469
Solar PV	46
Geothermal	45
Solar CSP	22
Biomass	18
Nuclear	16
Wind	12
Ocean	8
Hydro	4

For each province, we construct models of PEV usage using the following information:

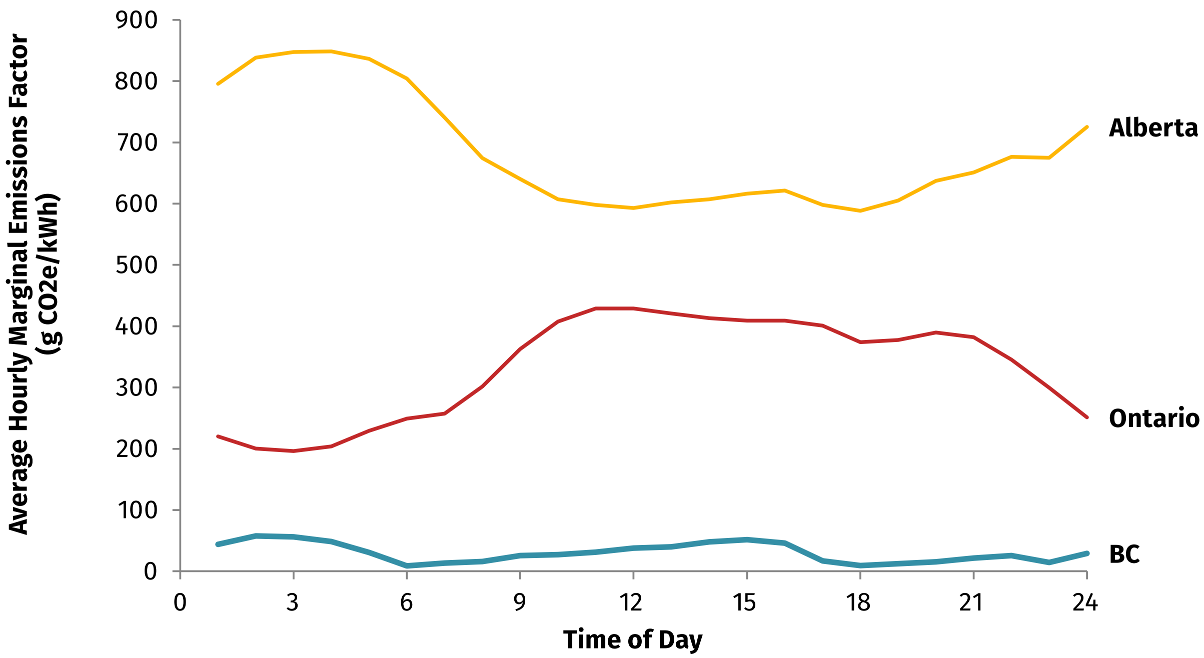
- **Annual average GHG emissions factors** (2012 values) from Environment Canada's National Inventory Report 1990—2012, Part 3 (Environment Canada, 2014).
- **GHG emissions from gasoline use** (for conventional vehicles, HEVs and PHEVs) are estimated using well-to-wheels (WtW), which covers the lifecycle emissions associated with fuel production, transportation, and use. We conducted a review of literature values for emissions factors from combustion and upstream (production and distribution) of gasoline (Lattanzio, 2014; Ma et al., 2012; Samaras & Meisterling, 2008). We assume a 2:1 oil sands to conventional oil blend for gasoline production, which aligns with the Canadian Association of Petroleum Producers (2013) projections for domestic production. Therefore, we use a WtW emissions factor of 3,335 g CO_2e/L for gasoline (2,516 g/L combustion and 819 g/L upstream).

Figure 38 summarizes the average hourly marginal emissions factor for electricity in Alberta, Ontario, and British Columbia, which can be explained as follows:

- British Columbia's electricity system is dominated by large hydro. However, due to its import of coal-fired electricity from Alberta overnight, emissions are higher during the early morning, approaching 60 g CO_2e/kWh. Imports from the US (absolute average 675 kW) and Alberta (absolute average 284 kW) are about 14% compared to domestic consumption (6976 kW).
- In Alberta, emissions intensity of electricity is high due to the province's dependence on coal-fired electricity (Environment Canada, 2014). We find that the calculated hourly marginal emissions factor fluctuates more than the hourly average, with higher emissions during low load hours (peaking at around 3AM) and lower emissions during the early afternoon. This is due to the peak hour marginal demand being met by peaking natural gas and imported hydro electricity from BC.

» Ontario's policies to phase-out coal generation and increase renewables have contributed to a considerable decrease in average emissions intensity over the past five years, decreasing nearly 40% since 2009. The majority of current generation is from nuclear, with the balance supplied by natural gas, hydro, solar, and other renewables. During the mid-afternoon, the marginal emissions factor is about three times higher than the average hourly emission factor, when that the marginal demand is being met largely through natural gas fired plants.

Figure 38: Calculated near-term average hourly marginal emissions factor for electricity generation in BC, Alberta, and Ontario, by hour



13.3. Short-term Results

There is substantial regional variation in the fleet-wide emissions intensity of PEV travel compared to conventional gasoline vehicles and HEVs. Across the scenarios using "marginal emissions" estimates (Figure 39), British Columbia shows the greatest potential emission reduction from PEVs due to its very clean electricity generation system, with Scenario 3 (BEV-204 + enhanced charging) achieving a 98% reduction. Under Scenario 1 (User-informed), which reflects the most likely near-term scenario with existing recharge access, PEVs can reduce fleet-average GHG emissions intensity by 79% in British Columbia, 44% in Alberta, and 58% in Ontario relative to conventional (gasoline) vehicles. The three scenarios achieve modest reductions in Alberta, due largely to their emissions-intense electricity grid.

Figure 39: Emissions intensity of plug-in electric vehicles, g CO2e/km (using hourly marginal emissions factors for electricity, including trade)

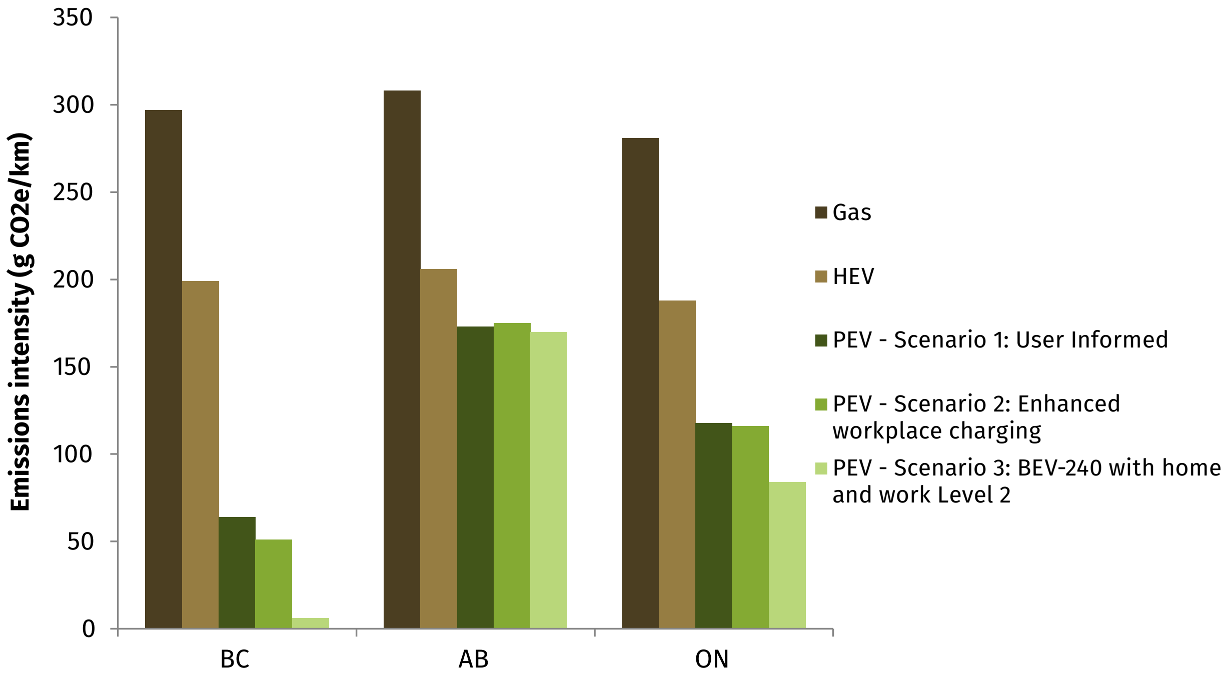
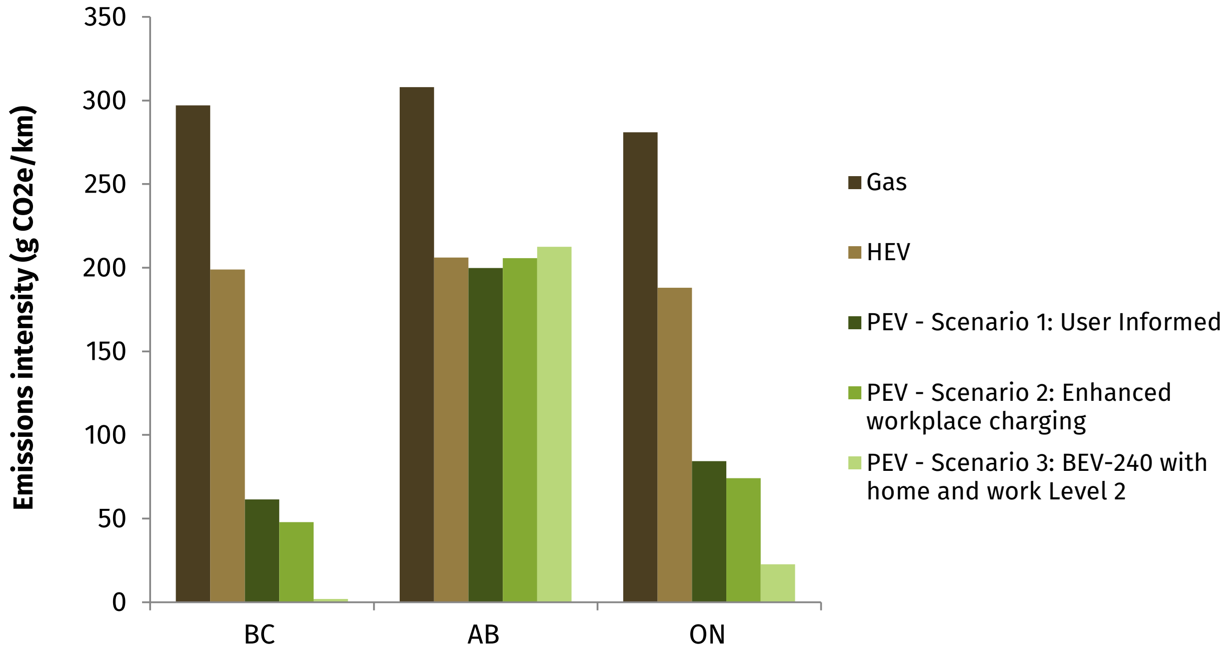


