Who wants zero-emissions vehicles and why? Assessing the Mainstream market potential in Canada using stated response methods

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Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

Extensive deployment of zero-emissions vehicles (ZEVs) is likely essential for Canada to achieve its greenhouse gas reduction targets, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (HFCVs). To effectively promote ZEVs, it is critical to understand the factors that influence consumer interest in ZEVs. In this study, I surveyed 2,123 Canadians that intend to buy new vehicles to develop insights into “latent demand” among consumers, (that is, what demand would be if the ZEVs were fully available in the market), including ZEV-related preferences and possible underlying motivations for interest. Specifically, I analyze results from two stated response methods: design exercises and a stated choice experiment. First, the design exercises reveal that 21% of respondents are interested in ZEVs (a proxy for latent demand), where interest is primarily in PHEVs, followed by BEVs and HFCVs. ZEV-interested respondents tend to be younger and have higher education and income levels, and are also unique in measures of lifestyle engagement, values, and environmental concern. The design exercises also revealed that HFCV-interested respondents are distinct from PHEV- and BEV-interested respondents in their values and possible underlying motivations. Using data from the stated choice experiment, I estimated a latent class discrete choice model, and identified five unique respondent segments. Thirty-six percent of respondents fall probabilistically into segments which have strong preferences for ZEVs, 20% of respondents are undecided about ZEVs but remain open to them, and 44% of respondents prefer conventionally fueled vehicles. The latent class model indicates that respondents who prefer ZEVs are younger and have higher education levels, and have greater environmental concern, more environmental-oriented lifestyles, and stronger pro-social values. Results from this study indicate that financial subsidies and home recharging could be effective in increasing latent demand. Policy makers would be wise to consider the range of preferences and possible motives for ZEV interest when designing ZEV-supportive policy.

Keywords: electric vehicle; plug-in hybrid electric vehicle; hydrogen fuel cell vehicle; consumer research; survey; latent class choice model

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List of Acronyms

ANOVA	Analysis of Variance
BEV	Battery electric vehicle
CV	Conventional vehicle
CZEVS	Canadian Zero-Emissions Vehicle Survey
DC	Direct current
DCM	Discrete choice model
GHG	Greenhouse gas
HEV	Hybrid electric vehicle
HFCV	Hydrogen fuel cell vehicle
LCM	Latent class model
NEP	New environmental paradigm
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
START	Sustainable Transportation Action Research Team
WTP	Willingness-to-pay
ZEV	Zero-emissions vehicle

Chapter 1. Introduction

Transportation is the second-largest contributor to Canada's greenhouse gas (GHG) emissions, with passenger vehicles alone generating 16% of the nation's total GHG emissions (Environment and Climate Change Canada, 2017). Accomplishing deep GHG reductions outlined in international and national climate mitigation agreements requires cutting passenger vehicle emissions (International Energy Agency, 2015; Jaccard, Hein, & Vass, 2016; Williams et al., 2012). Some research and models suggest that stemming passenger vehicle emissions in the long term (i.e., by 2050) requires consumers to shift from driving conventional, fossil fuel powered vehicles to driving zero-emissions vehicles (ZEVs) (Bahn et al., 2013; Greene & Ji, 2016; Vass & Jaccard, 2017). ZEVs, which *can* have zero tailpipe emissions, include battery electric vehicles (BEVs) that are powered solely by electricity, plug-in hybrid electric vehicles (PHEVs) that are powered by both gasoline (or diesel) and electricity, and hydrogen fuel cell vehicles (HFCVs) that are powered by hydrogen only. Drawing from Canada's existing electricity grid, PHEVs and BEVs (collectively known as plug-in electric vehicles, or PEVs) can eliminate 34-98% of vehicle tailpipe emissions relative to a conventional vehicle (CV) (Axsen, Goldberg, et al., 2015; Requia et al., 2017), with potential further reductions as the electricity grid continues to decarbonize (Axsen, Goldberg, et al., 2015; Plötz et al., 2017). Given this potential, transportation researchers suggest that 80-90% of new vehicles sales be ZEVs by 2050 to ensure climate mitigation targets are met (Bahn et al., 2013; Greene, Park, & Liu, 2014; Kyle & Kim, 2011; McCollum & Yang, 2009; National Research Council, 2013).

To increase the broader understanding of how the Canadian consumer market for ZEVs may develop, this study focuses on evaluating which ZEVs Canadians want and why. Achieving the level of sales required to reach GHG reduction targets necessitates that vehicle consumers adopt ZEV technologies; however, ZEVs are such new technologies that the extent to which consumers will demand and use them remains unknown. For instance, current sales levels do not reflect "latent demand" for ZEVs (i.e., demand that is not realized due to real world constraints) because there are barriers to adoption such as lack of consumer awareness of ZEVs, inadequate refueling/recharging infrastructure, and insufficient vehicle supply (Wolinetz & Axsen, 2017). It is critical to understand consumers' latent demand for ZEVs, as well as the factors that impact this demand, to aid industry and government institutions in anticipating and planning the transition to decarbonized passenger vehicle transportation.

Vehicle consumers are an inherently complex and diverse group, with a spectrum of preferences and motivations for using ZEVs (Rezvani, Jansson, & Bodin, 2015). Previous efforts to describe and characterize consumer ZEV preferences have found that some consumers patently reject ZEVs, whereas others embrace ZEVs wholeheartedly (Axsen, Bailey, & Castro, 2015; Dimitropoulos, 2014). Consumer motives for ZEV interest are also diverse, and may be driven by a combination of functional, symbolic, societal, and/or environmental considerations (Axsen, Orlebar, & Skippon, 2013; Noppers et al., 2014). Identifying the range of consumer ZEV preferences (i.e., which ZEVs they want) and motivations (i.e., why they want them) is important for understanding future ZEV demand, which in turn is imperative to government and industry planning efforts.

In this study, I focus on "Mainstream" new vehicle buyers who have not purchased a ZEV, and are likely to be the segment of consumers who can appreciably increase Canadian ZEV market share (i.e., the proportion of new vehicle sales). Studying consumer preferences and motives for ZEV use is challenging, however, because consumers may not be sufficiently familiar with ZEVs to have existing and stable preferences. For example, research consistently finds that Mainstream consumers have low awareness of ZEVs (Yetano Roche et al., 2010), are confused about how they operate (Axsen, Langman, & Goldberg, 2017; Caperello & Kurani, 2012), and do not know how they are refueled (Axsen, Goldberg, et al., 2015; Kurani, Caperello, & TyreeHageman, 2016).

To attend to the challenge of ZEV consumer research, I employed the "reflexive participant" approach (Axsen, Goldberg, et al., 2015; Turrentine & Kurani, 1998) in a multi-part, web-based survey to help respondents learn about and construct preferences for ZEVs and their unique attributes. The reflexive participant approach views the respondent as an active part of the research method, and the survey format is designed to help respondents form and express their preferences (Axsen et al., working paper). In addition, the reflexive participant approach prompts respondents to reflect on their current vehicle usage and how ZEVs may be compatible with their lives. To facilitate respondents' preference construction and reflection, I collected data on respondents' awareness of and interest in ZEVs, as well as their values, lifestyle practices, and personal contexts.

Central to this approach was the application of two stated response[1] techniques to elicit ZEV preferences. Broadly, stated response methods refer to a variety of techniques applied to evaluate consumer preferences for alternatives (e.g., vehicle types) by observing how participants respond to hypothetical choice and decision contexts (Lee-Gosselin, 1996). Specifically, I employed a stated choice experiment and design exercises. When used in concert, the stated choice experiment and design exercises can yield complementary insights into consumer preferences and possible motivations for ZEV use (Axsen, Bailey, et al., 2015). Stated choice experiment data provide a quantified, aggregate perspective on preferences, and can associate respondent characteristics with overall patterns of preferences. Design exercise results show a disaggregate distribution of preferences and can relate respondent characteristics to specific drivetrain interests. Utilizing the strengths of both methods (described below) can enrich the understanding of Canadian Mainstream consumers' preferences and potential motivations for using ZEVs.

I used the two stated response methods in a survey of Canadian new vehicle buying households to explore the following research questions:

1. Which ZEVs (including PHEVs, BEVs, and HFCVs) do Mainstream Canadian consumers want?
2. Who are these consumers, and which motivations underlie their vehicle preferences?
3. What implications do these findings have for ZEV policy in Canada?

In the remainder of this chapter, I explain both stated response methods used in this study, summarize related literature, and describe how both methods complement one another. I then describe past research investigating consumer motivations for

[1]Researchers often use the term "stated preference" to refer to techniques which survey respondents to understand their preferences, in contrast to "revealed preference" surveys of actual behaviour. However, following Lee-Gosselin (1996), I use the term "stated response" to better encapsulate the breadth of preference-eliciting techniques.

vehicle preferences. Next, I briefly summarize the current policy climate for ZEVs in Canada, and then state the overall research objectives of this study.

1.1. Insights from stated choice experiments

Researchers who seek to *quantitatively* evaluate consumer preferences for ZEVs frequently employ stated choice experiments in surveys. Stated choice experiments are a type of a stated response method called “stated preference,” an approach which involves asking survey respondents to choose between predefined options, trading off attributes specified in each presented option (Lee-Gosselin, 1996). Typically, stated choice experiments present respondents with a series of “choice sets” containing at least two hypothetical alternatives (e.g., vehicle types), where each alternative is characterized by a set of attributes (e.g., vehicle price, driving range), with systematically varying levels (e.g., $20,000 vs. $40,000, 100 km vs. 400 km) set by the researcher (Louviere, Hensher, & Swait, 2000). Respondents then choose the alternative they most prefer in each choice set.

Stated choice experiments allow researchers to examine consumer preferences when actual market data (i.e., revealed preference data) is non-existent or incomplete, as is the case with alternative fuel vehicles in most markets, including ZEVs (Al-Alawi & Bradley, 2013; Bunch et al., 1993). While revealed preference analysis of ZEV consumers’ preferences is possible, ZEV availability and adoption is so limited[2] that it does not provide adequate insight into Mainstream consumers preferences. For example, those who already own ZEVs tend to be different from Mainstream consumers, in terms of their demographics, values, lifestyles and preferences for ZEVs (Axsen, Goldberg, & Bailey, 2016). Given the limits of revealed preference data, as well as researchers’ affinity for statistical methods to quantify data, stated choice experiments have gained popularity within the transportation research discipline over the last 25 years, particularly following California’s implementation of a ZEV sales mandate in the 1990s (e.g., Brownstone, Bunch, & Train, 2000; Bunch et al., 1993; Hidrue et al., 2011; Potoglou & Kanaroglou, 2007).

[2]Canadian ZEV market share (measured as the proportion of all vehicles registered in Canada) is currently 0.81% as of November, 2017 (Klippenstein, 2017).

The analysis of stated choice experiment data in discrete choice models (DCMs) can quantify respondent preferences for the hypothetical alternatives and their attributes. The theoretical pillar of DCMs (and stated choice experiments) is rational choice theory, where there are two assumptions: *(1)* in a set of alternatives, each option gives an individual a certain amount of utility (or personal benefit); and *(2)* consumers balance the costs and benefits of the attributes defined in the choice set, and select the alternative that affords them the highest utility (Train, 1986). Accordingly, DCMs quantitatively represent how individuals choose among competing alternatives in the choice set by estimating utility coefficients that represent the value consumers place on the alternatives (e.g., vehicle types) and their associated attributes (e.g., purchase price, driving range). DCMs and stated choice experiments also assume that consumer preferences are static, existing and expressible, similar among consumers and contexts, and follow identifiable patterns (Hensher, Rose, & Greene, 2005).

Many studies employing stated choice experiments and DCMs focus primarily on consumer valuation of vehicle functional characteristics, such as electric driving range, refueling/recharging time and cost, and purchase price. Researchers consistently find that consumers value financial attributes (i.e., lower purchase prices, as well as lower operating and fuel costs) (Bunch et al., 1993; Daziano & Bolduc, 2013; Ewing & Sarigöllü, 1998; Hackbarth & Madlener, 2013; Ziegler, 2012). Consumers also place substantial importance on both driving range and refueling/recharging infrastructure, as indicated by statistically significant coefficients in DCMs (Bunch et al., 1993; Daziano & Bolduc, 2013; Ewing & Sarigöllü, 1998; Hackbarth & Madlener, 2013; Hoen & Koetse, 2014; Tran et al., 2013; Ziegler, 2012). In terms of specific vehicle technologies, researchers observe that on average Mainstream consumers prefer CVs and hybrid vehicles (HEVs) to ZEVs (Daziano & Bolduc, 2013; Hackbarth & Madlener, 2013; Helveston et al., 2015; Hoen & Koetse, 2014), but PHEVs are usually preferred over BEVs (Helveston et al., 2015; Hoen & Koetse, 2014), and BEVs are preferred to HFCVs (Hackbarth & Madlener, 2013). However, given that the ZEV market is highly varied (i.e., not all consumers have the above order of preferences for vehicle technologies), it is valuable to explicitly represent preference heterogeneity in DCMs to develop a deeper understanding of the Mainstream consumer market.

To account for consumer preference heterogeneity, latent class choice modeling is increasingly applied to stated choice experiment data. This type of DCM groups consumers into distinct, relatively homogenous classes (or segments) based on similar patterns of preferences and individual characteristics, estimating separate sets of coefficients for each class to capture preference heterogeneity (e.g., Axsen, Bailey, et al., 2015; Brand et al., 2017; Dimitropoulos, 2014; Hidrue et al., 2011; Sheldon, Deshazo, & Carson, 2017). Latent class models (LCMs) can also include respondent characteristics, such as demographics and psychographic constructs (e.g., values, attitudes, beliefs), as “covariates,” which can reveal associations between consumer preferences and personal characteristics. Linking these characteristics to specific preferences for ZEVs may provide insights into underlying motivations for preferences, as well as aid in characterizing and distinguishing consumer market segments.

Only five published studies (to my knowledge) have estimated LCMs to describe preferences for different ZEV types, with all finding that distinct consumer segments (in the Netherlands, UK, US, and Canada) have differing valuations of ZEVs and their attributes. In four of these LCM studies, researchers found that about one-third of respondents fall into groups attracted to or receptive to ZEVs – particularly PHEVs and BEVs – compared to the remaining two-thirds of respondents who have a negative valuation of ZEVs (Axsen, Bailey, et al., 2015; Brand et al., 2017; Dimitropoulos, 2014; Hidrue et al., 2011). Consumers that prefer PHEVs may be distinct from other ZEV-interested consumers, as they tend to have strong valuation of PHEVs, significant valuation of vehicle functional attributes (e.g., driving range and recharging time), and sensitivity to operating and fuel costs (Axsen, Bailey, et al., 2015; Dimitropoulos, 2014; Sheldon et al., 2017). In comparison, consumers with a higher valuation for BEVs seem less impacted by vehicle functional characteristics in their preferences; for example, some LCMs indicate that these consumers do not significantly value increases in electric driving range (Axsen, Bailey, et al., 2015; Dimitropoulos, 2014) or shorter recharging time (Dimitropoulos, 2014). Consumers in classes with strong, positive valuation of ZEVs tend to have higher levels of environmental values and lifestyles, as well as interest in new technologies (Axsen, Bailey, et al., 2015; Dimitropoulos, 2014; Hidrue et al., 2011, Sheldon et al., 2017). Demographically, these consumers tend to be middle-aged or younger, and have higher income and education levels (Hidrue et al., 2011; Sheldon et al., 2017).

While most LCM studies have primarily focused on assessing preferences for PEVs, to my knowledge no LCM study has assessed preferences for HFCVs as well as

PEVs, which is a novel contribution of this study. HFCVs are a viable ZEV technology that have not yet penetrated the consumer vehicle market, but are forecasted by many researchers to be a potentially important part of a decarbonized passenger vehicle future (McCollum & Yang, 2009; National Research Council, 2013; Romejko & Nakano, 2017). Thus, it is important to understand consumer valuation for this vehicle technology and its attributes, as well as how it compares to that of PEVs, along with CVs and HEVs.

DCMs are undoubtedly useful tools for evaluating consumer ZEV preferences. However, the rational choice theory assumptions underlying stated choice experiments – namely, that consumers have static, established preferences – may not always hold for the case of ZEVs (Kurani, Turrentine, & Sperling, 1996). Given that ZEVs are new technologies, consumers may be insufficiently familiar with the technologies to have defined, expressible preferences for ZEVs and their attributes (Kurani, Turrentine, & Sperling, 1994). For instance, research continually finds that new vehicle buyers have low awareness of ZEVs (Axsen et al., 2017; Yetano Roche et al., 2010), and cannot identify the correct fuel type for several PEV models (Axsen, Langman, et al., 2017; Kurani et al., 2016). Alternatively, theories of consumer preference construction suggest that consumer preferences are more likely to be stable and clearly defined when consumers are familiar and experienced with the product in question (Bettman, Luce, & Payne, 1998). When respondents have limited familiarity with a product, their preferences can be viewed as outcomes from – rather than inputs to – novel choice decisions, and are likely to change as they learn about and experience the product (Bettman et al., 1998). Because stated choice experiment methods rely on these assumptions and may overlook underlying drivers of consumer behaviour, other stated response methods have emerged to understand consumer preferences from an alternative perspective.

1.2. Insights from the “reflexive participant approach” and design exercises

The “reflexive participant approach”, which offers an alternative framework to the rational choice approach to survey research, was developed to address some of the limitations of stated choice experiments noted above (Axsen et al., working paper; Kurani et al., 1994). In response to their dissatisfaction with conventional stated choice experiment techniques, a few researchers in the 1990s introduced more interactive survey and stated response methods into consumer transportation and ZEV research to investigate preference formation and expression for new vehicle technologies. These researchers' methods gave rise to an emergent survey methodology called the "reflexive participant approach," which involved a high degree of respondent reflection on how new vehicle technologies could (or could not) be suitable for their households. Inspired by pioneering work by Lee-Gosselin (1990), Kurani et al. (1994, 1996) developed interactive "stated adaptation" techniques to integrate into household interviews and surveys about travel behaviour, prompting households to indicate the perceived electric driving range they would require to carry out their transportation needs. Stated adaptation is a type of stated response method in which respondents indicate how they would behave in a new situation under a set of constraints set out by the researcher (Lee-Gosselin, 1996). In the last decade, advancements in web-based, electronic survey methods allowed this interactive approach to be refined and implemented on larger samples, evolving into a type of stated adaptation method called "design exercises" (e.g., Axsen & Kurani, 2013; Axsen et al., 2015; Kurani et al., 2016). Also following theories of consumer preference construction (i.e., proposed by Bettman, Luce, & Payne, 1998), design exercises involve educating participants about novel alternatives, and providing clearly defined decision contexts to facilitate the construction and expression of reliable preferences for ZEVs (Axsen et al., working paper; Turrentine & Kurani, 1998). There are two assumptions fundamental to design exercises, arising from the reflexive participant approach: *(1)* consumer preferences for a product are not necessarily formed and stable, and *(2)* consumer preferences can be specific to each individual/household's specific context (Turrentine & Kurani, 1998).

The design exercises employed in this study task respondents to design a vehicle they would like to purchase within a customized context of vehicle attributes, price conditions, and household conditions. Design exercises differ from stated choice experiments in that respondents build their own alternatives, rather than selecting from pre-defined alternatives and fixed attributes imposed by choice sets. Instead, respondents construct their most preferred alternative by selecting attributes to match their preferences and household context (e.g., access to home recharging, and commuting distance). Analysis of these design selections allows researchers to gain descriptive insights into consumer preferences for ZEVs that are complementary to quantitative stated choice experiment outcomes, which will be explained in Section 1.3.

Only eight published studies (that I know of) have included design exercises, with most focusing on consumer demand for HEVs and PEVs in North America. HEVs are often the most frequently selected vehicle type, accounting for 35%-45% of selected designs in several Canada- and US-based studies (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013; Kurani et al., 2016). Nevertheless, like the choice studies summarized above, design exercise studies have found consistent interest in electrified vehicles: approximately one-third of new vehicle buyers consistently selected some type of PEV design (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013; Kurani et al., 2016). PHEVs are typically selected more frequently than BEVs, being designed about two to four times as often as BEVs (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013; Kurani et al., 2016). To my knowledge, only one other study includes HFCVs as a design possibility, and in this study 5-6% of respondents selected a HFCV (Kurani et al., 2016).

Design exercise research has also evaluated how functional attributes, such as vehicle price and home recharging access are linked to PEV preferences. These studies find that PEV selections in general occur more frequently when price attributes are lower (e.g., approximating conditions with a purchase subsidy, or future purchasing conditions where economies of scale and technological innovation drive down the price of PEVs) (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013; Kurani et al., 2016). Respondents with home recharge access tend to select PEVs more frequently than respondents lacking access, with one study observing three times the PHEV selections among respondents with home Level 2 charging compared to those with no home recharge access (Axsen & Kurani, 2013).

In addition to home recharging access and price, vehicle supply (i.e., availability of ZEVs in a range of body sizes) is also associated with consumer preferences for ZEVs (Wolinetz & Axsen, 2017), and lack of ZEV supply is cited as a barrier to widespread ZEV adoption (Browne, O'Mahony, & Caulfield, 2012; Greene & Ji, 2016). Only one other study employing design exercises has examined how constraining vehicle supply impacted respondent design selections, finding that limiting ZEV availability to certain body sizes had a negligible impact on designs (Kurani et al., 2016) – though this results was described as potentially being more an indication of a methodological limitation than an actual finding. Examining the role of limited vehicle supply (i.e., in terms of the current availability of ZEVs in limited body sizes) in shaping consumer ZEV preferences thus remains a challenging and understudied area that this study will contribute to.

1.3. Complementarity of stated response methods

Arguably, both stated response methods are valuable for evaluating consumer preferences for ZEVs, and offer complimentary insights. Table 1 broadly compares stated choice experiments and design exercises, and summarizes their respective key strengths and weaknesses.

Stated choice experiments and DCMs offer an analytical framework for quantitatively estimating consumer preferences in aggregate. Model outputs are useful in describing consumer preferences for ZEVs, forecasting ZEV market shares under technological and policy scenarios, and estimating willingness-to-pay (WTP) for ZEV attributes (e.g., electric driving range, recharging time), infrastructure (e.g., destination recharging/refueling facilities), and policy incentives (e.g., purchase rebates). The ability of DCMs to quantify consumer valuation of vehicles and their attributes, as well as the trade-offs respondents make when choosing between alternatives are key strengths of the stated choice experiment approach. Furthermore, stated choice experiments typically include more attributes than design exercises, which allows for a broader assessment of ZEV attribute valuation. Stated choice experiments are also “price neutral,” in that price attributes are systematically varied (to higher and lower levels) and the effect of price changes can be easily simulated. Conversely, design exercises require the researcher to set specific vehicle price scenarios (explained in Section 2.2.1), which are speculative by nature. When used in concert with design exercises (and more broadly, with the reflexive participant approach), stated choice experiments can also contribute to the process of preference formation, and elicit more stable preferences. Additionally, LCMs can account for heterogeneity in consumer preferences by identifying homogenous segments of consumers.

Design exercises provide an alternative approach for exploring consumer interest in ZEVs, examining how consumers’ preferences are associated with their individual contexts and characteristics. Results from design exercises show the distribution of interests in ZEVs (e.g., drivetrains and attributes), allow for a comparison of respondent contexts (e.g., frequency of respondents with home recharge access who select a ZEV vs. CV or HEV), and can describe respondents (e.g., in their demographics and values) in relation to design interests. Another key strength of design exercises is that the results allow for a direct comparison between respondents who select each drivetrain, thus permitting a nuanced comparison of respondents with differing preferences (e.g., in their demographic and social characteristics). For instance, consumers who are interested in one of the three ZEV types can be compared to one another, as well as to those who are interested in CVs and HEVs, which is done in this study. DCM results do not permit this type of comparison because of the aggregated nature of choices (e.g., respondents interested in PHEVs may be grouped with those interested in BEVs). Lastly, the role of vehicle supply in shaping consumer preferences is difficult to represent and is rarely included in stated response methods (Al-Alawi & Bradley, 2013; Wolinetz & Axsen, 2017). Although still difficult to execute well, supply effects may be easier to incorporate into design exercises because of the emphasis on explaining the context to respondents.

I applied both stated response methods in this study of Canadian Mainstream vehicle consumers, using the strengths of both methods to better understand the varied preferences and potential motivations for using ZEVs among respondents. An advantage of using both methods is that obtaining results that approximately agree with each other can provide a "validation" of sorts. For example, observing a similar order of preferences for each drivetrain, or finding similar characteristics associated with ZEV preferences, can increase confidence in the results. In addition, both methods are useful for indicating the latent demand for ZEVs, that is, the level of sales of ZEVs that could be realized with the removal of real world constraints (e.g., lack of vehicle supply, or lack of awareness). DCM results can estimate latent demand using aggregated results, where simulations using this data often use probabilities and significant coefficients to estimate latent demand under various technology and policy conditions (e.g., Wolinetz & Axsen, 2017). Design exercises estimate latent demand by observing the disaggregated distribution of design selections subject to certain conditions, such as vehicle prices and supply.

Table 1. Comparison of the two stated response methods applied in this study (adapted from Axsen, 2013).

	Stated choice experiment/discrete choice model	Design exercise
Underlying framework	Rational choice theory	Reflexive participant approach
Consumer preferences are considered…	Static Pre-existing Known by consumer Same across contexts Follow aggregated pattern	Formed/change over time Constructed May be unknown Can change across contexts Can be specific to individuals/households
Assumptions	Perfect information Utility maximization Preferences are static and uniform	Consumers construct preferences as they learn about new technology Design reflects interest Context-specific
Method	1. Establish attributes, levels and choice set 2. Show respondent series of choice sets 3. Respondent chooses alternative 4. Estimate aggregated model	1. Establish detailed design context 2. Carefully communicate context to respondent 3. Respondent chooses alternative and attributes 4. Observe distribution of disaggregated results
Researcher specifies…	Alternatives Systematically varying attribute levels	Alternatives Attributes available Design context
Respondent selects…	One alternative	One alternative Attribute levels
Respondent is considered…	An actor that enacts their preferences	A participant in the research process
Respondent interest is…	Aggregated	Disaggregated
Results	Valuation of attributes (WTP) Estimate/simulate market share under policy/technology scenarios	Frequency distribution Compare consumer segments Compare contexts
Best for…	Established technology/behaviour	Emerging technology/behaviour
Key strengths	Quantified estimation of preferences Can be used in quantitative models to forecast latent demand under policy and technology scenarios Can account for consumer heterogeneity Typically includes more attributes Price neutral	Directly helps consumers form and express reliable preferences Proxy for latent demand Can account for consumer heterogeneity Allows for comparison between potential buyers of each drivetrain Can examine how vehicle supply is related to preferences
Key weaknesses	External validity cannot be confirmed Preferences may not be formed and expressible	External validity cannot be confirmed Research design must be carefully constructed Results more difficult to analyze statistically Need to assume battery/fuel cell costs

1.4. Consumer research on motivations for vehicle use

Understanding consumer motivations for ZEV use are important because they can help explain ZEV interest. Consumers have a variety of functional (e.g., Axsen et al., 2013), symbolic (e.g., Heffner et al., 2007; Steg, 2005), private (e.g., Hafner, Walker, & Verplanken, 2017), and societal motivations (e.g., Axsen, Cairns, Dusyk, &, Goldberg under review) for their vehicle preferences. Functional motivations for vehicle preferences, such as saving money and vehicle reliability, are emphasized in the literature; however, observing automaker advertisements' appeal to consumers' social status, lifestyle, and emotions illustrates that vehicle adoption has deeper motives (Steg, 2005). Furthermore, certain functional aspects of ZEVs, such as limited driving range and high purchase price, are cited as deterrents for consumer adoption (e.g., Browne, O'Mahony, & Caulfield, 2012; Graham-Rowe et al., 2012; Greene & Ji, 2016; Krause et al., 2013; Kurani, Caperello, & TyreeHageman, 2016; Sovacool & Hirsh, 2009), yet empirical research suggests that symbolic and environmental attributes are linked to BEV use, indicating that there are other reasons consumers adopt ZEVs aside from functional motives (Axsen, Cairns, Dusyk, & Goldberg, under review; Noppers et al., 2014). It is therefore valuable to explore the range of underlying motives for ZEV adoption and interest because policies aiming to change consumer behaviour (i.e., to encourage ZEV purchases) will be most effective when reasons behind the behaviour are understood (Steg, 2005). To develop insights into consumers' possible underlying motivations for using ZEVs, this study explores associations between respondents' preferences for ZEVs and their lifestyles, values, environmental concern, and demographics, which I address here in turn.

First, consumer lifestyles are related to ZEV adoption and interest. Following lifestyle theory, "lifestyle" can be defined as sets of related practices and activities that connect to an individual's identity or self-concept (Axsen, TyreeHageman, & Lentz, 2012; Giddens, 1991). Engagement in both technology- and environment-oriented lifestyles have been associated with interest in pro-environmental technology (Axsen et al., 2012). North American BEV-owners state that attraction to new technology contributed to their purchase decision (Hardman, Shiu, & Steinberger-Wilckens, 2016), and PEV-owners (Axsen et al., 2016) as well as "green vehicle" owners (Jansson, 2011) exhibit higher levels of innovation seeking, technology-orientation, and pro-environmental activity engagement than non-owners. Interest in PEVs (Axsen, Bailey, et al., 2015; Axsen et al., 2012), and ZEVs in general (Kurani et al., 2016), is also associated with greater technology and environmental lifestyle orientation. Some researchers theorize that HFCVs may also appeal to consumers with technology- and environmentally-oriented lifestyles because of the observed association between PEV interest/adoption and lifestyle, but empirical research has not yet tested this theory (Hardman, Shiu, et al., 2017).

Second, research has also linked ZEV adoption and interest with values, defined as trans-situational principles that guide an individual's behaviour (Schwartz, 1992). Adopters of "green vehicles" in Sweden display higher levels of "novelty seeking" values (Jansson, 2011), and Canadian PEV owners have significantly higher biospheric values, and lower traditional and egoist values than non-owners (Axsen et al., 2016). Consumers who are interested in PEVs also have higher openness to change (Axsen, Bailey, et al., 2015) and biospheric values than disinterested consumers (Axsen, Bailey, et al., 2015; Ziegler, 2012). Additionally, greater levels of altruistic values are associated with support for ZEV-related policies (Coad, de Haan, & Woersdorfer, 2009), and intention to adopt a PEV (White & Sintov, 2017). To my knowledge, associations between consumer values and HFCV interest have yet to be reported in the literature, however some researchers speculate that pro-social values may also drive HFCV interest (Hardman, Shiu, et al., 2017; Yetano Roche et al., 2010).