Figure 40: Emissions intensity of plug-in electric vehicles, g CO2e/km (using average annual emissions factors for electricity from Environment Canada, 2014)



Emissions intensity of PEVs was also calculated using average annual emission factors from Environment Canada (2014) for 2012 (BC: 8.2 g CO2e/kWh; Alberta: 820 g CO2e/kWh; Ontario: 96g CO2e/kWh) (Figure 40). Due to the lack of temporal (time-of-day) resolution, accounting for marginal generators and electricity trade, this method estimates higher PEV emissions intensity in Alberta, and lower emissions intensity in Ontario, compared to the previous hourly marginal method. Peak charging occurs in the early evening in all regions, which in Alberta corresponds to high import volumes of clean hydro electricity from British Columbia. In contrast, evening charging in Ontario corresponds to peak generation being supplied by emissions-intense natural gas.

Some previous studies indicate that PEV usage will have higher GHG emissions than HEVs and even conventional vehicles in coal-based regions. For example, Samaras & Meisterling, 2008 find that PHEVs have higher lifecycle GHG emissions where electricity generation intensity exceeds 750 g/kWh. In contrast, our short-term Alberta models (using hourly marginal emission factors) indicate that PEV GHG intensities are consistently lower then HEVs and CVs in all three scenarios. One reason is that the previous study focuses on annual "average" emissions. We find that using marginal hourly GHG emissions factors results in lower calculated vehicle emissions intensity in Alberta and higher vehicle emissions intensity in Ontario compared to using annual average GHG emissions factors (Table 34).

This is due to the fact that our analysis accurately reflects and attributes time-of-day demand from PEVs to specific, hourly marginal generators; average emissions factors do not capture the marginal intensity of PEV charging. Consequently, studies based on average intensity factors may overestimate (Alberta) or underestimate (Ontario) the GHG impacts of PEVs relative to our approach. These differences explain why some studies (e.g. Ribberink & Entchev, 2013) suggest the PEV adoption in regions with high emissions intensity (such as Alberta) are equivalent to or worse than HEVs or CVs. Using average annual emission factors, we find PEVs have a similar GHG emission intensity compared to HEVs in Alberta.

Table 34: Emissions intensity of plug-in electric vehicles, g CO2e/km

Scenario	Province	Gasoline	HEV	PEV: Annual Average Emission Factors (Environment Canada, 2014)	PEV: Hourly Marginal (using historical generation data)
1. "User Informed"	British Columbia	297	199	62	64
	Alberta	308	206	200	173
	Ontario	281	188	84	118
2. "Enhanced workplace"	British Columbia	297	199	48	51
	Alberta	308	206	206	175
	Ontario	281	188	74	116
3. "BEV-240 w/extended access"	British Columbia	297	199	2.0	6.4
	Alberta	308	206	212	170
	Ontario	281	188	23	84

14. A PEV Market Share Forecasting Model

Research Highlights for Section 14

Forecasts of PEV sales (in terms of new market share) can vary widely—e.g., from 1% to 28% in 2020, and from 1% to 70% in 2030. Here we use the data and analyses presented earlier in this report from the NVOS survey to construct a PEV market share forecast model for British Columbia. Specifically, we build a "constrained choice model" that simulates consumer preferences as well as real-world constraints such as PEV model availability and variety, and lack of consumer awareness.

Our findings show that in British Columbia:

» Overall, unconstrained demand (or "latent demand") for PEVs translates to a 32% new market share by 2020.

» Constraints, however, including limited home charging access, limited PEV availability and variety, and limited familiarity, bring this forecast down to 1%.

» Using sensitivity analysis, our market share forecasts are most sensitive to PEV availability and variety, home charging access, incremental PEV costs, and PEV familiarity. Forecasts are not sensitive to gasoline or electricity costs.

» With the current supply of PEVs in Canada (7 models), new market share in 2030 cannot exceed 4—5%, while increasing supply (56 models) could increase that share to over 20%.

» Results suggest that strong, supply-focused policy, such as a Zero-Emissions Vehicle (ZEV) Mandate, is required to induce substantial PEV adoption in British Columbia.

14.1. Background

Many jurisdictions have announced PEV sales targets for 2020 that will require new market shares of PEVs to increase by a factor of six (IEA, 2013). However, it is very difficult to accurately predict the future sales or market share of an emerging technology such as PEVs. Previous studies and reports have predicted a variety of market share penetration rates for PEVs. For example, in the studies below, forecasts for PEV new market share range from 1% to 28% in 2020, and range from 1% to 70% in 2030:

- Sullivan (2009) forecasted PHEV new market share to be 1—5% in 2020 and 1—15% in 2030, with variations due to the cost of gasoline and the application of subsidies and sales tax exemptions.
- Sikes et al. (2010) forecasted PHEV new market share to be 2—18% in 2020, with the variation driven by the level of subsidy and the rate at which PEV battery costs fall.
- AECOM (2011) forecasted a PEV new market share of 17% in 2020 and 28% in 2030, assuming only home charging is available and sustained cost reductions for vehicle batteries. With Level 1 home charging and DC fast public charging, the PEV new market share forecast grew to 28% in 2020 and 70% in 2030.
- Bahn et al. (2013) forecasted no PEV adoption until after 2030 without the influence of policies. Under a climate policy scenario where Canadian jurisdictions meet their GHG targets, BEVs gain significant new market share, accounting for 20% of total kilometers travelled by 2020.

Generally, PEV sales or market share forecasts suffer from one or more of the drawbacks noted by Al-Alawi and Bradley (2013): models do not have a strong interface with survey data, they do not account for PEV supply, they do not represent the impact of government policy, they do not forecast alternative vehicle adoption within the context of other competing types of alternative vehicles, they do not consider different consumer or vehicle sales segments, and/or they do not allow sufficient sensitivity analysis.

In this chapter, we use some of the NVOS data and analyses presented in previous sections to construct a model to predict market share for PEVs. We focus on the province of British Columbia, as we have richer data for this region—though this method can be applied to other regions in Canada or internationally. To forecast PEV market share, we integrate aspects of two PEV market analyses described in Section 3.1: constraints analyses and discrete choice modelling. Constraints analyses look at functional limitations to PEV market share, e.g. recharge access and driving patterns, neglecting consideration of consumer motivations and decision processes. Discrete choice models quantify consumer valuation of PEVs and their attributes, but stated preference choice models tend to produce overly optimistic forecasts of PEV adoption. We thus attempt to blend aspects of these two approaches using a constrained choice model. We use data drawn from the NVOS to construct this model, as described in the next section.