Third, environmental concern is also linked to ZEV adoption and interest. North American BEV-owners cite helping the environment as a motive for their vehicle purchase (Axsen, Goldberg, et al., 2015; Hardman et al., 2016). Furthermore, greater concern about climate change and other environmental problems is associated with positive attitudes towards ZEVs (Petschnig, Heidenreich, & Spieth, 2014), stronger willingness to consider a PHEV purchase (Krupa et al., 2014), greater interest in PEVs (Axsen, Bailey, et al., 2015; Jensen, Cherchi, & Mabit, 2013; Krause et al., 2013; Kurani et al., 2016; Noppers et al., 2014), and stronger PEV adoption intentions (Daziano & Bolduc, 2013; Egbue & Long, 2012; White & Sintov, 2017). Associations between pro-environmental attitudes and positive support for fuel cell buses, hydrogen fuel in general, and hydrogen refueling stations have also been observed (Ricci, Bellaby, & Flynn, 2008; Tarigan et al., 2012; Yetano Roche et al., 2010). Researchers hypothesize that environmental concern could also spur HFCV preferences because it appears to be a factor in PEV adoption and interest (Hardman, Shiu, et al., 2017; Yetano Roche et al., 2010).

Finally, demographic characteristics are also related to ZEV preferences, with researchers finding links between ZEV interest and age, education, income. Understanding how demographics are linked to ZEV preferences is useful in describing and characterizing consumers attracted to ZEVs. Specifically, studies have associated greater interest in ZEVs with younger ages (Egbue & Long, 2012; Hidrue et al., 2011; Higgins, Paevere, Gardner, & Quezada, 2012; Peters & Dütschke, 2014; Sheldon et al., 2017), highly educated (Carley et al., 2013; Coad et al., 2009; Egbue & Long, 2012; Hidrue et al., 2011), and higher income-earning consumers (Higgins et al., 2012; Sheldon et al., 2017).

Most studies examining motivations for ZEV use have mainly focused on PEVs in general, and I am not aware of any other studies that have empirically explored motivations for HFCV interest. A novelty of this study is that I assess motivations for interest in each individual drivetrain (i.e., CV, HEV, PHEV, BEV and HFCV) and compare motivations among respondents interested in each drivetrain type. To my knowledge no other studies have examined possible motivations associated with specific ZEV drivetrain preferences (i.e., PHEV vs. BEV vs. HFCV). Given observations from the literature, I expect to observe a positive association between preferences for ZEVs and engagement in technology- and environmentally-oriented lifestyles, biospheric, altruistic, and openness to change values, and environmental concern. Conversely, I anticipate finding that traditional and egoist values are negatively associated with ZEV preferences. In terms of demographic characteristics, I expect to find preferences for ZEVs to be positively associated with income and education, as well as an association between ZEV preferences and consumers of middle age.

1.5. Canadian ZEV policy context

As mentioned, transportation is a key sector for decarbonization, where Canadian research suggests that by 2050, 80-90% of new passenger vehicle sales must be ZEVs to accomplish GHG reduction goals (Bahn et al., 2013; Sykes & Axsen, 2017), such as the federal government’s commitment to reducing Canada’s GHG emissions by 30% below 2005 levels by 2030 described in the 2016 *Pan-Canadian Framework on*

Clean Growth and Climate Change. However, effective policy is required to facilitate mass-market uptake of ZEVs (Brand et al., 2017; Tran et al., 2013; Wolinetz & Axsen, 2017). As explained above, research suggests that consumers' preferences, values, and lifestyles, are key factors influencing ZEV adoption. Contextual characteristics, such as access to refueling/recharging infrastructure, vehicle supply, and price, are also linked to consumer adoption of ZEVs (Brand et al., 2017; Hidrue et al., 2011; Wolinetz & Axsen, 2017). Thus, understanding these consumer and contextual characteristics that impact ZEV adoption is critical to informing effective policy.

ZEVs are unlikely to secure a foothold in the passenger vehicle market without effective policy (Browne et al., 2012; Greene et al., 2014; Tran et al., 2013). Policy initiatives can help remove substantial barriers to widespread ZEV uptake, such as high upfront costs, driving range limitations, limited recharging and refueling infrastructure, lack of vehicle availability, and lack of consumer awareness of ZEV technologies (Browne et al., 2012; Graham-Rowe et al., 2012; Greene & Ji, 2016; Krause et al., 2013; Kurani et al., 2016; Sovacool & Hirsh, 2009). Policies that support ZEV uptake among consumers can be broadly categorized as 'demand-focused' and 'supply-focused' based on their target of either consumers or suppliers (Melton, Axsen, & Goldberg, 2017). Demand-focused policies aim to directly increase consumer demand for ZEVs and include financial and non-financial incentives, refueling and recharging infrastructure deployment and information campaigns. Supply-focused policies are intended to increase ZEV availability by encouraging (or requiring) producers to increase ZEV production and innovation. Examples of supply-focused policies include research and development funding, fuel efficiency standards, and sales mandates.

In Canada, ZEV policy is dominated by demand-focused policies (particularly subsidies) and is fragmented among provinces (Melton et al., 2017), though Canadian ZEV market share remains under 1% (Klippenstein, 2017). One notable exception is Quebec's soon-to-be implemented ZEV sales mandate, which requires automakers to sell a specified and growing proportion of ZEVs as part of total sales. Some researchers suggest that this supply-focused policy, first introduced by California beginning in the 1990s, could be the most effective policy to support ZEV uptake in Canada (Wolinetz & Axsen, 2017). With the policies that are planned and currently in place, Canadian ZEV market share may only reach 10% by 2040, which falls short of the expected 80-90% new market share by 2050 required to meet climate mitigation targets (Melton et al., 2017). Therefore, Canada must implement more ZEV-related policy to reach the level of ZEV sales needed to reach GHG reduction targets. Under the *Pan-Canadian Framework on Clean Growth and Climate Change*, the federal government is working with provincial and territorial governments to create a national ZEV strategy by 2018 to support the deployment of ZEVs and their infrastructure.

I use the findings related to consumer preferences and possible motivations for ZEV interest to develop insights for ZEV policy direction in Canada. Given that my methods are useful in estimating latent demand (i.e., under conditions specified in the stated choice experiment and design exercises, explained below) and only crudely examine vehicle supply effects, findings will be relevant primarily to demand-focused policy.

1.6. Research objectives

As mentioned, I employed design exercises and a stated choice experiment in a survey of Canadian new vehicle buying households to explore the following three research questions:

1. Which ZEVs do Mainstream Canadian consumers want?
2. Who are these consumers, and which motivations underlie their vehicle preferences?
3. What implications do these findings have for ZEV policy in Canada?

Arising from these three key questions, the objectives of this study are to:

- describe the distribution of vehicle design selections under different purchasing conditions, with regards to price and vehicle supply availability (using data from the design exercises);
- describe varied consumer preferences and valuations of ZEVs and their attributes (using data from the stated choice experiment);
- identify associations between vehicle preferences and respondent values, lifestyles, environmental beliefs and demographics (using data from the design exercises and stated choice experiment);
- and (cautiously) suggest directions for Canadian ZEV policy based on the findings.

The remainder of this paper will be structured as follows. In Chapter 2, I describe the survey instrument employed in this study, including the mechanics of the design exercises and stated choice experiment. In Chapter 3, I present results from the survey, as well as specific findings from the design exercises and stated choice experiment. In Chapter 4, I discuss my findings in the context of the three research questions (above) and in comparison to the literature, discuss the limitations of this study, offer recommendations for future research directions, and provide some concluding remarks.

Chapter 2. Method

In this chapter, I describe the survey and data analysis methodology employed in this study. First, I summarize the survey instrument, including survey design, implementation, and data cleaning procedures. Second, I detail how the design exercises were planned and applied in the survey, as well as how I analyzed the data from the design exercises. Third, I describe how the stated choice experiment was designed and implemented in the survey, and explain the latent class choice model specification.

2.1. Canadian Zero-Emissions Vehicle Survey (CZEVS) instrument overview

The Sustainable Transportation Action Research Team (START) designed a two-part, web-based survey examining specific factors shaping consumers' preferences for, perceptions of, and willingness to adopt ZEVs. We call our survey the Canadian Zero-Emissions Vehicle Survey (CZEVS), which built on START's 2013 consumer survey of the Canadian electric vehicle market (see Axsen, Goldberg, et al., 2015). Figure 1 depicts the overall flow of CZEVS and chronological order of its various parts, including Part 1, the Buyers' Guide and Part 2, all explained next.

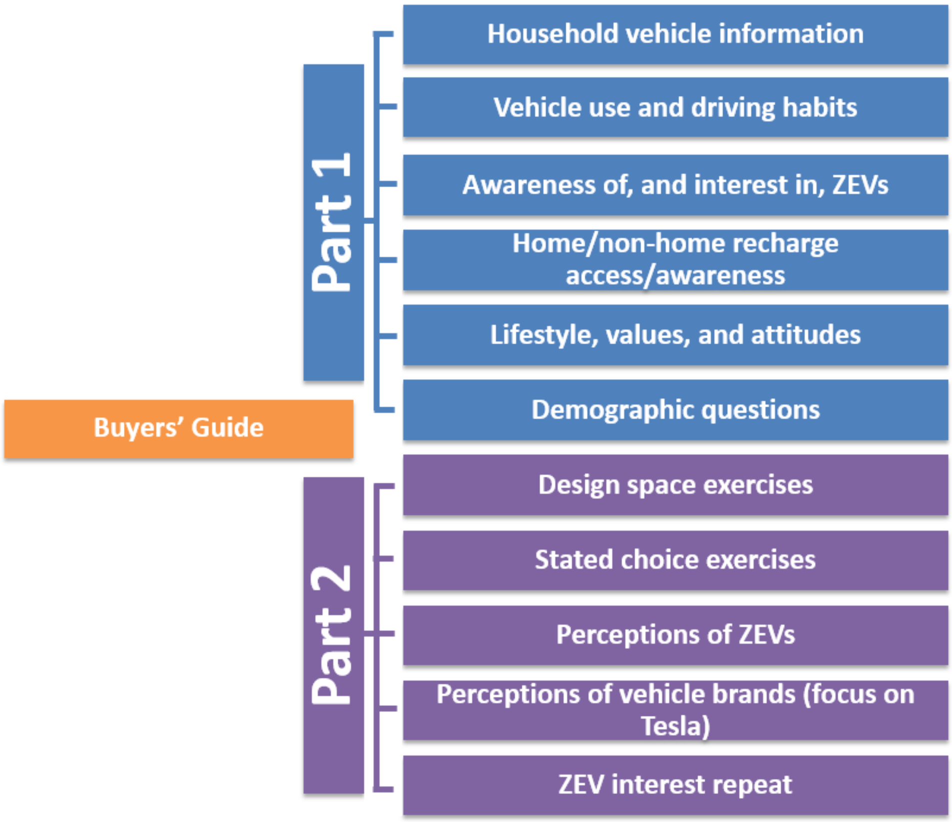


Figure 1. Overview and chronological flow of CZEVS.

Following the reflexive participant approach, CZEVS was deliberately designed to help respondents learn about ZEVs, as research shows that consumers mostly do not understand the differences between PHEVs, BEVs, and HFCVs, or how they are refueled (Axsen, Langman, & Goldberg, 2017; Kurani et al., 2016). Through specific questions and prompts, the survey also encouraged respondents to reflect on their travel behaviour, recharging access (e.g., at home and at places they commonly park), and lifestyle practices, to induce respondents to consider how their lives are compatible (or not) with ZEVs. This approach allowed for learning and consideration to occur over time, as respondents completed the multi-part survey over a minimum of twenty-four hours.

CZEVS consisted of two separate parts, each gathering different types of data. Part 1 of CZEVs was a 25- to 30-minute questionnaire that collected background information on respondents' household vehicle information (e.g., makes, models, and odometer readings of currently owned/leased vehicles), vehicle use and driving habits (e.g., frequency and distance of trips), awareness of and familiarity with ZEVs, home and work recharging access, as well as demographics. Part 1 also included several scales related to respondent lifestyles, values, and environmental concern (i.e., through the lenses of lifestyle theory, value theory, and the New Environmental Paradigm), which I used in my analysis of respondents' possible motivations for ZEV interest:

- Technology and environmental lifestyle engagement: measured through questions about how often respondents engage in ten activities (five for each lifestyle) on a five-point scale ranging from "*never*" to "*very frequently*". The five technology-orientation measures included activities such as "researching new technology", and "working on or tinkering with technology", and the five environmental-orientation measures included activities such as "promoting environmental conservation", and "attending environmental meetings". These scales were adapted from Axsen et al. (2012). I summed responses to the scales to assign each respondent two composite scores, one for their engagement in a technology-oriented lifestyle, and one for their engagement in an environmental-oriented lifestyle.

- Environmental concern: measured via a 15-item version of the New Environmental Paradigm (NEP) scale (Cordano, Welcomer, & Scherer, 2003), where response options ranged from 1 ("*strongly disagree*") to 5 ("*strongly agree*"). Examples of items from the scale include "the balance of nature is very delicate and easily upset", "humans were meant to rule over the rest of nature" (reverse coded), and "humans are severely abusing the environment". I summed responses to this scale (after accounting for reverse coding negatively phrased questions) and assigned each respondent a score for their environmental concern.

- Values: biospheric (i.e., eco-centric), altruistic (i.e., self-transcendent or pro-social), egoist (i.e., self-enhancement or pro-self), traditional (i.e., familial, cultural or religious), and openness to change values were assessed based on a 15-item value scale developed by Stern, Dietz, & Guagnano (1998). Respondents indicated how important items are as a guiding principle in their lives from 1 ("*not at all important*") to 4 ("*extremely important*"). Examples of items included: "respecting the earth, harmony with other species" (relating to biospheric values); "equality, equal opportunity for all" (relating to altruistic values); "wealth, material possessions, money" (relating to egoist values);

“family, security, safety for loved ones” (relating to traditional values); and “curious, interested in everything, exploring” (relating to openness to change values). I summed responses to the respective values scales, assigning each respondent a score for their biospheric, altruistic, egoist, traditional and openness to change values.

After completing Part 1 of CZEVS, respondents each received a “ZEV Buyers’ Guide”, which served as a primer on the various ZEV technologies and prepared respondents for the next part of the survey. The Buyers’ Guide explained the differences between CVs, HEVs, PHEVs, BEVs, and HFCVs using visual aids (Figure 2), provided explanations for the vehicles’ various features (e.g., approximate driving range, recharging/refueling time[3], and home and destination recharging/refueling potential), answered several “frequently asked questions”, and explained the format of the design exercises and choice sets that respondents would encounter in Part 2. Based on a similar primer developed by Axsen, Goldberg et al. (2015), the two key intentions of the Buyers’ Guide were to *1)* expose respondents to the technologies and survey activities in Part 2 using accessible, non-expert language, and *2)* prompt respondents to engage in the reflexive process by explaining the trade-offs among the technologies and their attributes.

[3] PHEVs and BEVs can be charged either “slower” or “faster”. Slower (or Level 1) charging uses a standard, 120-volt outlet, whereas faster (or Level 2) charging uses a 220-volt outlet and requires a special vehicle charger to be installed near this type of outlet. Most publicly accessible chargers are Level 2 chargers. In addition, direct current (DC) fast chargers use 480-volt, direct current outlets to charge vehicles very quickly (e.g., charging a battery to 80% of its full charge in 30 minutes), and are available at some public destinations.

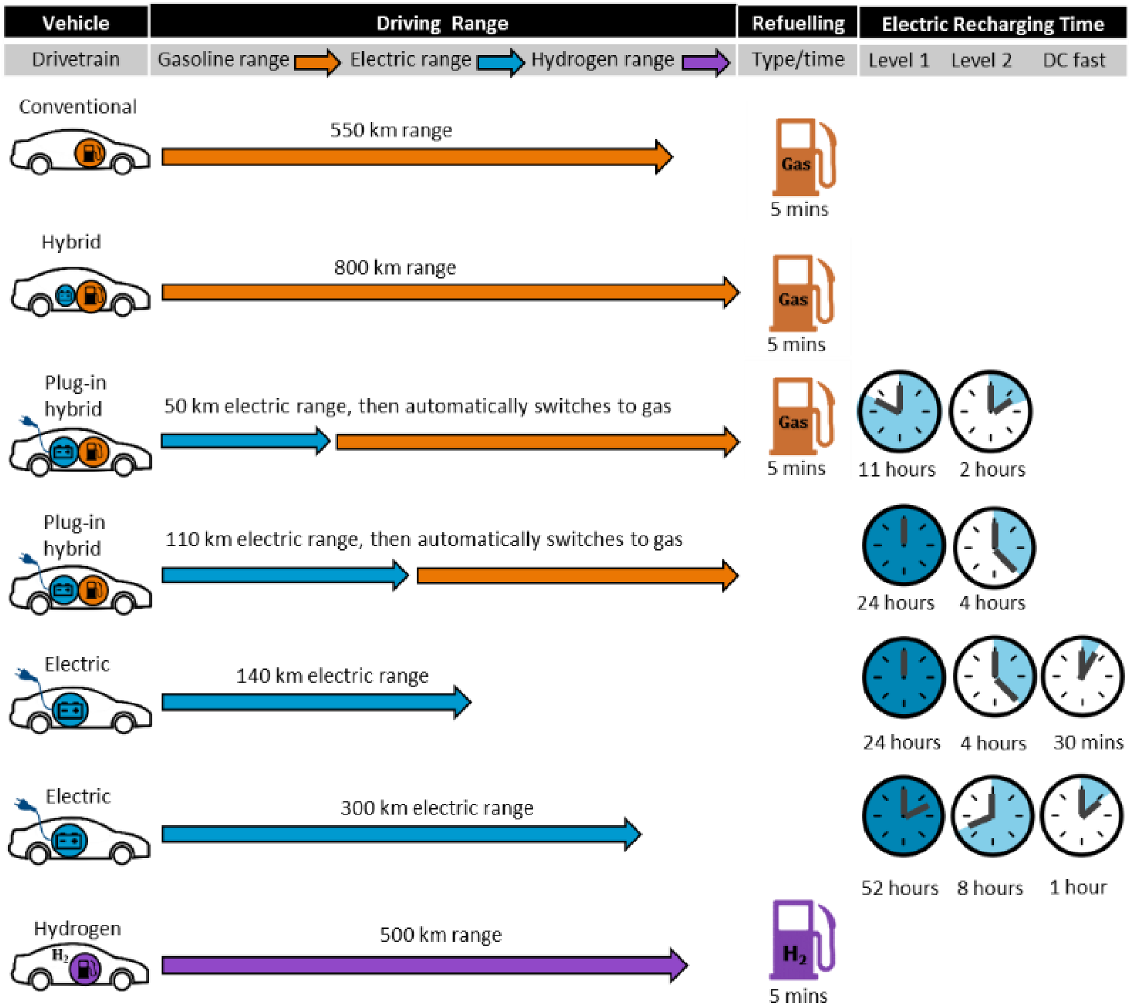


Figure 2. Example of a visual aid used in the ZEV Buyers' Guide.

Respondents could complete Part 2 at least twenty-four hours after completing Part 1 and reviewing the Buyers' Guide. Part 2, which also took 25-30 minutes to complete, included the design exercises and stated choice experiment (explained in further detail below), as well as questions about respondents' perceptions of ZEVs (e.g., images associated with each ZEV technology), and of specific vehicle brands (e.g., beliefs about which brands represent the future of electric mobility).

2.1.1. Screening for quality of response

Members of the survey design team and I removed some respondents from the data set to assure only high-quality responses were included in subsequent analyses.

We applied several criteria to decide which respondents should be removed from each part of the survey, assigning respondents a “point” for each of the following measures:

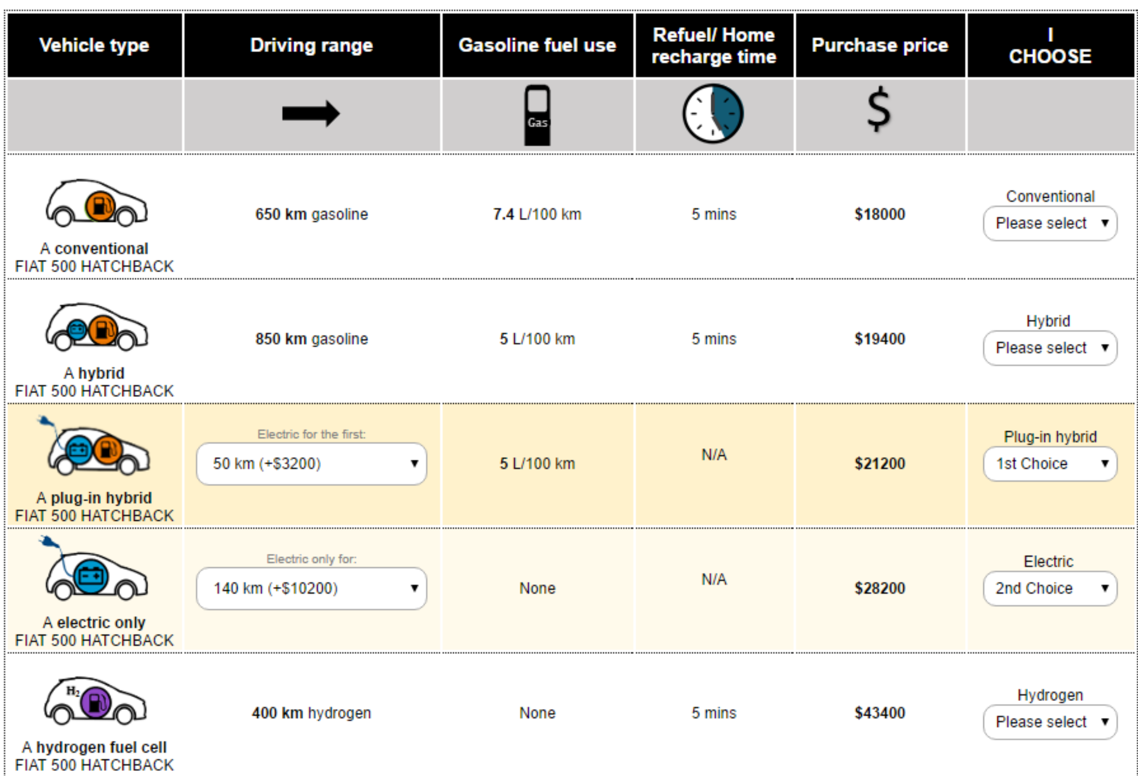
- The respondent completed the survey in under ten minutes;
- The respondent failed the “quality control” question included in the survey;
- The respondent answered, “I don’t know” to more than 20 questions;
- The respondent indicated that they did not understand the design exercises;
- The respondent indicated that they did not understand the stated choice experiment;
- The standard deviation of their responses to question scales was zero (i.e., which indicated that the respondent provided the same response for each item in the scale).

If a respondent scored two or higher on these criteria, we considered removing the respondent, and examined their responses in detail to search for inconsistencies and nonsensical responses. If a respondent was deemed to have provided poor-quality responses according to any of these measures, they were removed from the survey sample. We also reviewed comments at the end of the survey, and removed respondents who indicated that they experienced major technical problems when they completed the survey. Only respondents who provided good quality responses to both Parts 1 and 2 of the survey were included in analyses.

2.2. Design exercises

I used the design exercises to evaluate consumers’ interest in ZEVs by setting up conditions that approximate certain aspects of an actual vehicle purchase decision. As a key part of the reflexive participant approach, the design exercises prompted respondents to select from a series of design options to create their preferred vehicle. The design exercises were tailored to each respondent’s context to ensure that the exercises were as realistic as possible. Prior to beginning the design exercises, respondents indicated the make, model, and approximate purchase price of the next vehicle they anticipate purchasing or leasing to serve as a “base” vehicle from which to build their ideal design. Respondents selected their base vehicle from a drop-down menu consisting of 2016 model year vehicles sold in Canada (Natural Resources Canada, 2017). If respondents selected an HEV or ZEV as their base vehicle, they were asked to select a CV most similar to their initial selection for the purpose of this exercise. Using this CV as a base vehicle, the design exercise presented respondents with their chosen CV, as well as HEV, PHEV, BEV, and HFCV versions of that vehicle (Figure 3).

Respondents selected their first choice ideal vehicle by choosing one of the five base vehicle versions, as well as specifying levels for particular attributes, where applicable. For instance, for the PHEV and BEV versions, respondents could alter two vehicle attributes: kilometers of electric driving range (i.e., 20 km, 50 km, 80 km, or 110 km for PHEVs; and 100 km, 140 km, 220 km, or 300 km for BEVs); and speed of home recharging time (i.e., based on respondents' self-reported access to Level 1 or Level 2 recharging, or none at all, indicated in Part 1). Each additional level of customizable attributes was assigned a price, which was added incrementally to the approximate purchase price of the base vehicle. Other than these attributes, respondents were instructed to imagine that all other vehicle features (e.g., appearance, comfort, and performance) were identical among vehicle versions. After indicating their first choice in a given iteration of the design exercise, respondents were also asked to indicate their second choice of vehicle (i.e., if that first choice vehicle drivetrain was not available).



Vehicle type	Driving range	Gasoline fuel use	Refuel/ Home recharge time	Purchase price	I CHOOSE
A conventional FIAT 500 HATCHBACK	650 km gasoline	7.4 L/100 km	5 mins	$18000	Conventional Please select
A hybrid FIAT 500 HATCHBACK	850 km gasoline	5 L/100 km	5 mins	$19400	Hybrid Please select
A plug-in hybrid FIAT 500 HATCHBACK	Electric for the first: 50 km (+$3200)	5 L/100 km	N/A	$21200	Plug-in hybrid 1st Choice
A electric only FIAT 500 HATCHBACK	Electric only for: 140 km (+$10200)	None	N/A	$28200	Electric 2nd Choice
A hydrogen fuel cell FIAT 500 HATCHBACK	400 km hydrogen	None	5 mins	$43400	Hydrogen Please select

Figure 3. Example of design exercises.

Respondents completed up to four design scenarios based on vehicle price (higher and lower) and vehicle supply (unconstrained and constrained) (Table 2). These scenarios were intended to simulate current and potential future purchasing conditions in Canada. The higher price scenarios reflected present-day (i.e., at the time of survey design in 2016) purchase prices, and the lower price scenarios represented anticipated future prices. Figure 4 depicts the vehicles available in the unconstrained and constrained scenarios. The constrained vehicle supply scenarios were intended to reflect current Canadian purchasing conditions (i.e., at the time of survey design), as listed on Natural Resource Canada's 2016 vehicle database (Natural Resources Canada, 2017), where ZEVs are only available in a limited number body sizes. In the constrained scenarios, respondents' ZEV designs were limited as follows: BEVs were restricted to compact cars and sedans; PHEVs were restricted to compact cars, sedans, and mid-size SUVs; and HFCVs were restricted to mid-size SUVs[4] (i.e., non-greyed out icons in Figure 4). Conversely, the unconstrained vehicle supply scenarios were intended to be a proxy for prospective purchase conditions under a ZEV sales mandate, where zero-emissions drivetrains could be available in a variety of body sizes.

Table 2. Summary of four design exercise scenarios.

	Higher price	Lower price
Unconstrained vehicle supply	Scenario 1: Future vehicle supply, current prices. Respondents could design their vehicle with any of the drivetrains (CV, HEV, PHEV, BEV, or HFCV).	Scenario 3: Future vehicle supply, future prices. Respondents could design their vehicle with any of the drivetrains (CV, HEV, PHEV, BEV, or HFCV).
Constrained vehicle supply	Scenario 2: Current vehicle supply, current prices. Respondents who selected a vehicle *in Scenario 1* that is currently unavailable in Canada (i.e., a "greyed out" vehicle in Figure 2) were asked to choose either to keep that vehicle body size and switch to an available drivetrain or to keep the chosen drivetrain and switch to available vehicle body size.	Scenario 4: Current vehicle supply, future prices. Respondents who selected a vehicle *in Scenario 3* that is currently unavailable in Canada (i.e., a "greyed out" vehicle in Figure 2) were asked to choose either to keep that vehicle body size and switch to an available drivetrain or keep the chosen drivetrain and switch to available vehicle body size.

[4] See appendix for a description of how vehicles are grouped into five vehicle size class categories.

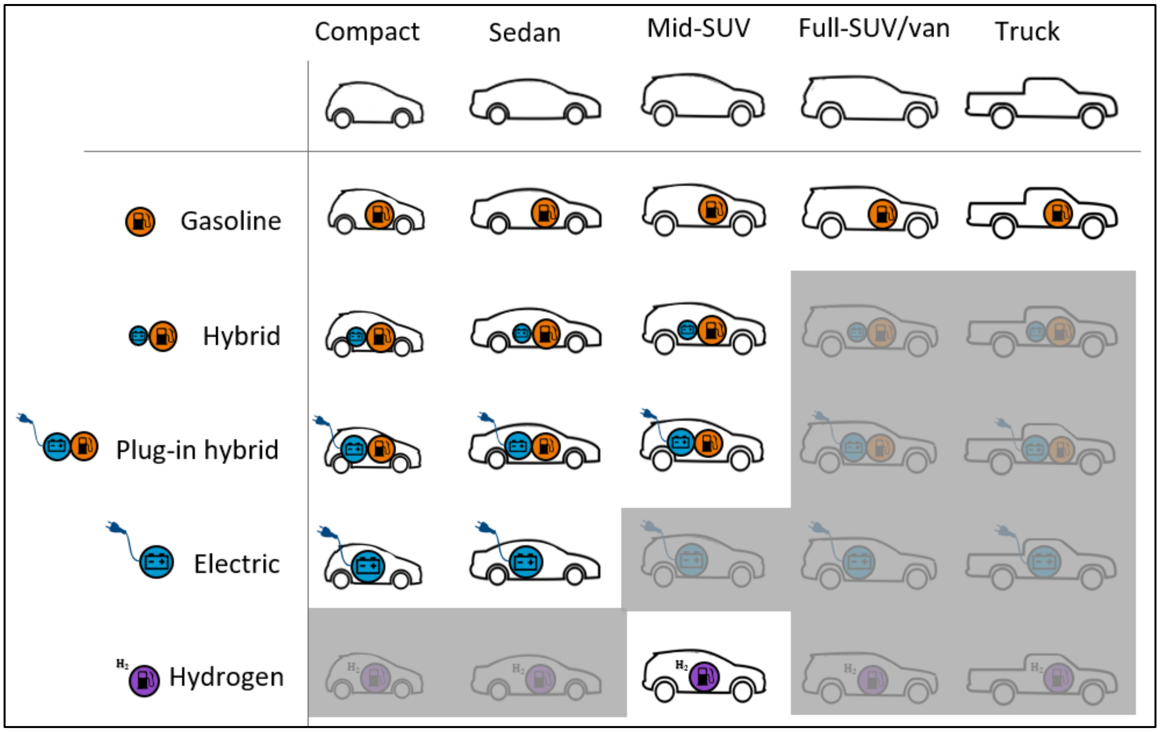


Figure 4. **Body size and drivetrain options in the design exercises. All 25 vehicle types were available for design in the "unconstrained vehicle supply" scenarios. Greyed out vehicles represent vehicle designs that were unavailable in the "constrained vehicle supply" scenarios.**

2.2.1. Incremental prices

Prices[5] incremental to the purchase price of the base vehicle were calculated for HEVs, PHEVs, BEVs, and HFCVs for each of five vehicle classes (i.e., compact, sedan, mid-size SUV, full-size SUV/minivan, and pickup truck), and for various electric driving ranges (i.e., 20-110 km for PHEVs and 100-300 km for BEVs), which are shown in Table 3. I calculated incremental prices for the higher and lower price scenarios to estimate current and future prices of ZEVs, accounting for the cost of the battery or fuel cell stack, as well as cost savings from changes to the motor, engine, exhaust, and electronics[6]. My calculations were informed in part by Wolfram & Lutsey (2016), who detailed current and projected costs of battery and fuel cell technologies.