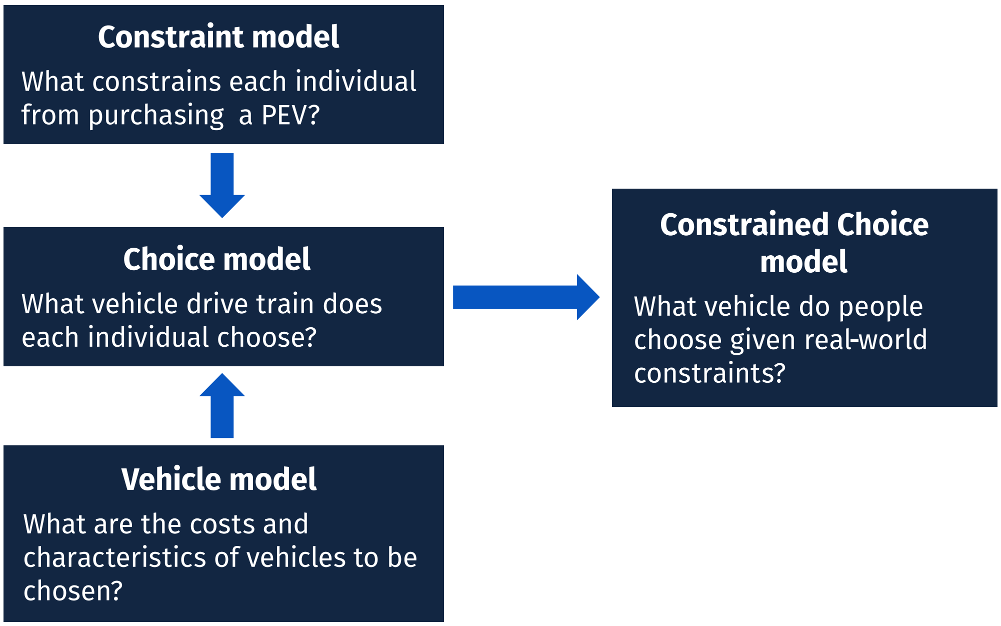
Our methodology satisfies many of the criteria suggested for a robust PEV market share forecast made by Al-Alawi and Bradley (2013). It incorporates a vehicle choice model and a constraint model parameterize through an extensive interface with survey data. It also accounts for constraints on vehicle supply in terms of vehicle existence and retail availability. As well, it can simulate the impact of policies and allows for a detailed sensitivity analysis of model parameters. Finally, it accounts for heterogeneous consumer preferences and markets, as well as multiple competing drivetrain technologies.

Below, we briefly summarize the forecast methodology and our PEV market share forecast under two potential scenarios. We conclude by discussing the potential impact of a zero-emission vehicle mandate and the future avenues for research suggested by this analysis.

14.2. Methods: Constrained Choice Model

Our constrained choice model consists of three sub-models: the vehicle model, the choice model, and the constraint model (Figure 41). The objective is to produce a "realistic" forecast of PEV sales in the passenger vehicle sector, i.e. a forecast that reflects consumer perceptions and behaviours, as well as real-world constraints in terms of awareness, recharge access and vehicle supply. We use survey data from the British Columbia subsample of Mainstream (n = 531) to forecast market share under different conditions, from 2015 to 2030. Below we describe the three components of the model in more depth.

Figure 41: Structure of the PEV Market Share Forecasting Model



1. The **discrete choice model** represents what we call "latent demand"—the total, unconstrained demand for PEVs. Latent demand represents what total sales or market share could be if respondents had full awareness of PEVs, and if PEVs were fully available in all the varieties (makes, models, trims) that consumers would want to buy. This latent demand (or unconstrained choice) of each respondent is represented as a probability for choosing a CV, HEV, PHEV or BEV. These choice probabilities are based on the discrete choice models that we estimated using NVOS data—specifically the "preference-based" latent class model that we present in Section 10.1.
2. The **vehicle model** specifies the details of each vehicle in the choice model. The vehicle model includes four vehicle classes: compact, sedan, mid-SUV and full-SUV. Each Mainstream respondent is represented in the vehicle model and is modelled as choosing between different vehicle types for their preferred class based on their responses in Part 3 of the NVOS. The four vehicle types included are:

- A conventional (gasoline) version (CV)
- An HEV version
- A PHEV version with an electric ranges of 64km
- A BEV version with electric ranges of 120 km

Table 35 and Table 36 show the energy intensity, incremental up-front costs, and energy prices we assumed for each vehicle type for each vehicle class. Table 37 shows the electricity and gasoline prices we have assumed for the forecast, in order to set a value for weekly energy cost (based on the respondents reported odometer reading and vehicle age). As part of the sensitivity analysis, we also tested the impact of modeling PEVs with different ranges, (including PHEV-16, PHEV-32, BEV-80, BEV-160, BEV-200 and BEV-240).

Table 35: Energy consumption by vehicle archetype, electricity (kWh/100km) and gasoline (L/100km)

Vehicle Type	Vehicle Class							
Drivetrain	Compact		Sedan		Mid-SUV		Full-SUV	
	L/100km	kWh/100km	L/100km	kWh/100km	L/100km	kWh/100km	L/100km	kWh/100km
CV	6.0	0.0	7.2	0.0	8.6	0.0	10.4	0.0
HEV	4.0	0.0	4.8	0.0	5.8	0.0	6.9	0.0
PHEV-64	1.5	7.1	1.8	8.9	2.2	10.7	2.6	12.9
BEV-120	0.0	14.0	0.0	17.5	0.0	21.0	0.0	25.2

Table 36: Incremental upfront cost relative to combustion vehicles, $CDN

Drivetrain	Compact	Sedan	Mid-SUV	Full-SUV
CV	0	0	0	0
HEV	$1,380	$1,740	$2,050	$2,470
PHEV-64	$3,560	$4,260	$5,190	$6,120
BEV-120	$8,940	$10,690	$13,930	$16,600

Table 37: Energy price forecasts[a]

	2015	2020	2025	2030
Gasoline, $/L	$1.10	$1.12	$1.11	$1.11
Electricity $/kWh	$0.09	$0.10	$0.10	$0.11

a Based on National Energy Board (2013), Canada's Energy Future, High Scenario.

3. The **constraints model** took the "latent demand" estimate that was provided by the discrete choice model and vehicle choice model, and then added in real world constraints. This model multiplied their unconstrained probability (latent demand) of buying a PHEV or BEV with a series of constraint coefficients specific to each individual. The constraint coefficients have values ranging from zero (total constraint) to one (unconstrained), and address three specific types of constraint: home charging access, PEV familiarity, and PEV availability. Each constraint was uniquely determined for each participant based on their survey responses. We describe each constraint in turn below.

   » **Home charging access –** We assume that respondents who will initially buy a PEV (1) have a 120 V outlet, which is not part of strata common property and is at least 25ft from their regular parking spot, and (2) would be willing to use this home outlet for vehicle charging (as stated in the NVOS Home Recharge Assessment).

   » **PEV familiarity –** We assume that a respondent must be "familiar" with PEV technology in order to purchase one in the first place. Before we informed respondents about PEV technology and available design options in Part 2, we asked respondents to report their familiarity with the Nissan Leaf or Chevrolet Volt in the Background Survey (Part 1). Individuals that reported themselves as "unfamiliar" or "somewhat familiar" with PEVs were assumed not to initially buy a PEV (even if they selected PEV models in Part 3 of the survey). To represent the dynamic of consumer familiarity, we assume that a rising market share for PEVs will increase consumer familiarity over time. For respondents not familiar with PEVs, their familiarity increases from 0 to 1 following a logistic curve as PEVs gain market share. This function is parameterized such that when the PEV new market share is 5%, there is no constraint on sales due to familiarity (i.e. all consumer are "familiar" enough with PEVs to consider buying one).

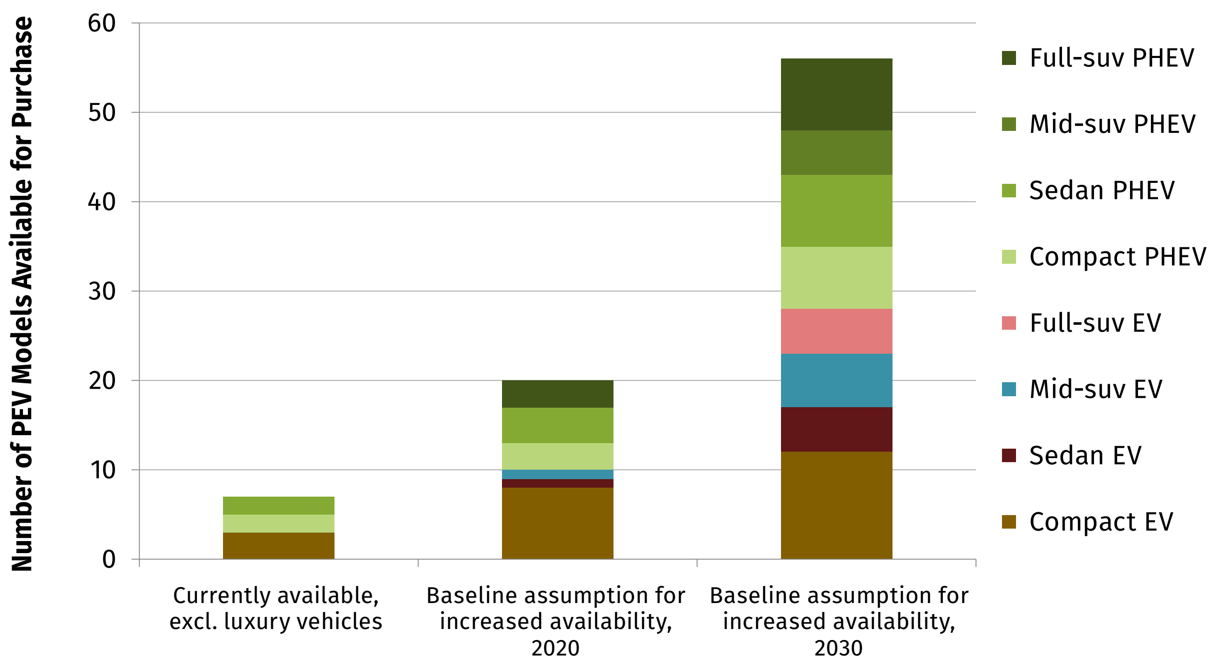
   » **PEV availability –** Even if respondents that selected PEV models in Part 3 of the survey have home charging access and are relatively familiarity with PEVs, we assume that they cannot purchase a PEV if the supply is not available. We address several components of supply:

   - We assume the respondent can only buy a PEV if there is a PEV available for sale in their preferred vehicle class (compact, sedan, Mid-SUV, Full-SUV).
   - We assume that the respondent can only buy a PEV if there is an automotive dealership close to the respondent's reported home city or municipality that: (a) is certified to sell PEVs, or (B) advertises the capacity to stock PEVs (only if the brand does not certify dealerships for PEV sales).
   - We assume that the respondent is more likely to purchase a PEV if there are a variety of models available in their preferred vehicle class. Vehicle buyers tend to have a variety of preferences beyond vehicle class, including style, safety, size, comfort and brand. We account for this by applying a scaling factor to the availability constraint based on the variety of each PEV type in each class. The scaling factor is the number of PEV makes/models in a given drivetrain/class combination divided by 5. If there are 5 or more different types of PEV available in a given type and class, e.g. PHEV Sedans, then we

assume there is not constraint. But any value less than 5 reduces the probability of a respondent purchasing a PEV.

- Our model represents present PEV availability and variety based on vehicle manufacturer offerings—as of 2015 there are currently seven PEV models available in British Columbia (excluding luxury vehicles). In our baseline scenarios (Figure 42), we look at manufacturer announcements to estimate future availability. We assume that PEV availability increases to 20 PEVs in British Columbia in 2020, and even further in 2030. We also assume PEVs are available from all brands and all dealerships, such that by 2030 there are 56 PEVs available with no constraints due to dealership access.

Figure 42: PEV availability and variety in the forecast scenarios



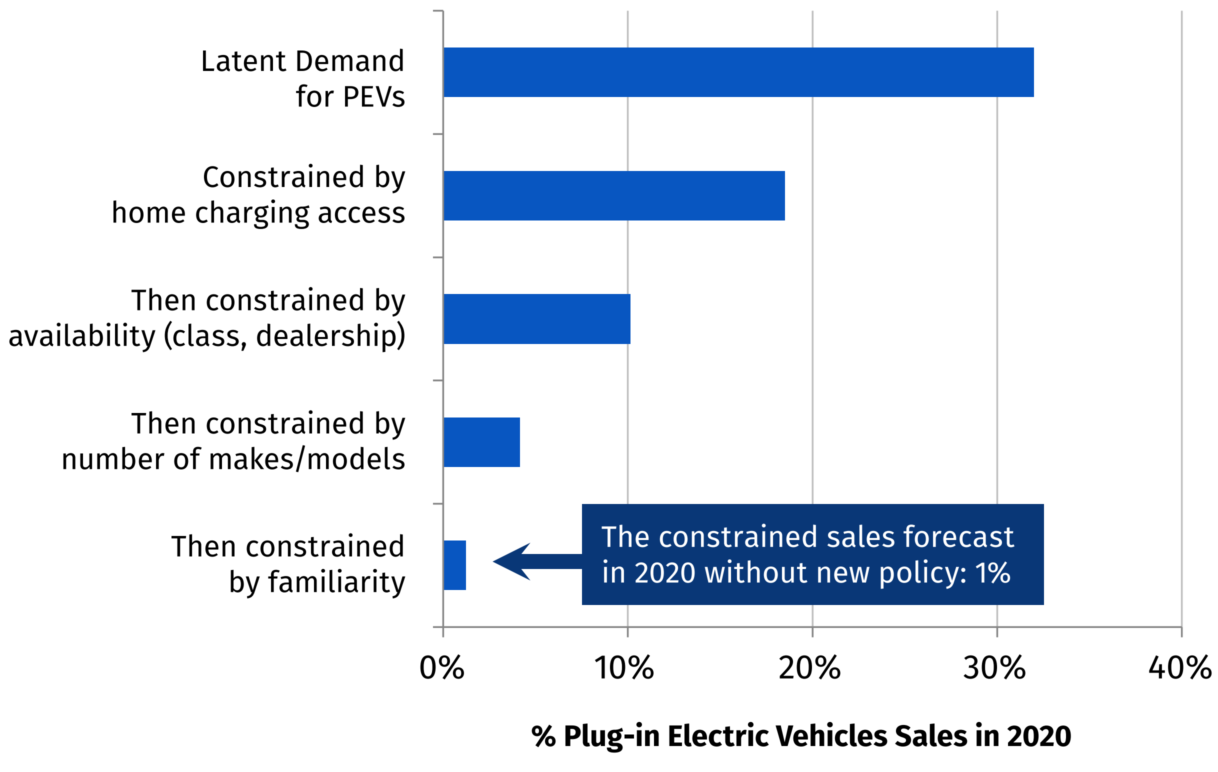
We conducted a sensitivity analysis to understand the model's response to variations in eight different parameters: PEV availability/variety (+/- 25% variation in the factor that scales PEV demand based on available models), home charging constraint (+/- 25% charging with the same reliability as charging at home), PEV incremental cost relative to combustion vehicles (+/- 25%), the rate at which PEV familiarity increases driven by PEV sales (+/- 25%), weekly gasoline and electricity cost (+/- 25%), PHEV archetype (16 and 32km electric range rather than 64 km), BEV archetype (80 and 160 km electric range rather than 120 km).

14.3. Results and Implications

Using the discrete choice model and vehicle model, we estimate that the "latent demand" or unconstrained demand for PEVs in 2020 is approximately 32% of new vehicle sales. This value is similar to the level of PEV interest we found among Mainstream respondents in Section 8.1. However, such a forecast is inevitably inflated, as it does not account for the various constraints.

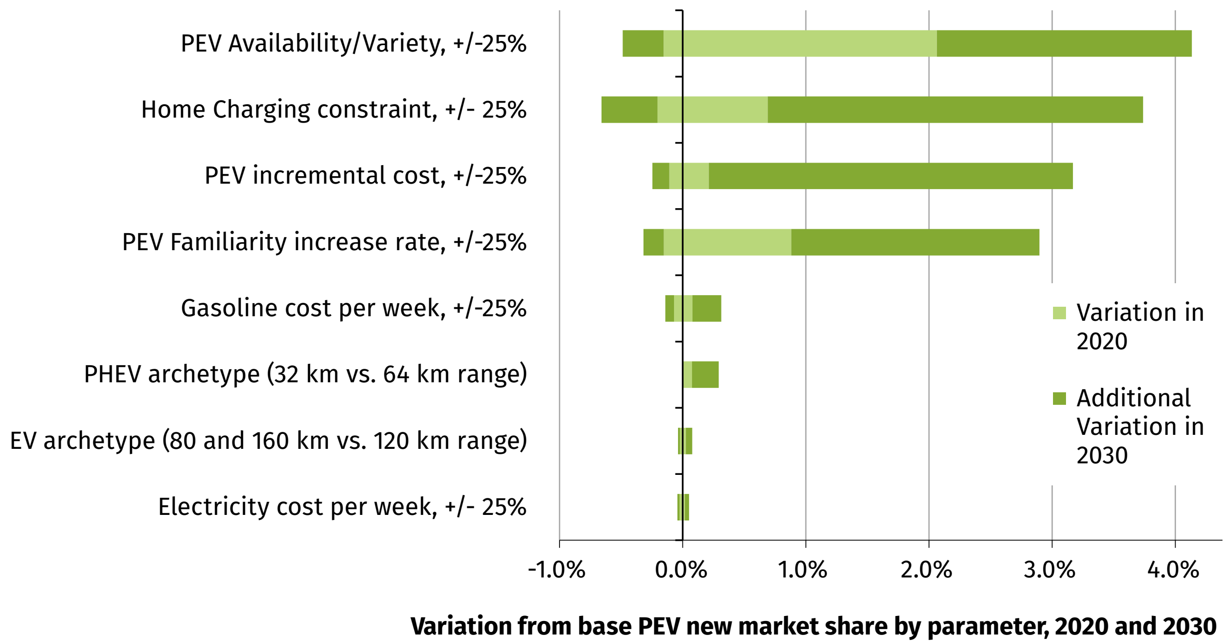
Figure 43 depicts how our 2020 forecast of PEV market share decreases as we add in the various parts of our constraints model. Limiting PEV sales to those with home charging reduces the market share to 18%. Further constraining sales based on PEV model availability reduces the market share to 10%. Scaling demand based on the limited number of PEV makes and models (or limited variety) reduces forecasted market share to 4%. Finally, if only those who are familiar with PEVs can buy PEVs, the market share falls to roughly 1% in 2020. This 2020 forecast is more in line with the present day (2014) level of PEV market share in British Columbia.