[5]We calculate overall "prices", which include a markup on costs incurred by manufacturers. Costs refer to the raw costs of production by manufacturers and suppliers.

[6]It should be noted that battery and fuel cell stack costs contribute the most to overall ZEV prices, relative to a CV (National Research Council, 2013; Nykvist & Nilsson, 2015; US Department of Energy, 2014; Wolfram & Lutsey, 2016).

The higher price scenario values were intended to reflect Wolfram & Lutsey's (2016) "present day" (at the time of their study) ZEV cost scenario, in terms of technological and production conditions. For instance, incremental battery costs were approximately CAD $380/kWh, based on production volumes of about 50,000 vehicles per year for PHEVs and BEVs (Sakti et al., 2015; Wolfram & Lutsey, 2016), and fuel cell stack costs were approximately CAD $300/kW, based on production of about 1,000 HFCVs per year (US Department of Energy, 2014; Wolfram & Lutsey, 2016). The lower price scenario values represented Wolfram & Lutsey's (2016) 2030 ZEV cost scenario, which envisioned an optimistic future with regards to technological and production conditions. Here battery and fuel cell costs were projected to fall to approximately CAD $150/kWh and CAD $70/kW, respectively, assuming production volumes of around 500,000 PHEVs and BEVs per year, and 100,000 HFCVs per year (National Research Council, 2013; Nykvist & Nilsson, 2015; US Department of Energy, 2014; Wolfram & Lutsey, 2016). Between these two scenarios, the design exercise incremental prices represent a range of present day and more optimistic future assumptions about technology costs, technological learning, and economies of scale.

I believe that the incremental price estimates were roughly realistic in the higher price and suitably optimistic in the lower price scenarios. Previous design exercise work reveals that 60-70% of respondents did not select ZEVs priced at more than $5,000 above a CV (Axsen, Bailey, et al., 2015; Kurani et al., 2016). Thus, the challenge of setting design exercise incremental prices is in assigning price levels that are "realistic" (i.e., as per assumptions of costs and production volumes found in the literature), but also low enough to assure a sufficient proportion of respondents select some type of ZEV. Any estimates of future battery and fuel cell costs are speculative and uncertain. However, given the exploratory nature of the design exercises, my analysis does not depend on using "correct" incremental prices but rather that the prices are an accurate estimation of the premiums consumers may face now and in the future.

Table 3. Prices incremental to CV base vehicles used in the design exercises.

Vehicle type and battery range (km)	Higher price scenario Compact	Sedan	Mid-SUV	Full-SUV	Truck	Lower price scenario Compact	Sedan	Mid-SUV	Full-SUV	Truck
Hybrid electric (HEV)										
HEV	$1,400	$1,700	$2,100	$2,500	$3,000	$900	$1,100	$1,200	$1,400	$1,600
Plug-in hybrid (PHEV)										
PHEV-20	$2,300	$2,800	$3,300	$3,900	$4,600	$1,200	$1,400	$1,700	$1,900	$2,300
PHEV-50	$3,200	$3,800	$4,600	$5,400	$6,400	$1,800	$2,200	$2,600	$3,100	$3,600
PHEV-80	$4,000	$4,800	$5,900	$6,900	$8,200	$2,500	$3,000	$3,700	$4,300	$5,100
PHEV-110	$4,800	$5,700	$7,200	$8,400	$10,100	$2,700	$3,200	$4,000	$4,700	$5,700
Battery electric (BEV)										
BEV-100	$7,700	$9,300	$12,000	$14,400	$17,100	$1,100	$1,300	$1,700	$2,000	$2,400
BEV-140	$10,200	$12,100	$15,800	$18,800	$22,400	$1,700	$2,100	$2,700	$3,200	$3,800
BEV-220	$15,000	$17,700	$23,400	$27,700	$32,900	$3,400	$4,000	$5,300	$6,300	$7,500
BEV-300	$19,900	$23,300	$30,900	$36,600	$43,400	$4,500	$5,300	$7,000	$8,300	$9,800
Hydrogen fuel cell (HFCV)										
HFCV	$25,400	$30,400	$38,300	$45,400	$53,800	$5,400	$6,400	$8,100	$9,600	$11,000

2.2.2. Data analysis

To evaluate my first research question (which ZEVs respondents want), I analyzed the design exercise results by comparing the frequencies and distribution of respondent vehicle selections in the four scenarios. Specifically, I compare design frequencies across different scenarios, namely:

- Higher and lower price scenarios, under conditions of unconstrained vehicle supply (i.e., current and future prices, given future vehicle supply);
- Unconstrained vehicle supply and lower price scenario, organized by respondents' self-reported home recharge access (i.e., none, Level 1 or Level 2 potential);
- Unconstrained and constrained vehicle supply scenarios, under the lower price condition (i.e., future and current vehicle supply, given future prices);
- When respondents' first choice vehicle designs were "unavailable" (i.e., serving as a "sensitivity analysis" of sorts to assess the robustness of the distributions of ZEV versus CV and HEV selections).

To explore my second research question (which motivations may underlie respondents' vehicle preferences), I also examined how respondent lifestyles, environmental concern, values, and demographic characteristics are associated with vehicle designs (using the designs from the unconstrained, lower price scenario). I analyzed these associations by first segmenting respondents by their drivetrain selections. I then used an analysis of variance (ANOVA) test of association to assess whether respondent segments significantly differ overall in their lifestyles, values, and environmental concern. For characteristics found to differ across respondent segments, I employed Tukey post-hoc tests to reveal which segments (if any) differ specifically from one another. I also used a chi-square test of association to assess whether significant differences in respondents' age, education, and income exist overall among drivetrain segments.

2.3. Stated choice experiment and latent class model

Complementary to the design exercises, the stated choice experiment also served to elicit consumer preferences for ZEVs. Respondents completed the stated choice experiment directly following the design exercises in Part 2 of CZEVS. As with the design exercises, the stated choice experiment was customized for each respondent based on the make, model, and expected price of their next vehicle purchase or lease. The same base vehicle (make and model) that was selected by each respondent prior to their design exercises was used in the stated choice experiment.

2.3.1. Stated choice experiment design

The stated choice experiment presented respondents with choice sets that contained CV, HEV, PHEV, BEV, and HFCV versions of their base vehicle, each with a defined set of eight attributes (Figure 5). The choice sets specified the following attributes for each vehicle: driving range (gasoline, electric or hydrogen); recharging/refueling time (both at home and at work for PHEVs and BEVs); access to Level 2 chargers at destinations; fast charging access along major highways; hydrogen refueling station abundance; weekly fuel cost; purchase price; and purchase subsidy. Table 4 details the attributes and levels in the stated choice experiment. Home and work recharging time were specified as the number of hours required to fully charge a battery, based on the electric range level of the BEV and PHEV, as well as the body size of the base vehicle, at various speeds of charging (i.e., Level 1 or 2). Access to Level 2 chargers at destinations was represented as a proportion of destinations that a respondent visits (e.g., “1 in 10”), and hydrogen refueling access was represented as availability of hydrogen fuel at a proportion of existing gasoline stations (e.g., “1 in 4”). Access to DC fast charging along major highways was specified as a binary “all” or “none” variable, where the two levels for this attribute were access to DC fast charging along all major highways (in 50 km intervals) in a region or no access to DC fast charging. All charging attributes were specified as “contextual variables”, meaning both PHEVs and BEVs received the same level in each choice set (i.e., this created a “charging context” common to all alternatives). Respondents each completed six choice sets, with the levels of the specified attributes systematically varying in each choice set according to the experimental design (explained next). Aside from the specified drivetrains and attributes, respondents were asked to assume that the vehicle alternatives were the same, in terms of appearance, comfort and performance.

Vehicle type	Range	Recharge/ refuel time	Destination recharging	Fast recharging or H_2 refueling access	Fuel cost	Purchase price & incentive	I CHOOSE
			Level 2	or	$	$	
A **conventional** RAM 1500 4X4 FFV	**750 km** gasoline	**5 min.**	-	-	**$100** / week	**$50000** **-$0** / **$50000**	Conventional
A **hybrid** RAM 1500 4X4 FFV	**750 km** gasoline	**5 min.**	-	-	**$80** / week	**$57500** **-$0** / **$57500**	Hybrid
A **plug-in hybrid** RAM 1500 4X4 FFV	First **110 km** electric/ **690 km** gasoline	Home: **48 hrs** Work **8 hrs**	**1 in 10** destinations	At rest stops (every 50 km) on all major highways	**$30** / week	**$70000** **-$0** / **$70000**	Plug-in hybrid
A **electric only** RAM 1500 4X4 FFV	**140 km** electric	Home: **46 hrs** Work: **7.5 hrs**	**1 in 10** destinations	At rest stops (every 50 km) on all major highways	**$50** / week	**$65000** **-$0** / **$65000**	Electric
A **hydrogen fuel cell** RAM 1500 4X4 FFV	**600 km** hydrogen	**5 min.**	-	**1 in 25** gas stations	**$115** / week	**$55000** **-$5000** / **$50000**	Hydrogen

Figure 5. Example of choice sets.

Table 4. Attributes and levels in stated choice experiment.

		CV (base vehicle)	HEV	PHEV	BEV	HFCV
Range		*Fixed:* Selected by respondent (based on average range of class of their next anticipated vehicle): Compact - 650 km Sedan - 650 km Mid-SUV- 650 km Full-SUV/minivan - 750 km Truck - 750 km	*Fixed:* Selected by respondent (based on average range of class of their next anticipated vehicle): Compact - 850 km Sedan - 850 km Mid-SUV - 850 km Full-SUV/minivan - 1000 km Truck - 750 km	First 20 km electric/ 780 km gasoline First 50 km electric/ 750 km gasoline First 80 km electric/ 720 km gasoline First 110 km electric/ 690 km gasoline	100 km electric 140 km electric 220 km electric 300 km electric	300 km hydrogen 400 km hydrogen 500 km hydrogen 600 km hydrogen
Recharge/ refuel time	Home recharging time	*Fixed:* 5 min.	*Fixed:* 5 min.	Not available X[a] hrs. (Level 1) X[a] hrs. (Level 2)	Same as for PHEV	*Fixed:* 5 min.
	Work recharging time	*n/a*	*n/a*	Not available X[a] hrs. (Level 1) X[a] hrs. (Level 2)	Same as for PHEV	*n/a*
Destination recharging	Level 2 access	*n/a*	*n/a*	1 in 3 destinations 1 in 10 destinations 1 in 20 destinations 1 in 50 destinations	Same as for PHEV	*n/a*
Fast recharging or H_2 refueling access	1) Highway-based fast chargers 2) Fuel station-based H_2 refueling	*n/a*	*n/a*	No access along major highways At rest stops (every 50 km) on all major highways	Same as for PHEV	1 in 2 gas stations 1 in 4 gas stations 1 in 10 gas stations 1 in 25 gas stations
Fuel cost		*Stated by respondent:* $__ / week	$[40% less] / week $[30% less] / week $[20% less] / week $[10% less] / week	$[90% less] / week $[70% less] / week $[50% less] / week $[30% less] / week	$[90% less] / week $[70% less] / week $[50% less] / week $[30% less] / week	$[30% less] / week $[15% less] / week Stated fuel cost $[15% more] / week
Purchase price		*Stated by respondent:* $__	Stated CV purchase price $[5% more] $[15% more] $[25% more]	$[10% more] $[20% more] $[30% more] $[40% more]	$[10% more] $[20% more] $[30% more] $[40% more]	$[10% more] $[20% more] $[30% more] $[40% more]
Incentive		*Fixed:* $0	*Fixed:* $0	$0 $5,000 $10,000	$0 $5,000 $10,000	$0 $5,000 $10,000

[a] Recharge time was calculated as the time required to fully recharge a depleted battery. This time is a function of the vehicle's electric driving range, the base vehicle type (where larger vehicle bodies are assumed to consume more electricity), and the speed of the home charger (i.e., Level 1 or 2).

An optimally orthogonal experimental design was generated using the SAS catalogue's choice mktEx macro function (Kuhfeld, 2005) to distribute all possible combinations of attributes and levels into choice sets. The smallest orthogonal main-effects plan design to achieve orthogonality was 144 choice sets divided into 24 blocks containing six choice sets each. Each respondent was randomly assigned to one block of six choice sets. The mktEx macro optimizes D-efficiency (an indicator of the goodness of the experimental design), and the present D-efficiency was 93%, which is higher than the guideline of 80% or greater to indicate a "good" design that is both balanced and orthogonal (Bliemer & Rose, 2011). I used an efficiency design to ensure that certain restrictions in attribute variations were met, for example that charging attributes for PHEV and BEV alternatives received the same levels in each choice set (i.e., the above mentioned "contextual variables").

2.3.2. Latent class model specification

I used respondents' choices in the stated choice experiment to estimate a type of discrete choice model called a latent class model (LCM), which I briefly introduced in Section 1.1. Discrete choice models can quantify respondent preferences for the different vehicle types and their attributes by estimating utility coefficients that represent the value respondents place on each vehicle type and their associated attributes. LCMs differ from other kinds of discrete choice models in that they segment respondents based on patterns of preferences for vehicle types and attributes, as well as other respondent characteristics (e.g., demographics, lifestyles, values, and environmental concern). LCMs quantify heterogeneity in consumer preferences by dividing respondents into a specified number of classes and then estimating separate sets of coefficients for each class (Greene & Hensher, 2003; Shen, 2009; Zito & Salvo, 2012). I interpreted statistically significant coefficients as a measure of respondent interest or disinterest in the vehicle attributes, and thus this segmentation approach allowed each class of respondents to be described by their interest in vehicles types, attributes, and other characteristics (i.e., covariates) observed to be associated with these preferences. I estimated the LCM using LatentGold version 5.0 (Vermunt & Magidson, 2013). Because the researcher must choose the number of classes to estimate, I selected a solution that:

1. Arrived at a clearly interpretable solution;
2. Avoided large classes (i.e., larger than 50% of the sample) and small classes (i.e., less than 5% of the sample);
3. Avoided solutions where two or more classes are the same; and
4. Maximized three statistical measures of quality and parsimony: the Consistent Akaike Information Criterion (CAIC), the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) (Louviere et al., 2000).