Figure 43: Impact of constraints on the electric vehicle sales in British Columbia, 2020



Because there is extensive uncertainty in all these assumptions, we conducted sensitivity analysis to understand how our main modeling assumptions affect our results. Specifically, we varied each of our main eight parameters by plus or minus 25% to see how that variation affects our PEV market share forecasts for 2020 and 2030 (Figure 44).

Figure 44: Sensitivity analysis of PEV sales forecast



The model is most sensitive to PEV availability and variety, home charging access, the incremental cost of PEVs, and the rate at which PEV familiarity increases. As well, variation in individual parameters produces an asymmetric variation in PEV sales. There is greater variation towards increased sales because the model endogenously changes the PEV familiarity constraints, producing a positive feedback to sales.

We used our "constrained choice" model to forecast PEV market share to the year 2030, accounting for the significant uncertainty in three of the key parameters identified in the sensitivity analysis: PEV availability/variety, the incremental cost of PEVs and the rate at which familiarity with PEVs can increase. We created two primary scenarios:

» The "c**urrent PEV availability**" scenario assumes that only seven PEV models are consistently available each year until 2030.

» The "**increasing PEV availability**" scenario assumes that the availability of PEV models increases up to 56 by the year 2030 (as shown in Figure 42).

We applied upper and lower bounds to various assumptions in these scenarios. The upper bounds have a faster rate of PEV familiarity (+25%), less scaling due to limited PEV makes and models (-25%), and incremental costs for PEVs that fall to 25% of the values show in Table 36. The lower bounds to these scenarios have a lower rate of familiarity (-25%), greater scaling (+25%) and static PEV incremental costs.

Results from this modeling exercise clearly indicate that the "latent demand" for PEVs cannot translate to actual market share unless PEVs become widely available, in terms of the number and variety of vehicles for sale and the locations at which they are sold (Figure 45). In other words, our PEV market share forecasts are dominated by supply-side constraints. Unless auto suppliers bring more PEVs into the British Columbia market, it is unlikely that PEVs will account for more than 1% of new vehicle sales in 2020. If the number and availability of PEVs does not increase between 2020 and 2030, they will account for, at most, 4—5% of new vehicle sales in British Columbia by 2030, even if the incremental cost of PEVs fall by 75% and awareness of PEVs is substantially higher than today. On the other hand, greater PEV availability could result in the PEV market share being significantly higher, potentially reaching up to 20% of new vehicle sales by 2020.

Figure 45: PEV new market share scenario results

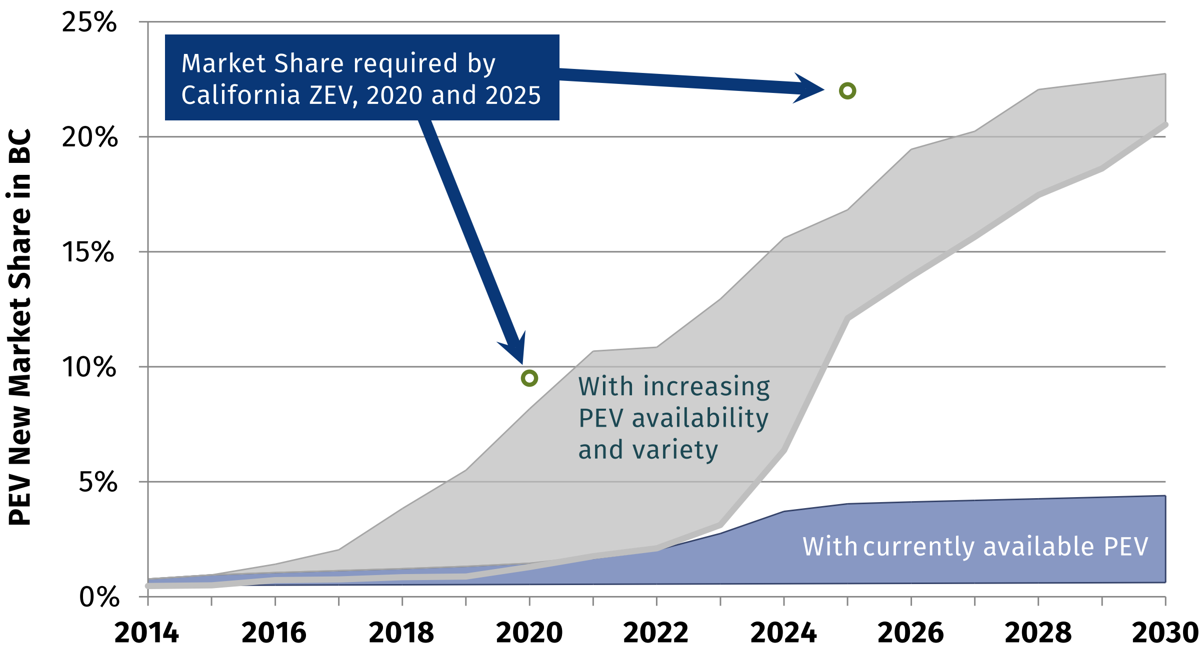


Figure 45 also identifies the approximate PEV new market share numbers that are required in California by the state's zero emission vehicle (ZEV) mandate: 6—10% in 2020 and 21—23% in 2030. The ZEV mandate requires that automakers sell a certain percentage PEV or hydrogen powered vehicles. Clearly, policies such as ZEV mandates incentivize auto companies to make PEVs more widely available in a greater variety of models, to stock these vehicles in dealerships, and to market such vehicles in the region with the policy (e.g. California). Because British Columbia does not presently have a ZEV mandate or similar supply-focused policy in place (see Section 2 for more discussion of policy types), there is no pressure on auto companies to address such supply constraints.

15. Acceptance of Utility Controlled Charging

Research Highlights for Section 15

Utility controlled charging (UCC) could be an important method to control the timing of PEV charging to reduce environmental impacts, increase the use of renewable energy, and potentially reduce grid costs. We explore respondent acceptance of various UCC programs, finding that:

Among Mainstream (NVOS) respondents:

- Awareness and understanding of electricity sources and the idea of UCC is very low.
- Once explained, there is general openness to UCC programs, where probability of enrollment in such a program is higher with decreased electrical bills, increased access to renewable electricity, and increased "guaranteed minimum charge" or more charge each morning.
- There is significant heterogeneity among respondents that are "Pro-UCC" (79%), where 34% are motivated by guaranteed minimum charge or more charge, 28% are motivated by cost savings, and 17% are motivated by increased renewable electricity.
- Interviews indicate that some see linking PEVs to green electricity as "natural," but there is concern regarding loss of control and lack of trust in the utility.

Among PEV Pioneer (PEVOS) respondents:

- UCC acceptance is much higher relative to Mainstream respondents, where PEV Pioneer respondents are willing to pay 50% more for guaranteed minimum charge, and 4 times more for increased renewables.
- Two-thirds of respondents are clearly "Pro-UCC"; the remaining third places a lower value on UCC and is much more sensitive to decreases in guaranteed minimum charge.
- Interviews indicate that motives for UCC enrollment are primarily related to supporting the environment (renewables) or supporting technology development.

NOTE: This Section includes analysis from a manuscript that is currently in peer review.

Full Citation: Bailey, J. H. and, J. Axsen (Revise and resubmit). Anticipating consumer acceptance of utility controlled charging for plug-in vehicles, Submitted to *Transportation Research Part A: Policy and Practice.*

We define utility controlled charging (UCC) as when an electric utility (or an appointed third party) somehow controls the charging of PEVs either by deciding when the vehicle is charged or by drawing power from the vehicle to the grid. UCC can be framed according to a number of benefits: it has the potential to facilitate load management (Druitt and Früh, 2012; Kempton and Tomić, 2005a), reduce electricity system costs (Tomić and Kempton, 2007) subsidize the PEV market (Kempton and Tomić, 2005a, b) and increase the use of renewable sources of electricity (Lund and Kempton, 2008; Tomić and Kempton, 2007; Weis et al., 2014). As demonstrated in Section 12, scenarios of "unconstrained" PEV charging can lead to evening peaks in electricity demand that might cause challenges in grid management. And potentially, the timing of PEV charging could be shifted to match the availability of intermittent sources of renewable energy, such as wind power.

No research has explored consumer acceptance of UCC as we define it here, though a few studies explore consumer perceptions of PEV-grid connections and interactions. Axsen and Kurani (2013a) found that offering enrollment in a green electricity program to accompany a PEV purchase increased stated interest in PEVs by 23%. A second related study by Parsons et al., (2013) investigated consumer preferences for V2G, a complex type of UCC where power stored in PEVs may be discharged back to the electric grid. The authors find that potential revenues from V2G are not likely be substantial enough to incentivize PEV purchases, largely due to the heavy discounting assigned by all consumers to future V2G revenue.

In this section we investigate Mainstream (NVOS) and Pioneer (PEVOS) respondents' acceptance of UCC for nightly residential PEV charging, focusing on the role of UCC in facilitating the efficient use of intermittent renewable electricity sources. We assess nightly charging because, currently, most PEV owners charge their vehicles during this time (US DOE, 2012).

15.1. Early Mainstream Acceptance of UCC (NVOS)

Methodological Approach

We focus our analysis on the Early Mainstream NVOS respondents, as these respondents are most likely to be affected by a UCC program in the near term. Our main focus is to quantify consumer preference for enrollment in a UCC program, including tradeoffs between usage of renewable sources of electricity, impacts on their electricity bill, and charging inconvenience.

Drawing from the NVOS survey, we analyze data from questions related to perceptions of electricity sources and lifestyles in Part 1, and preference for UCC (attitudinal questions and a discrete choice experiment) in Part 3. In Part 2, participants were provided with information about UCC and how UCC may be used in conjunction with PEVs and renewable electricity before completing Part 3. The survey instrument is explained in more detail in Section 4.2.

Our main analysis is the estimation of a discrete choice model, similar to that for vehicle choice in Sections 8 and 10. For UCC, we estimated a multinomial logit model (MNL) and a latent class model (LCM) to help identify heterogeneity in consumer preferences for UCC. As explained in Section 10, a LCM addresses heterogeneity by grouping respondents according to different patterns of preferences. The latent class specification allows for the inclusion of individual specific variables such as socio-demographic, attitudinal and value based variables. These individual variables facilitate the interpretation of class membership (Strazzera et al., 2012). We estimated our choice models using Latent Gold (Vermunt and Magidson, 2005).

Since there are no previous examples of discrete choice experiments investigating UCC preferences, we took care when generating attributes and levels. Attributes and levels were extensively pre-tested, to assess respondent understanding of the concept. We used four attributes to represent the UCC charging decision. Each attribute was assigned four levels that varied between the alternatives depicted in each choice set (see Table 11).

To represent the inconvenience associated with UCC (due to the integration of intermittent sources of renewable electricity), we use the attribute "guaranteed minimum charge" (GMC). The survey described UCC scenarios where the electric utility might delay charging of the PEV until later in the evening or take electricity from the vehicle battery when it is plugged-in. The GMC was described as: "the minimum level of charge that your battery would have after a night of being plugged-in." For example, if your GMC were 50%, then in the morning your PEV battery would be at least half full, but it could also be higher. We represented GMC as a percentage of charge (e.g. 90% state of charge), and informed respondents of the corresponding electric driving range in km (dependent on their vehicle design).

NVOS Discrete Choice Model Results

We present the latent class specification alongside a multinomial logit (MNL) to demonstrate how results differ when accounting for heterogeneity in preferences (Table 38). The MNL coefficients estimate that, on average, UCC is perceived as a disutility (i.e. negatively) relative to uncontrolled charging, with all attributes held equal. Coefficient estimates for the monthly electrical bill, GMC and percentage of renewables were all of the expected sign, and were all statistically significant at a 99% confidence level. Interestingly, all the dummy coefficients for source of green electricity were negative relative to the base of "mixed sources." Wind was least desirable among the green electricity sources depicted.

The bottom of Table 38 translates the coefficient estimates into willingness-to-pay (WTP) values, where on average, respondents were WTP an additional $92/year to increase their morning GMC by 10%, and were WTP $15/year to increase the amount of renewable electricity by 10%. The MNL estimates assume homogeneous preferences amongst the respondents.

To represent variability in preferences for UCC among the Early Mainstream NVOS sample, we tested various latent class model specifications. Overall, we found that the 4-class model (Table 38) provided the best combination of interpretability and mathematical rigor. We also varied model specification through different combinations of socio-demographic and attitudinal covariates.

The final model only includes significant covariates for parsimony. The Latent Class model shows that the four classes have substantially different preferences and individual characteristics. The first class demonstrated the least interest in UCC, while the three were interested in UCC for different reasons. We briefly describe each class below:

1. The **Anti-UCC class** (21% of Early Mainstream respondents) has significant negative estimates for the UCC alternative specific constant and also for the renewable electricity coefficient. Members are highly sensitive to changes in GMC compared to other groups, indicating that members are not open to the potential inconvenience associated with UCC. The Anti-UCC class was more likely to be significantly older and less educated than members of the other classes.

2. The **Charged focused** class (33% of Early Mainstream respondents) are relatively sensitive to changes in the GMC level and monthly electricity bill. This class did not have a significant UCC constant estimate, nor was the renewable electricity coefficient significant. These respondents are most likely to see UCC as an "invasion of privacy."

3. The **Cost motivated** class (28%) had a significantly positive constant estimate for UCC. These respondents are the most sensitive to increases in costs and are willing to pay the least for additional units of renewables and GMC, relative to the other Pro-UCC classes. Cost is thus a priority for respondents in this class. These individuals were significantly more likely to have technologically oriented lifestyles and were less likely to have altruistic values relative to other classes.

4. The **Renewables focused** class (17%) includes individuals that value UCC and renewable electricity most highly. These respondents are less cost sensitive than the other Pro-UCC classes and are the only class to have significant parameter estimates for the sources of renewable electricity. These individuals prefer mixed sources of renewable electricity to small hydro, wind and solar respectively. These respondents are significantly more likely to be highly educated and have a higher level of biospheric values than the other classes.

Table 38: MNL and LCM specifications of the discrete choice model accompanied by WTP estimates and model summary statistics (Mainstream NVOS sample)

Parameter	**MNL**	**Latent Class Model**			
		Class 1	**Class 2**	**Class 3**	**Class 4**
Probability of class membership:		**Anti-UCC**	**Charge Focused**	**Cost motivated**	**Renewable focused**
	100%	**20.6%**	**33.7%**	**28.4%**	**17.2%**
	Coeff	Coeff	Coeff	Coeff	Coeff
Alternative specific constants					
Utility controlled charging	-0.307 ***	-4.571 ***	0.339	1.552 **	3.565 ***
Model attributes					
Monthly electric bill (CAD)	-0.029 ***	-0.016 ***	-0.053 ***	-0.218 ***	-0.019 ***
Guaranteed minimum charge in the morning (%)	0.023 ***	0.025 ***	0.056 ***	0.033 ***	0.015 ***
Percentage of green electricity (%)	0.004 ***	-0.017 ***	-0.001	0.013 ***	0.014 ***
Type of green electricity (base = “mixed sources”)					
Dummy - 1 if wind.	-0.337 ***	0.363	-0.297 *	-0.196	-0.521 **
Dummy - 1 if small hydro.	-0.034	0.089	0.195	0.099	-0.369 *
Dummy - 1 if solar.	-0.154 **	0.684 *	-0.172	0.175	-0.569 ***
Class membership probability model (with Class 2 as the base)					
Intercept		-1.9 **	0	-0.624	-4.665 ***
Demographics					
Age: Continuous		0.016 *	0	0	-0.011
Dummy - 1 if income > 80k/yr.		0.05	0	0.257	-0.154
Dummy - 1 if Bachelors or higher		-0.564 **	0	0.35	1.066 ***
Lifestyle & Attitudes					
Technologically oriented lifestyle: Scale (0—25)		0.033	0	0.062 **	0.041
Biospheric values: Relative scale (0—12)		0.035	0	0.096	0.454 ***
Altruistic values: Relative scale (0—12)		0.007	0	-0.158 *	-0.107
Privacy concern: Likert (-2 – 2)		-0.063	0	-0.232 **	-0.262 *
Annual WTP ($CAD)					
For a 10% increase in GMC	$92	$188	$127	$18	$95
For a 10% increase in % of renewables	$15	-$128	-$2	$7	$88
To adopt UCC	-$124	-$3428	$77	$85	$2252
Log Likelihood	-4546.00	-3389.762			
Overall Pseudo R^2	0.159	0.566			

* Significant association at 90% confidence level

** Significant association at 95% confidence level

*** Significant association at 99% confidence level

15.2. PEV Pioneer Acceptance of UCC (PEVOS)

We also estimated MNL and latent class choice models using data collected from PEV Pioneers—the PEV Pioneer respondents. The PEVOS survey included the same UCC choice experiment as the NVOS survey. Table 39 presents the latent class specification alongside the multinomial logit (MNL) specifications from the Mainstream (NVOS) and PEV Pioneer (PEVOS) samples to demonstrate how results differ.

The PEVOS MNL indicates that, on average, UCC is perceived as a disutility relative to uncontrolled charging, but not as negatively as for Mainstream respondents. Coefficient estimates for the electrical bill, GMC and percentage of renewables were all of the expected sign, and were all statistically significant at a 99% confidence level. Relative to the base of “mixed sources” solar was significantly preferred amongst PEV Pioneer respondents. PEV Pioneer respondents expressed higher WTP values for GMC (48% higher) and for renewable electricity (4 times higher).