Last, I calculated WTP values, which represent the relationship between respondents' valuation of an additional unit of an attribute relative to vehicle purchase price, for coefficients found to be significant at a 90% confidence level or greater for each class.

Chapter 3. Results

3.1. Data collection

The market research company Research Now recruited a sample of new vehicle buyers between January and June 2017. The sample included individuals from every Canadian province, with oversamples in Ontario, Quebec, British Columbia, the City of Vancouver, and Metro Vancouver to allow for regional comparisons (which is not the focus of this study). As per the respondent quality screening procedure explained in Section 2.1.1, I removed 49 respondents from the sample, and the final sample consists of 2,123 respondents who completed both Parts 1 and 2. In Table 5, I compare the sample to Canadian census data, as demographic information about the target population (i.e., households who intend to purchase a vehicle in the next 12 months) is not available. I applied corrective weights to the sample to correct for any biases introduced by the regional oversamples. On average, the sample is slightly older, and has higher levels of education and income than the general population, which is typical of new vehicle buying/leasing households (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013).

Table 5. Demographic data for CZEVS respondents and Canadian Census data.

	CZEVS Sample	Canadian Census[a]
Sample size	2,123	
Population size		33,476,688
Age (of person filling out the survey)		
15-34	24%	31%
35-44	18%	16%
45-54	21%	19%
55-64	22%	16%
65+	15%	18%
Household income (pre-tax)[b]		
<$40,000	16%	25%
$40,000-$59,999	19%	19%
$60,000-$89,000	25%	24%
$90,000-$124,999	22%	17%
$125,000+	19%	15%
Highest level of education completed (of person filling out the survey)[c]		
Other	18%	60%
College, CEGEP, or other non-university diploma	34%	22%
University degree (Bachelor)	30%	14%
Graduate or professional degree	18%	5%
Residence type		
Detached House	65%	62%
Attached House (e.g. townhouse, duplex, triplex, etc.)	12%	17%
Apartment	22%	20%
Mobile Home	1%	1%
Residence ownership		
Own	77%	69%
Rent	23%	31%
Number of people per household		
1	19%	28%
2	42%	34%
3	20%	16%
4	20%	23%

[a] I use 2011 Census data here as the complete set of 2016 Census data are not available. Census data are from Statistics Canada: http://www12.statcan.gc.ca/census-recensement/2011/rt-td/index-eng.cfm.
[b] I exclude n = 216 respondents (or 10.2% of the sample) who did not report their income from these proportions.
[c] I exclude n = 20 respondents (or 0.9% of the sample) who did not report their education from these proportions.

3.2. Design exercise results

As a reminder, respondents completed up to four design exercises, with varying levels of price and vehicle supply (higher and lower for both). In this section, I describe the frequencies of vehicle design selections in the higher and lower price scenarios under conditions of unconstrained and constrained vehicle supply, distribution of selections organized by respondents' home recharge access, as well as selections when respondents’ first choices were “unavailable”. These analyses show the distribution of design selections, providing indications of which ZEVs Mainstream Canadians want. I also describe the results of the ANOVA and chi-square tests of association, which compare respondents who selected each drivetrain type in their lifestyles, values, environmental concern, and demographic characteristics. This final analysis shows associations between specific drivetrain interests and respondent characteristics, helping to reveal underlying characteristics that could be motives for ZEVs interest.

3.2.1. Frequency and distribution of vehicle designs

I first show results from the unconstrained vehicle supply scenarios. Figure 6 depicts the distribution of vehicle design selections in the higher and lower price scenarios. Respondents selected CVs most often (55% and 45% in the higher price and lower price scenarios, respectively), followed by HEVs (31% and 33%), PHEVs (11% and 12%), BEVs (2.2% and 5.4%) and HFCVs (1.5% and 3.6%). Of respondents who selected PHEV designs, about one third chose “mid” electric ranges (i.e., 50 km). “Higher” electric range PHEVs (i.e., 110 km) became more popular with lower (future) prices, increasing from one quarter to one-third of total PHEV selections. Among respondents who selected BEVs, their selection of electric driving ranges were evenly split among the range options (i.e., 100, 140, 220, and 300 km) in the higher and lower price scenarios. In total, 14% and 21% of respondents selected a ZEV in the higher and lower price scenarios. Given future purchasing conditions in terms of price and vehicle supply, 21% is a proxy for the latent demand for ZEVs in this sample of Mainstream vehicle buyers.

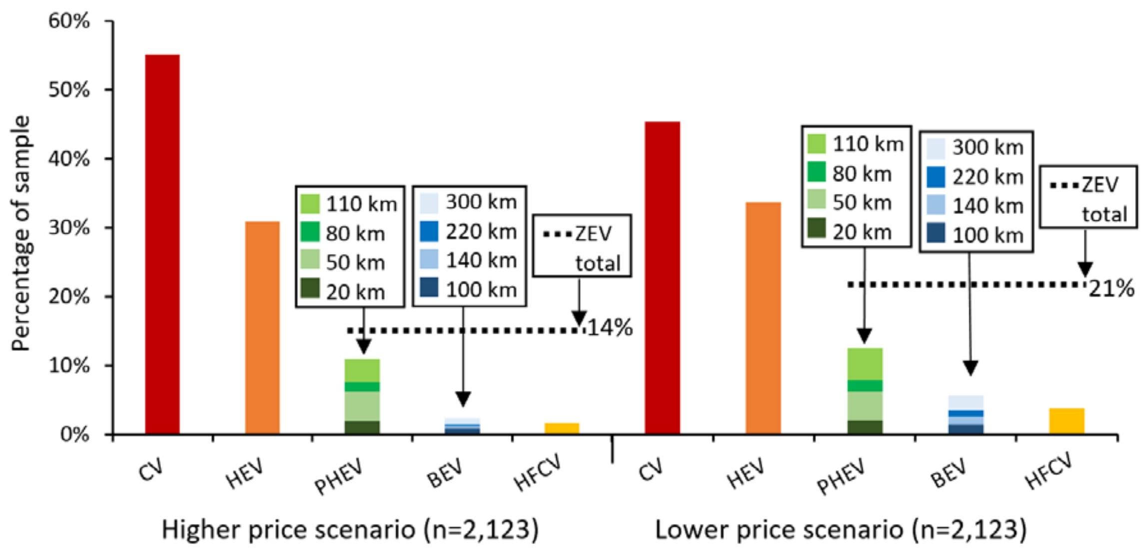


Figure 6. **Frequency of vehicle designs in the unconstrained vehicle availability, higher and lower price scenarios. ZEV total refers to the summation of PHEV, BEV and HFCV selections.**

I also examine the distribution of vehicle designs from the lower price scenario among respondents with no home recharge access, Level 1 access only, and potential Level 2 access (i.e., a respondent had an existing charger or could reasonably install one) (Figure 7)[7]. Across all respondents, ZEVs were generally selected more frequently among those with Level 2 home recharge potential (ZEVs were 25% of selections), compared to those with Level 1 access only (ZEVs were 19% of selections), and without home recharge access (ZEVs were 22% of selections). PHEVs were selected in approximately equal frequencies in each group (13% of selections among respondents with Level 2 potential, 12% among respondents with Level 1 access only, and 12% among respondents without home recharge access). However, “higher” electric range (i.e., 110 km) PHEV selections were more popular among respondents with access to either Level 1 or 2 home recharging. BEV selections were most frequent among respondents with Level 2 potential (9.2% of selections), compared to those with Level 1 access only (3.7% of selections), and those lacking home recharge access (5.6% of selections). Similar to the trend I observe in PHEV design selections, “higher” range BEVs (i.e., 220 and 300 km) were more frequent among respondents with Level 2 recharging potential. HFCVs were selected in approximately equal proportions among

[7]Note: I did not perform statistical analyses to compare the frequencies of drivetrains selected in each group due to concerns of inflating the likelihood of committing a Type I error (i.e., false positive) given the number of tests required to compare the groups.

respondents with varying levels of home recharge access (4.2% of selections among respondents with no home recharge access, 3.1% among those with Level 1 access only, and 3.4% among those with Level 2 potential), which is unsurprising because HFCVs cannot be plugged in to be recharged.

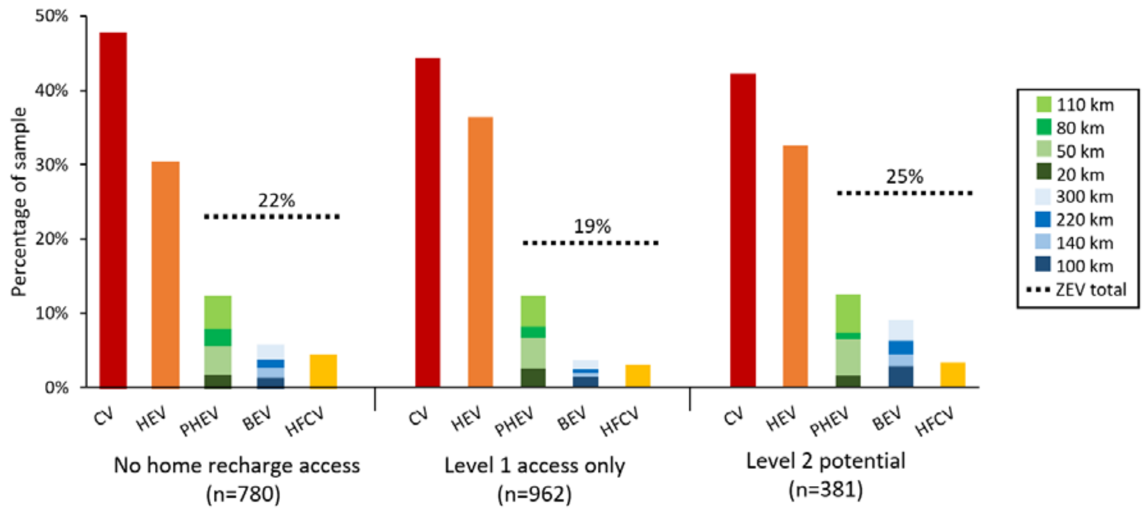


Figure 7. **Frequency of vehicle designs in the unconstrained, lower price scenario, organized by groups with no home recharge access, Level 1 access only, and Level 2 potential. ZEV total refers to the summation of PHEV, BEV and HFCV selections.**

The design exercises also elicited respondents' second choice vehicle selection in the unconstrained vehicle availability scenarios. Table 6 displays the frequencies of second choice drivetrains among respondents who selected a CV, HEV, PHEV, BEV or HFCV as their first choice. I examined the frequencies of second choices to explore the overall distribution of vehicle selections when the first choice is rendered "unavailable" (Figure 8). This exercise acts as a sensitivity analysis for first choice design results (shown in Figure 6), examining the robustness of the distributions of ZEV versus CV and HEV selections and adding additional perspective to my evaluation of which ZEVs Mainstream Canadians want under supply constraints. My intention is to assess how much the observed results were dictated by price. For example, I was particularly concerned about the role of HEV prices – where low incremental prices for HEVs might have drawn some respondents away from ZEV designs. I tested for this specific pattern in the second panel of Figure 8, which depicts the distribution of "second choice" drivetrains for respondents who selected an HEV as their first choice, displaying the selections of respondents that did not select an HEV alongside the second choices of those that did.

Respondents who selected an HEV as their first choice are more likely to select a CV as their second choice (68% of second choices) than a ZEV (32% of second choices), indicating that "low" HEV prices may have drawn away about a third of these respondents from ZEVs initially. However, I observe the highest frequency of ZEV selections (32% across the full sample, in Figure 8) when HEVs were "unavailable". As shown in the first panel of Figure 8, respondents who selected a CV as their first choice predominantly selected an HEV (86% of second choices) as their second choice. Respondents who designed a PHEV or HFCV as their first choice were more likely to select a CV or HEV (61% and 68% of second choices, respectively) as their second choice, compared to those who selected a BEV their first choice (CVs and HEVs were 30% of second choices). It appears that respondents who designed a BEV as their first choice tended to choose a different ZEV as their second choice, whereas respondents who selected a PHEV or HFCV as their first choice were less likely to select another ZEV[8].

Table 6. Distribution of second choice drivetrains among respondents.

First choice (% of total sample)	% Second choices (of respondents with a given first choice)				
	CV	HEV	PHEV	BEV	HFCV
CV (45%)	-	86%	6%	2%	6%
HEV (33%)	68%	-	21%	5%	6%
PHEV (12%)	14%	48%	-	34%	5%
BEV (5.4%)	9%	21%	63%	-	8%
HFCV (3.6%)	22%	46%	13%	18%	-

[8]Note: I did not perform statistical analyses to compare the frequencies of drivetrains selected in each group due to concerns of inflating the likelihood of committing a Type I error (i.e., false positive) given the number of tests required to compare the groups.

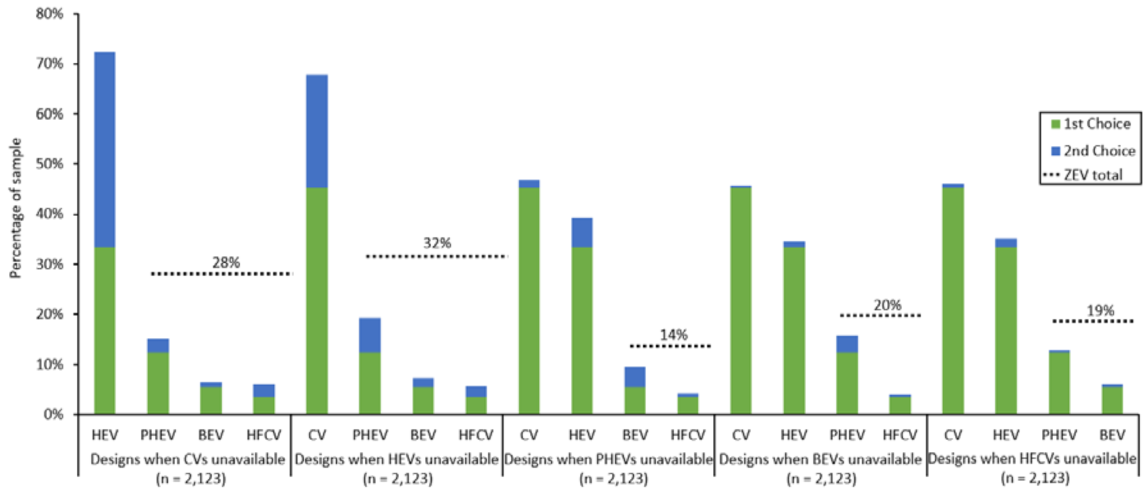


Figure 8. Frequency of vehicle designs when each drivetrain type was "unavailable", including respondents' first and second choices from the unconstrained, lower price scenario. ZEV total refers to the summation of PHEV, BEV and HFCV selections.

To examine if constrained vehicle supply is associated with respondents' design selections, I also assess the frequency of vehicle selections in the constrained, higher and lower price scenarios (top panel of Figure 9). In the constrained vehicle supply scenarios, respondents were limited to designing ZEVs only in body sizes available in Canada at the time of the survey design[9]. Overall, I observe that constraining respondents to selecting only vehicle body sizes (i.e., of the five body sizes included in the survey) that are currently available in Canada had a negligible effect on the frequency of PHEV and BEV designs. As shown in the top panel of Figure 9, 13% and 19% of respondents selected some type of ZEV in the constrained vehicle supply scenarios – compared to 14% and 21% in the unconstrained scenarios (shown in the bottom panel of Figure 9). Respondents selected CVs most frequently (59% and 50% of selections) followed by HEVs (29% and 31% of selections), and ZEVs (13% and 19% of selections). PHEVs were the most popular ZEV selection (10% and 12% of selections), followed by BEVs (1.9% and 4.7% of selections), and HFCVs (0.6% and 2.4% of selections). As shown in the bottom panel of Figure 9, the frequency of PHEV and BEV designs in the constrained scenarios was largely unchanged from the constrained scenarios; however, HFCV designs decreased by about half. In total, 8% and 11% of

[9] See Figure 2 for a reminder of ZEV vehicle sizes not currently available in Canada.

respondents selected a ZEV in the unconstrained vehicle supply scenarios that cannot currently be purchased in Canada.