While the MNL estimates assume homogeneous preferences amongst the respondents, we also estimated a latent-class model to represent heterogeneity. We identified two classes, which primarily differ by preference (not individual characteristics):

1. The **Pro-UCC** class (65% of PEV Pioneer respondents) is willing to pay to adopt UCC (as opposed to requiring reimbursement) and expresses a higher value for renewable sources of electricity.
2. The **Anti-UCC** class (35% of PEV Pioneer respondents) has an overall negative valuation of UCC. These respondents value GMC very highly—they are WTP over $430 to increase their morning GMC by 10%, which is higher than the other PEV Pioneer class and all four classes estimated from the Mainstream sample. Members of this class are more likely to be politically oriented than the Pro-UCC class and tend to have lesser environmental concern.

Table 39: MNL and LCM specifications of the discrete choice model accompanied by WTP estimates and model summary statistics for Mainstream (NVOS) and Pioneers (PEVOS)

	Early Mainstream	PEV Pioneer	PEV Pioneer	
	NVOS	PEVOS	PEVOS	
			Pro UCC	Anti UCC
Probability of class membership			65%	35%
Alternative specific constants				
Utility controlled charging	-0.307 ***	-0.450 ***	0.332	-0.845 ***
Model attributes				
Monthly electric bill (CAD)	-0.029 ***	-0.024 ***	-0.044 ***	-0.022 ***
Guaranteed minimum charge in the morning (%)	0.023 ***	0.028 ***	0.016 ***	0.080 ***
Percentage of green electricity (%)	0.004 ***	0.016 ***	0.023 ***	0.009 **
Type of green electricity (base = “mixed sources”)				
Dummy - 1 if wind.	-0.337 ***	-0.027	-0.053	0.315
Dummy - 1 if small hydro.	-0.034	0.490	0.065	0.301
Dummy - 1 if solar.	-0.154 **	0.063 ***	0.808 ***	-0.057
Class membership probability model (with Class 2 as the base)				
Intercept			[base]	0.102
Demographics				
Age: Continuous				0.022
Dummy - 1 if income > 80k/yr.				-0.226
Dummy - 1 if Bachelors or higher				-0.0626
Lifestyle & Attitudes				
Technologically oriented lifestyle: Scale (0—25)				-0.0509
Biospheric values: Relative scale (0—12)				0.1529 **
Altruistic values: Relative scale (0—12)				-0.0725
Privacy concern: Likert (-2 – 2)				-0.0668 *
Annual WTP ($CAD)				
For a 10% increase in GMC	$92	$136	$43.39	$432.65
For a 10% increase in % of renewables	$15	$78	$63.71	$47.35
To adopt UCC	-$124	-$19	$7.60	-$37.87
Log Likelihood	-4546.00	-963	-786	
Number of Individuals	530	94(84)[b]	94(84)[b]	
Number of Observations	3180	1068	1068	
Overall Pseudo R^2	0.159	0.19	0.43	

* Significant association at 90% confidence level

** Significant association at 95% confidence level

*** Significant association at 99% confidence level

15.3. Interview Insights: NVOS and PEVOS

To complement the quantitative analysis of NVOS and PEVOS survey responses, we also draw from the interviews conducted with subsamples of these respondents. As a reminder, the interview method included UCC design games, similar to those completed in the survey (see design game description in Section 4). We summarize our preliminary findings for both subsamples below.

NVOS Interviews with Mainstream Owners (n = 22)

To start with, interview participants had little awareness of the sources of electricity consumed in British Columbia and the challenges associated with integrating green electricity sources into the grid. Participants were almost universally aware of the different types of green electricity sources discussed in the interviews (solar photovoltaic, wind turbines, and small-scale hydro), but only 2—4 had a basic understanding of integrating green electricity into the grid. Most understood that green electricity may be intermittent, e.g. that wind "comes in spurts" and with solar panels "if it's not sunny out, they don't really work, right?". But most did not understand issues related to storage and grid integration. For example, Clair asked "But isn't it [wind energy] stored in some way? When the wind is blowing, don't they store that…?" Even after the rationale for UCC was more fully explained, many participants had trouble fully conceptualizing how UCC would facilitate integration of green electricity sources.

Of the 20 households that were interested in buying a PEV (as detailed in Section 8.3), 14 were willing to accept some amount of UCC in exchange for receiving green electricity (Table 40): five household accepted a higher level (50—60% guaranteed minimum charge) and nine a lower level (80—90% guaranteed minimum charge).

The motivation for accepting any level of UCC was consistently the desire to "receive" or support green electricity which was seen as environmentally friendly or "natural". Further, 3 households explicitly expressed that green electricity seemed to be an appropriate compliment to PEV ownership. As Liz stated: "having an electric car and the green electricity, I mean you're walking the walk."

Table 40: NVOS interview UCC design game choices

	Willing to accept high sacrifice UCC (50—60% guaranteed minimum charge)	Willing to accept low sacrifice UCC (80—90% guaranteed minimum charge)	Not willing to accept UCC (No sacrifice)
High PEV interest (Chose PEV in design game)	4	3	4
PEV Open (Did not choose PEV in design game but were open to PEV adoption in the future)	1	6	2
PEV Opposed	N/A	N/A	N/A

Although most participants were willing to accept some level of UCC, they did indicate some drawbacks associated with their participation. The three most frequently reported drawbacks were:

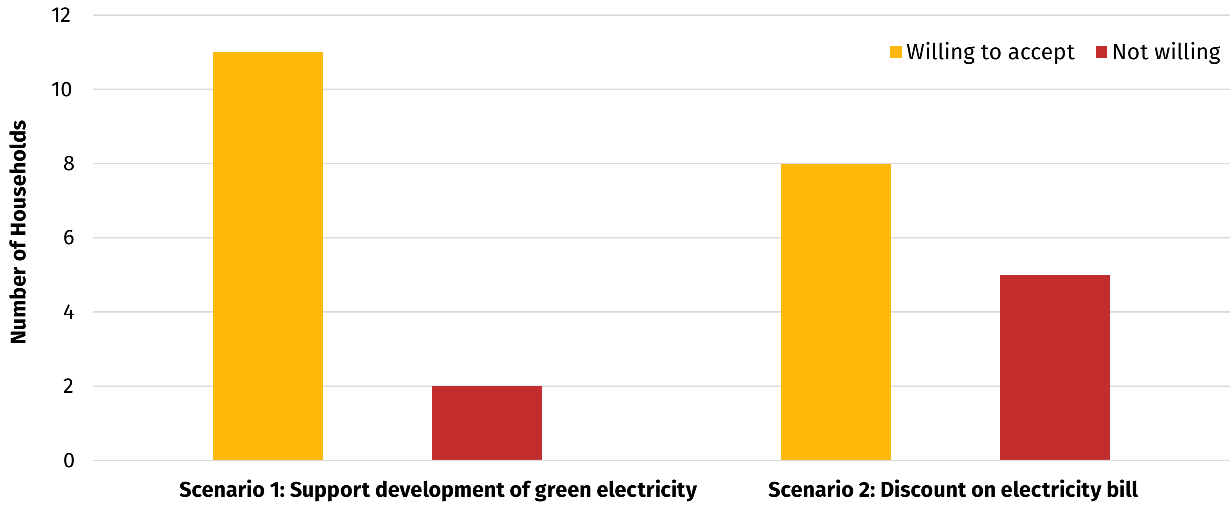
1. Insufficient compensation: “receiving” green electricity was not seen as adequate incentive for some participants; this was the primary reason for two households that rejected UCC.
2. Loss of control: at least 10 households associated a discomfort with UCC—what Mrs. Moretti called “relinquishing control” over when and how much their hypothetical PEVs’ batteries would be charged. For some, maintaining 100% guaranteed minimum charge (and thus not accepting UCC as presented in the interview games) was “about [having] peace of mind.” This discomfort was expressed by 3 of the households that did not accept any amount of UCC.
3. Lack of trust: 6 households expressed concern over the utility’s trustworthiness regarding the ability to administer UCC or provide green electricity. For the Mathews this concern meant that they were not willing to accept any amount of UCC despite strong positive perceptions of green electricity: “I don’t find the concept bad, but it’s just one more complication, something that could go wrong. I mean, things are misread… there’s some kind of bureaucracy gets in there, and you may find yourself at odds with it.”

PEVOS Interviews with PEV Pioneers (n = 12)

In contrast to the NVOS interviewees, all PEVOS interviewees were either previously aware of the concept of UCC or were quick to comprehend the concept once it was introduced. No participant demonstrated difficulty in understanding what UCC was and why such a concept might be desirable for utilities.

Willingness to accept UCC was very high among PEVOS interviewees. Of the 13 households interviewed, 11 were willing to accept UCC if it supported green electricity, while 8 were willing to accept UCC if it came with a discount on their monthly electricity bill (Figure 46). Those supportive of UCC clearly understood the potential environmental benefits of such a system. Some described as “where we needed to go” or “doing the right thing … Contributing to the hydro grid for clean power”. Participants that had previously researched UCC and smart grid programs tended to perceive UCC as part of technological progress. For example, one participant described UCC as the logical next step and explained that “you’re going to eventually have all your heaters and appliances and things … talk to some kind of centralized unit in your house”.

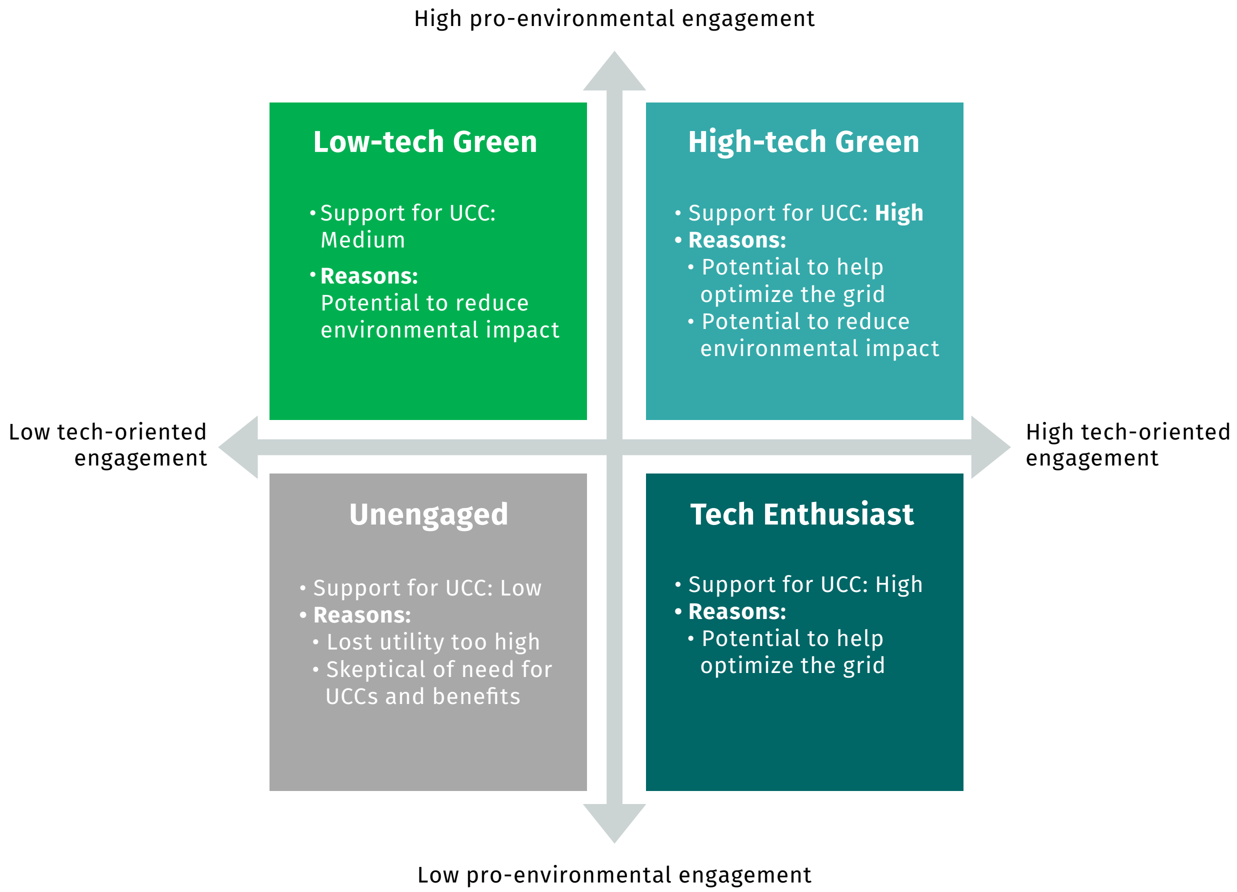
Figure 46: Willingness to accept UCC under both scenarios conducted in the PEV Pioneer PEVOS interviews (n = 13)



Although support for UCC was high, participants noted some concerns about UCC. One general concern was that if the utility were able to draw from the vehicle's battery, the battery would degrade more quickly. As stated by one participant: "the only condition I would really need would be ... a guarantee that it's not damaging to the vehicle in any way or degrading the battery". Accordingly, some households stated they would need either a guarantee from the utility, monetary compensation, or an extended battery warranty to accept UCC. Daily driving needs also caused concern. Three households stated they would be much more supportive of UCC if they had the ability to override it on select nights (all 3 households would be willing to pay for such a feature).

Further insights were gained by viewing UCC acceptance in light of respondent lifestyle engagement, using the qualitative segments described in Section 10.3 (see Figure 47). Tech Enthusiast and High-tech Green respondents were more likely to support UCC under both scenarios (green electricity support and electricity bill discount) due to its potential to help optimize the electricity grid. High-tech and Low-tech Greens were also motivated by UCC's potential to reduce environmental impacts, either by supporting green electricity development or optimizing the grid, thereby reducing the demand for new sources of generation to come online. Those lacking engagement in a tech-oriented lifestyle (i.e. Low-tech Greens and Unengaged) were less willing to accept UCC when support for green electricity was removed. Some explained that a financial discount would have to be higher (more than 20%) to compensate for potential inconvenience.

Figure 47: Perceptions of UCC benefits by lifestyle type



16. Future Research

This report presents the latest results from the Canadian Plug-in Electric Vehicle Study (CPEVS) as of May 25, 2015. Several of these analyses are already presented in greater detail in other publications (see Section 1.3 for details), while our research team plans to release more publications, white-papers and reports of these and related analyses. Future research directions may include (subject to funding):

- Conduct a dynamic, long-run analysis of how PEV usage could reduce GHG emissions, with the electricity grid of a given region transitioning with the transportation sector.
- Implementing the CPEVS method in other countries to assess PEV market potential.
- Applying the PEV market share forecast model to other Canadian regions (beyond British Columbia) and other countries.
- Linking the PEV discrete choice model with the utility-controlled charging choice model to create an integrated model of PEV choice and usage.
- Linking the PEV usage model with a detailed electricity dispatch model to quantify the potential for utility controlled charging of PEVs to facilitate the deployment of renewable energy.
- Using the PEV market share forecast model to quantify the effectiveness of different demand-focused and supply-focused policies, e.g. deploying public charging infrastructure, providing charging at multi-unit residential buildings, implementing a ZEV mandate, and providing various financial and non-financial incentives.

Please contact Jonn Axsen (jaxsen@sfu.ca) or Suzanne Goldberg (sgoldber@sfu.ca) for information on the most recent PEV analyses conducted by the Energy and Materials Research Group at Simon Fraser University.

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Appendix A: Charger Cost Installation Model

To customize installation costs for the PEV "design space" exercise (Section 4.2), 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 PEV charging stations) were not sent any further questions. Respondents that had a reliable parking space were categorized as follows:

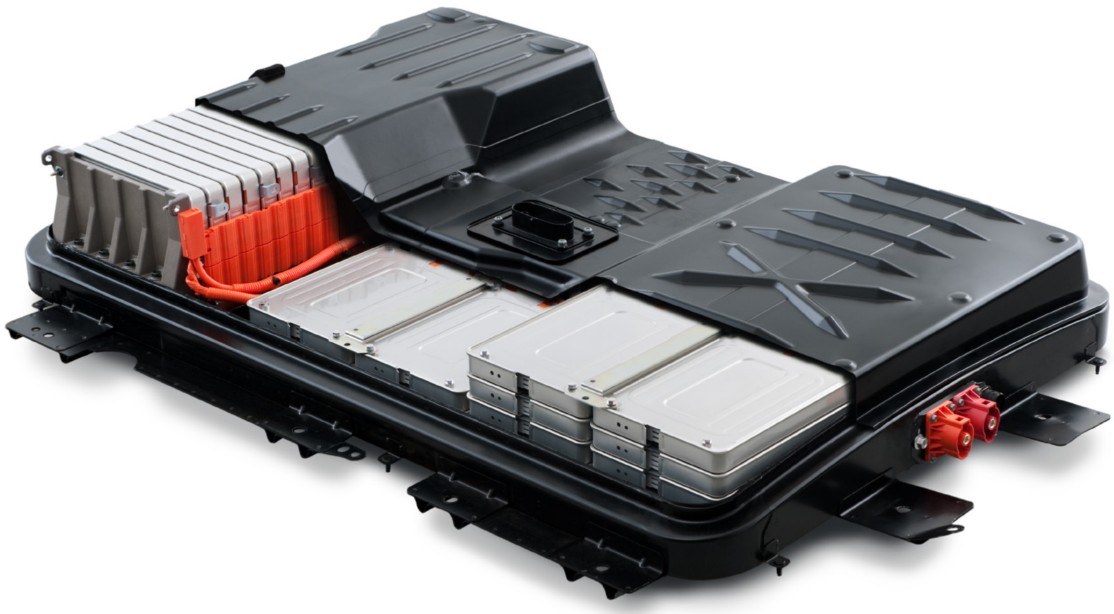
» A respondent has Level 1 access if they currently have a parking space within 25 feet of an existing 110/120-V outlet.

» 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 41 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 owners in San Diego, California (Axsen and Kurani, 2012c).

Table 41: 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



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