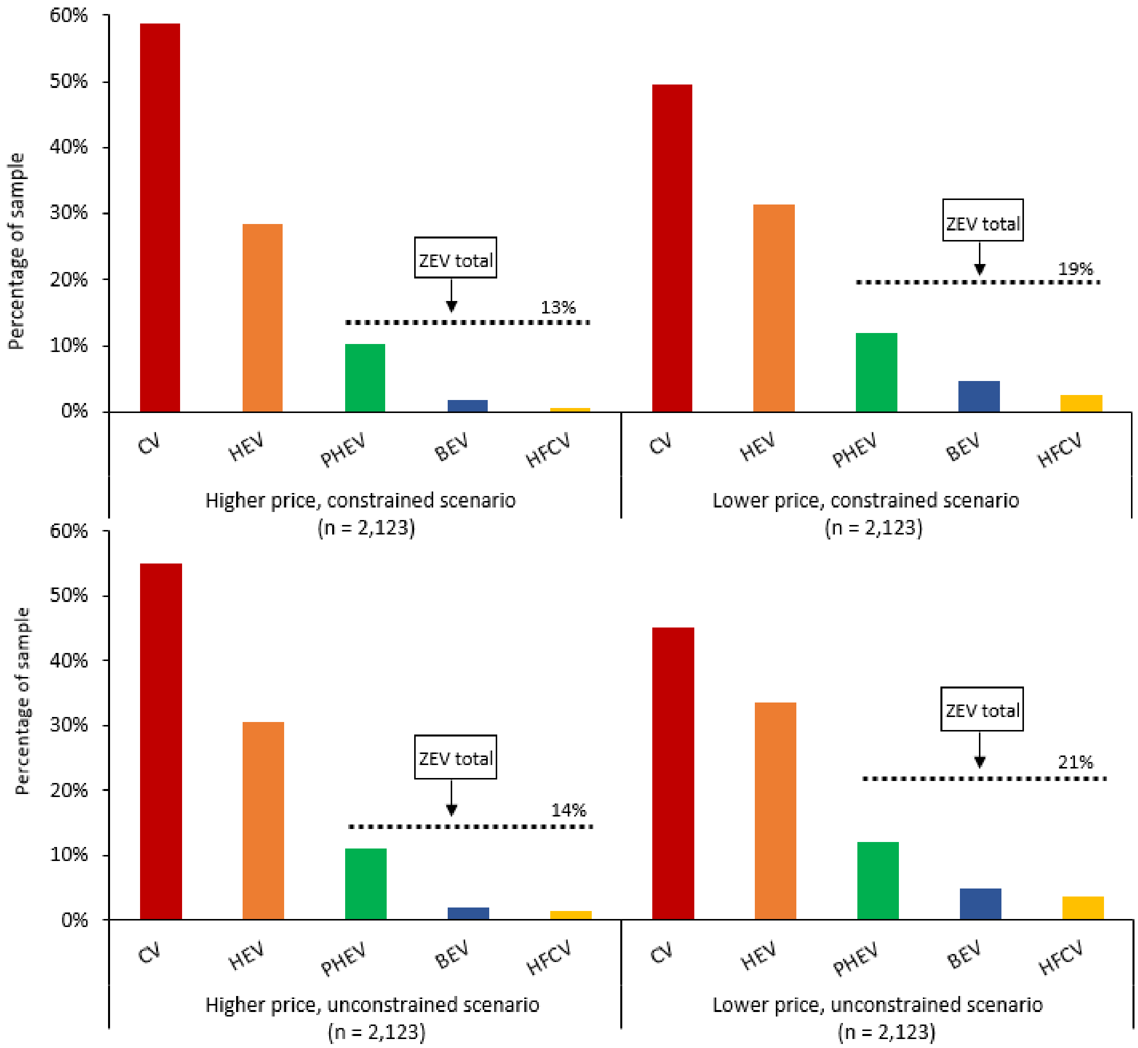


Figure 9. **Frequency of vehicle designs in the constrained (top panel) and unconstrained (bottom panel) vehicle supply scenarios. ZEV total refers to the summation of PHEV, BEV and HFCV selections.**

3.2.2. Comparing characteristics of respondents by vehicle selection (ANOVA and chi-square tests)

I explored possible underlying motivations for respondents' vehicle design selections by segmenting respondents by their drivetrain selection in the unconstrained, lower price scenario, and then performing ANOVA and chi-square tests of association to compare these segments in their lifestyles (i.e., technology- and environmental-oriented), environmental concern, values (i.e., biospheric, altruistic, traditional, and openness to change), and demographics (i.e., age, education, and income). I also performed Tukey post-hoc tests to explore which segments, if any, are significantly different from one another.

Respondents in the vehicle selection segments differ significantly, overall, in their levels of technology- and environmental-oriented lifestyle engagement, environmental concern, altruistic and traditional values, as well as age, education and income (Table 7). I observe a trend of higher technology and environmental lifestyle engagement, environmental concern, and altruistic and biospheric values among respondents who selected a ZEV, compared to those who selected a CV or HEV. Respondents who selected a ZEV are also younger, and have higher education and income levels in general, compared to those who selected a CV.

Table 7. ANOVA and chi-square results comparing respondent design segments in the unconstrained, lower price scenario (n = 2,123).

	CV-selections	HEV-selections	PHEV-selections	BEV-selections	HFCV-selections
Segment Size	961	710	262	115	76
Percent of sample	45.3%	33.4%	12.3%	5.42%	3.58%
Lifestyle, values and attitudes					
Technology-oriented lifestyle (mean score, 0-5)***	2.81[a b]	2.94[a]	3.00[b]	3.00	2.99
Environmental-oriented lifestyle (mean score, 0-5)***	2.66[a b c]	2.80[a]	2.89[b]	2.91[c]	2.76
Environmental concern (NEP mean score, 0-5)***	3.43[a]	3.50	3.53	3.65[a]	3.50
Biospheric values (mean score, 0-5)	3.25	3.23	3.28	3.35	3.19
Altruistic values (mean score, 0-5)***	3.38[a]	3.39	3.49[a b]	3.50[c]	3.23[b c]
Traditional values (mean score, 0-5)***	3.47[a]	3.41[b]	3.48[c]	3.34	3.22[a b c]
Openness to change values (mean score, 0-5)	3.07	3.10	3.15	3.15	3.07
Demographics					
Age (%)**					
<35	22.6	27.1	31.7	33.0	34.2
35-44	14.9	16.4	18.3	18.3	13.2
45-54	21.0	20.5	17.6	19.1	26.3
55-64	24.2	21.4	21.8	16.5	11.8
>65	17.3	14.7	10.7	13.0	14.5
Education (%)***					
Other	22.1	14.3	12.3	9.1	9.2
College, CEGEP, some university, or other non-university diploma	35.9	29.1	28.7	37.3	38.2
University degree (Bachelor)	26.8	33.8	39.5	30.9	31.6
Graduate or professional degree	15.2	22.8	19.5	22.7	21.1
Income (%)*					
<$40,000	17.4	12.5	14.0	16.7	27.5
$40,000-$59,999	20.4	16.6	18.2	14.7	18.8
$60,000-$89,999	26.1	25.9	20.2	19.6	14.5
$90,000-$124,999	20.0	22.9	22.7	24.5	14.5
>$125,000	16.1	22.0	24.8	24.5	24.6

***significant at p=0.01
**significant at p=0.05
*significant at p=0.1

Results from the Tukey post-hoc tests reveal distinct differences among those who designed different types of ZEVs, as well as differences from those who selected a CV or HEV. Specifically, I observe that:

- respondents who selected a PHEV have higher technology and environmental lifestyle orientation, as well as altruistic values, than those who selected a CV;
- respondents who selected a BEV have higher environmental concern than those who selected a CV; and
- respondents who selected a HFCV have lower altruistic values than those who selected a PHEV or BEV, as well as lower traditional values than respondents who selected a CV, PHEV, or HEV.

Interestingly, respondents who selected HFCVs do not follow the same trend of higher technology and environmental lifestyle orientation, environmental concern, and biospheric values as respondents who selected PHEVs or BEVs, although these findings were not significantly different when directly comparing these two groups of respondents. Taken together, my findings suggest that respondents who selected a ZEV are distinct from those who selected a CV in their lifestyles and values, but also that respondents who selected HFCVs are distinct in their values (and possibly lifestyle) from those who selected PHEVs and BEVs.

3.3. Latent class model results

In this section, I show results from the latent class model (LCM), estimated using data from the stated choice experiment. I first explain the overall results and then describe each class' specific results.

Latent class analyses were initially conducted on the stated choice experiment data using different numbers of classes. Table 8 displays the model diagnostics for three to seven latent class solutions. I select and present a five-class solution to the LCM as it reveals distinctions between the classes and provides a clearly interpretable solution, consistent with my research objectives. Table 9 displays the class-specific results and the class membership model for the LCM. The table first lists alternative-specific constants (ASCs) for HEVs, PHEVs, BEVs, and HFCVs, which represent each class of respondents' underlying valuation of the drivetrains relative to a CV. Table 9 then shows the attribute coefficients for each class of respondents, where coefficients significant at the 90%, 95%, and 99% confidence level are indicated using asterisks. I calculated WTP values in each class for coefficients that emerged as significant at the 90% confidence level or greater, which represent respondents' valuation of an additional unit of an attribute relative to vehicle purchase price. The drivetrain WTP values were calculated for each class by considering the drivetrain ASC as well as specific levels of range and recharging/refueling access (when significant). The class membership model, which depicts how lifestyles, values, and demographics are associated with each class, is shown in the second page of Table 9. The covariate coefficients that emerged as significant at the 90%, 95%, and 99% confidence level are also indicated using asterisks. In the class membership model, the "CV-oriented" class serves as the base class, and consequently the other four classes are compared to respondents in the "CV-oriented" class in terms of their demographic and other characteristics. Lastly, the third page of Table 9 displays each class' vehicle selections, which show the proportion of drivetrain selections by respondents in each class across all choice sets.

Table 8. Model diagnostics for 3-7 latent classes.

Number of classes	Log-likelihood (LL)	BIC[a]	AIC[3, b]	CAIC[c]	Number of parameters (k)	Pseudo R^2	Classes substantively different?	Avoids small or large classes?
3	-14572	29795	29399	29880	85	0.84	Yes	Yes
4	-14148	29214	28655	29334	120	0.83	Yes	Yes
5	**-13843**	**28873**	**28151**	**29028**	**155**	**0.82**	**Yes**	**Yes**
6	-13564	28583	27697	28773	190	0.82	No	Yes
7	-13433	28589	27540	28814	225	0.81	No	No

Model estimated using dummy coded ASCs and attributes. Number of individuals n = 2,123; number of observations N = 12,738

[a] Bayesian Information Criterion = -LL+[(k/2)ln(N)]

[b] Akaike Information Criterion = -2(LL-k)

[c] Consistent Akaike Information Criterion = -2ln(L) + p*(1+ln(N))

The sample was divided into classes based on probability of membership. Across the five classes, most ASCs are significant at the 99% confidence level. Each class is characterized by an apparent affinity for certain drivetrains, and I named the classes according to their respective affinities: "CV-oriented" (equivalent to 23% of sample); "HEV-oriented" (equivalent to 21% of sample); "PHEV-oriented" (equivalent to 22% of sample); "ZEV-curious" (equivalent to 20% of sample); and "PEV-enthusiast" (equivalent to 14% of sample). As expected, all classes show significant, negative valuation of vehicle purchase price, and significant positive valuation of ZEV incentives, meaning that all respondents value lower purchase prices and higher levels of ZEV financial incentives. PHEV, BEV, and HFCV range only emerged as significant for two classes (PHEV-oriented and ZEV-curious). Charging and refueling access attributes rarely emerged as significant, where only one class of respondents valued home charging (PHEV-oriented) and two classes value DC fast charging and hydrogen station availability (PHEV-oriented and CV-oriented). Other significant attribute coefficients in the LCM and covariate coefficients in the class membership model reveal additional distinctions between the classes in terms of vehicle preferences and personal characteristics, which I discuss next.

I use the significant coefficients, WTP values, and respondent vehicle selections (i.e., percentage of vehicle drivetrain choices in each class) in Table 9 to describe the key differences between the five classes:

- Respondents in the “CV-oriented” class display a strong negative valuation for all non-CV drivetrains, as evidenced by the negative ASCs and interacted WTP values. Unsurprisingly, “CV-oriented” respondents chose a CV in 95% of choices. The coefficient estimates indicate that respondents in this class have a slight positive valuation of DC fast charging and hydrogen refueling station access, despite underlying negative preferences for non-CV drivetrains. When considering these small positive valuations of refueling and recharging infrastructure, “CV-oriented” respondents still have highly negative WTP values for HEVs and all ZEVs.

- Respondents in the “HEV-oriented” class prefer HEVs, and have a negative valuation of all ZEV types, demonstrated by the ASCs and interacted WTP values. “HEV-oriented” respondents chose a HEV in 61% of choices, and a ZEV in less than 6% of choices. These respondents also negatively value fuel costs. The only significant coefficients emerging for this class relate to costs (including purchase price and ZEV incentives). However, this fuel cost sensitivity contrasts with a lack of interest in incentives, where this class has the lowest WTP value for ZEV incentives of all classes, and a similar WTP value for fuel cost savings to one other class. The class membership model reveals that respondents in the “HEV-oriented” class have higher environmental concern and altruistic values, yet lower biospheric values, relative to those in the “CV-oriented class”. “HEV-oriented” respondents are also more likely to have a Bachelor's or graduate degree than "CV-oriented" respondents, but are not significantly different from "CV-oriented" respondents in their age and income.

- Respondents in the "PHEV-oriented" class positively value PHEVs and HEVs, as well as HFCVs (i.e., with long range and high refueling access), and negatively value BEVs, as evidenced by the interacted WTP values. Significant coefficients reveal that "PHEV-oriented" respondents also show positive preferences for several ZEV attributes, namely PHEV and HFCV range, home recharging access, DC fast charging, and hydrogen refueling station availability. Interestingly, respondents in the "PHEV-oriented" class display the least negative WTP values for HFCVs, being the only class to have positive WTP values for HFCVs (when considering a HFCV with a 500km driving range and hydrogen fuel available at 100% of gasoline stations). Given this consistent valuation of range and recharging/refueling capabilities, these respondents may be most sensitive to these functional characteristics compared to other respondents. "PHEV-oriented" respondents show higher environmental concern and lower egoist values relative to "CV-oriented" respondents". These respondents are also more likely to be younger and have a graduate or professional degree, compared to "CV-oriented" respondents.

- Respondents in the "ZEV-curious" class are characterized predominantly by their uncertainty towards ZEV, rather than their affinity: the ASCs and interacted WTP values for "ZEV-curious" respondents show negative valuation of PHEVs, yet their choice selections reveal that they chose a ZEV about as often as they chose a CV or HEV. The sign and significance of the ASCs suggest that these respondents positively value HEVs, and negatively value PHEVs, but their valuation of BEVs and HFCVs is not significantly different from their valuation of CVs. This observed uncertainty towards ZEVs is further indicated by the coefficient and WTP estimates, revealing that these respondents have a slight positive valuation of PHEV range, and a negative valuation of BEV range. "ZEV-curious" respondents display the highest WTP values for PHEV range, although the WTP value for a PHEV with an 80km range suggests their range valuation is outweighed by their underlying negative preference for PHEVs. Nevertheless, "ZEV-curious" respondents have no significant preferences for any other ZEV attributes (other than purchase price and ZEV incentives). Despite their uncertainty about ZEVs and their attributes, respondents in this class chose a ZEV in about 55% of choices, and chose HFCVs almost as often as they chose HEVs (26% and 27% of choices, respectively). “ZEV-curious” respondents have greater engagement in an environmental lifestyle, higher environmental concern, and lower traditional values than “CV-oriented” respondents. These respondents are also younger and have higher education levels than “CV-oriented” respondents.

- Respondents in the “PEV-enthusiast” class have a strong positive valuation of PHEVs and BEVs, as well as HEVs to a lesser extent, as demonstrated by the positive ASCs and high WTP values for PHEVs, BEVs, and HEVs. Compared to respondents in the other four classes, those in the “PEV-enthusiast” class have the highest valuation of PEVs, which they selected in over 80% of choices. Other attributes, such as range and recharging access, do not influence these respondents’ valuation of PEVs, suggesting a strong, underlying affinity for PEVs. In the class membership model, the “PEV-enthusiast” class displays more significant covariates than any other class. The covariates indicate that these respondents have greater environmental lifestyle engagement and environmental concern, as well as lower traditional values, and openness to change values, compared to the “CV-oriented” class. Respondents in the “PEV-enthusiast” class are also more likely to be younger and more highly educated, specifically having a Bachelor’s degree, than respondents in the “CV-oriented” class.

In summary, the class-specific results demonstrate substantial variation in respondents’ valuation of ZEVs, with some segments showing negative valuation of ZEVs and others displaying strong valuation of ZEVs. The five classes are also varied in their valuation of ZEV attributes, where some classes show significant valuation of range and recharging/refueling attributes and others are ambivalent towards these attributes. The class membership model reveals that respondents with positive preferences for ZEVs tend to have higher environmental concern and environmental-oriented lifestyle engagement, lower traditional values, and are younger and more highly educated, in comparison to “CV-oriented” respondents.

Table 9. **Results for the 5-class latent class model. Number of individuals n = 2,123, number of observations N = 12,738.**

Segment name	CV-oriented		HEV-oriented		PHEV-oriented		ZEV-curious		PEV-enthusiast	
Percentage of respondents in each segment	23%		21%		22%		20%		14%	
Measure of vehicle interest (ASCs)										
HEV	-2.85	***	1.48	***	1.36	***	0.587	***	1.12	***
PHEV	-5.11	***	-1.55	***	0.701	***	-0.757	***	2.21	***
BEV	-8.56	***	-4.93	***	-2.65	***	-0.177		1.65	***
HFCV	-5.35	***	-4.28	***	-2.59	***	0.145		-0.288	
Measure of preferences (coefficients)										
PHEV range (km)	0.00262		-0.00292		0.00327	*	0.00371	*	0.00106	
BEV range (km)	0.00329		0.00377		0.00144		-0.00254	***	0.000555	
HFCV range (km)	0.000354		0.00240		0.00253	**	0.000259		-0.000101	
Vehicle price (CAD$)	-0.000153	***	-0.000277	***	-0.000299	***	-0.0000352	***	-0.0000140	***
Fuel cost (CAD$/week)	0.000861		-0.0132	***	-0.0144	***	-0.0000921		-0.00123	
Incentive value (CAD$)	0.000153	***	0.000130	***	0.000295	***	0.0000838	***	0.000100	***
Home charging (Level 1 or 2)	-0.0721		-0.267		0.615	***	0.000511		0.0854	
Workplace charging (Level 1 or 2)	-0.328		0.206		-0.0139		0.132		0.0427	
Public charging (% of destinations)	0.0144		0.00699		0.000719		0.00581		0.00212	
DC fast charging (access on major highways)	0.835	*	0.282		0.386	***	0.157		-0.0587	
Hydrogen station availability (% of gas stations)	0.0228	*	0.0175		0.0180	***	-0.000445		0.00612	
Implied willingness-to-pay										
Valuation of vehicle types ($ CAD)										
HEV (all else held constant)	$(18,681.73)		$5,362.84		$566.98		$16,587.14		$79,310.63	
PHEV-80km (all else held constant)	$(31,951.42)		$(6,389.39)		$3,205.19		$(13,027.14)		$162,630.53	
+ home charging					$5,282.25					
+ DC fast charging	$(26,534.42)				$4,515.74					
BEV-220km (all else held constant)	$(51,385.04)		$(14,756.07)		$(7,883.53)				$125,709.22	
+ home charging					$(5,806.47)					
+ DC fast charging	$(45,968.04)				$(6,572.99)					
HFCV-500km (all else held constant)	$(33,903.51)		$(11,143.61)		$(4,447.98)					
10% gas stations	$(32,407.66)				$(3,845.31)					
50% gas stations	$(26,424.25)				$(1,434.63)					
100% gas stations	$(18,944.98)				$1,578.72					

Segment name	CV-oriented	HEV-oriented	PHEV-oriented	ZEV-curious	PEV-enthusiast
Valuation of vehicle attributes ($ CAD)					
PHEV range (per km)			$10.73	$106.05	
BEV range (per km)				$(71.72)	
HFCV range (per km)			$8.61		
Fuel cost savings (per year)		$2,484.52	$2,499.87		
Incentive value (per CAD $1000 incentive)	$1,001.68	$468.61	$989.70	$2,371.31	$7,144.70
Home charging (of Level 1 or 2)			$2,077.06		
Workplace charging (of Level 1 or 2)					
Public charging (per % of destinations)					
DC fast charging (for access on major highways)	$5,417.00		$1,310.54		
Hydrogen stations (per % of gas stations)	$149.59		$60.27		
Class membership model [relative to base = CV-oriented]					
Technology-oriented lifestyle score	[Base]	-0.0681	0.0383	0.0183	0.146
Environment-oriented lifestyle score***	[Base]	0.149	-0.0658	0.285 **	0.438 ***
Environmental concern (NEP score)***	[Base]	0.547 ***	0.354 **	0.301 *	0.509 ***
Biospheric values score***	[Base]	-0.546 ***	0.131	-0.200	-0.104
Altruistic values score*	[Base]	0.470 ***	-0.0308	0.141	0.243
Traditional values score***	[Base]	0.192	0.241	-0.301 *	-0.374 **
Egoist values score**	[Base]	-0.00467	-0.339 ***	0.0410	0.0320
Openness to change values score**	[Base]	-0.166	0.136	0.124	-0.353 **
Age***					
15-34	[Base]				
35-44		0.0833	-0.502 **	-0.489 **	-0.258
45-54		-0.214	-0.622 ***	-0.916 ***	-0.830 ***
55-64		-0.231	-0.689 ***	-0.750 ***	-1.11 ***
65+		-0.115	-0.723 ***	-0.943 ***	-0.788 ***
Income					
<$40,000	[Base]				
$40,000-$59,999		0.377	0.523	-0.282	0.0191
$60,000-$89,000		0.208	0.319	-0.404	0.227
$90,000-$124,999		0.363	0.442	0.0110	0.410
$125,000+		0.354	0.565	-0.0848	0.645
Education***					
Other	[Base]				
College, CEGEP, or other non-university diploma		0.236	0.352	0.475 **	0.672 **
University degree (Bachelor)		0.642 ***	0.974 ***	0.471 *	0.970 ***
Graduate or professional degree		0.500 *	1.04 ***	0.556 **	0.599 *

Segment name	CV-oriented	HEV-oriented	PHEV-oriented	ZEV-curious	PEV-enthusiast
Respondent vehicle selections (across choice sets)					
CV	94.7%	33.3%	17.4%	17.9%	3.3%
HEV	3.5%	60.9%	27.1%	27.4%	9.6%
PHEV	0.9%	4.5%	45.7%	15.5%	51.4%
BEV	0.05%	0.4%	4.0%	13.6%	31.6%
HFCV	0.9%	0.9%	5.8%	25.6%	4.1%

*significant at 90% confidence level

**significant at 95% confidence level

***significant at 99% confidence level

[a] I only depict willingness-to-pay calculations where the coefficient estimates are significant at a 90% confidence level of greater

Chapter 4. Discussion and conclusions

Widespread consumer adoption of ZEVs can help Canada meet its climate change mitigation targets to reduce GHG emissions to 30% below 2005 levels by 2030; however, successful ZEV deployment depends on, among other things, consumer preferences and acceptance. In this study, I develop a deeper understanding of Canadian Mainstream consumers' varied preferences and possible motivations for using ZEVs by employing two stated response methods in a multi-part, web-based survey of 2,123 Canadians. Specifically, I use design exercises and a stated choice experiment in the survey to investigate which ZEVs Mainstream Canadians want, as well as the social and demographic characteristics that are statistically associated with these preferences. In the following section, I summarize key results from each stated response method in the context of these research questions, and explain how the methods offer complementary insights for each objective. I next describe some limitations of this study and then discuss the policy implications of this research.

4.1. Which ZEVs do Mainstream Canadian consumers want?

In the design exercises, the frequency of vehicle drivetrain selections indicates overall respondent interest in ZEVs, as well as which ZEVs are most and least preferred. Up to 21% of respondents are interested in ZEVs, as shown by their selected vehicle designs in the lower price scenario (corresponding with the lower incremental ZEV prices that might occur in the future). This proportion is a proxy for latent demand, that is, the sales of ZEVs that could be realized with removal of real world market constraints, including limited vehicle supply and high purchase prices. Past research in North America using design exercises has found a similar proportion of consumers who express interest in PEVs (Axsen, Bailey, et al., 2015; Axsen & Kurani, 2013) and ZEVs (Kurani et al., 2016). Among ZEV designs, respondents are most likely to prefer PHEVs, followed by BEVs, and HFCVs (12%, 5.4%, and 3.6% of selections in the unconstrained, lower price scenario, respectively). This order of preferences for PHEVs over BEVs is consistently observed in research in (Axsen, Bailey, et al., 2015) and the U.S. (Axsen & Kurani, 2013), and one other study that included HFCVs found the same order of ZEV preferences as I do (Kurani et al., 2016). Furthermore, the distribution of design exercise "second choices" (shown in Figure 8) reveals that respondents who selected a BEV as their first choice were more likely to select another ZEV if their first choice is unavailable, whereas those who selected a PHEV or HFCV as their first choice were split in their second choices among the remaining drivetrains. This observation suggests that respondents interested in BEVs have a stronger affinity towards ZEVs in general, compared to those who select a PHEV or HFCV, a finding which provides a novel contribution to the literature.

The LCM results reveal diverse interest in and valuation of ZEVs and their attributes amongst five segments of respondents. Probabilistically, 36% of the sample falls into a class with strong preferences for ZEVs (i.e., those in the "PHEV-oriented" and "PEV-enthusiast" classes), as revealed by strong, positive ZEV-related coefficients and corresponding WTP values. A third "ZEV-curious" class also indicated potential interest in purchasing a ZEV. I summarize each of these in turn:

- "PEV-enthusiast" respondents (equivalent to 14% of the sample) have the highest valuation of PEVs, with WTP values of over $125,000 for PEVs, indicative of their strong underlying PEV preferences. A study of Canadian consumers found similarly high WTP values for PEVs in one respondent segment (Axsen, Bailey, et al., 2015). It should be noted that that these WTP values are exaggerated and do not represent what a respondent would pay in reality; however, the WTP values denote the degree of enthusiasm for PEVs that these respondents possess.

- "PHEV-oriented" respondents (equivalent to 22% of the sample) also have strong preferences for ZEVs, but with more modest WTP values of about $3,000-$5,000 for PHEVs. Respondents in the "PHEV-oriented" class are more sensitive to ZEV attributes than other segments, namely fuel cost, home charging, DC fast charging, HFCV range, and hydrogen station availability. "PHEV-oriented" respondents' WTP values for PHEVs and BEVs increase when their valuation of home recharging and DC fast charging access is considered, demonstrating the importance of these attributes to their ZEV preferences. Other research has observed a similar sensitivity to functional vehicle attributes in respondents with a strong affinity for PHEVs (Axsen, Bailey, et al., 2015; Dimitropoulos, 2014; Sheldon et al., 2017). Notably, “PHEV-oriented” respondents are the only class to have positive WTP values for HFCVs (although only when considering their valuation of pervasive hydrogen refueling station availability and HFCV range of 500km).

- Respondents in the “ZEV-curious” class (20% of sample) are potentially open to ZEVs as well, as they exhibit sensitivity to PHEV range and ZEV incentives. However, simulations with this LCM data found that this class of respondents was not particularly sensitive to a $7,500 ZEV subsidy and increased charging infrastructure (Axsen et al., under review). Perhaps future improvements in PHEV range and even larger incentives could help entice these consumers towards a ZEV.

I find that the design exercises and stated choice experiment offer complementary insights into which ZEVs consumers are interested in. The design exercise results can represent respondents’ latent demand for ZEVs under specific price and supply conditions. The LCM results show the range of valuations for ZEVs and their attributes among respondents with ZEV preferences in different classes. Respondents in some classes have highly positive WTP values for ZEVs (particularly PEVs), whereas other respondents have more modest WTP or negative WTP values for ZEVs. Taken together, both methods depict the heterogeneity in vehicle drivetrain preferences within the sample; however, the design exercises demonstrate heterogeneity through disaggregated observations whereas the LCM shows heterogeneous preferences aggregated into five distinct consumer segments. Of respondents who are interested in ZEVs, the proportions of vehicle designs in all four design exercise scenarios indicate that PHEVs are more commonly preferred, followed by BEVs, and HFCVs. The WTP values in the LCM show that some segments also have this order of preferences for ZEVs, but some segments value HFCVs over BEVs (specifically the “HEV-oriented” and “PHEV-oriented” segments). Simulations with the LCM data, however, indicate that overall latent demand for the ZEV drivetrains is the same order as observed in the design exercises (Axsen, Kormos, Goldberg, & Long, under review).

4.2. Who are these consumers, and which motivations underlie their vehicle preferences?

I explore the characteristics that underpin respondents' interest in ZEVs via an ANOVA comparison of the design exercise results, a method that reveals associations between interest in ZEVs and respondent lifestyles, values, and environmental concern. The ANOVAs and Tukey post-hoc tests indicate that respondents who selected a PEV generally have greater engagement in technology- and environmental-oriented lifestyles, environmental concern, and altruistic values, compared to those who selected a CV. Other survey research has also linked technology and environmental lifestyle activities, greater environmental concern, and stronger altruistic values to consumer interest in PEVs (Axsen, Bailey, et al., 2015; Egbue & Long, 2012; Petschnig et al., 2014; White & Sintov, 2017) and ZEVs (Kurani et al., 2016). Interestingly, respondents interested in HFCVs are distinct from those interested in PEVs. I observe that those who selected a HFCV in the design exercises have lower altruistic and traditional values than respondents who select a PHEV or BEV. Furthermore, respondents interested in HFCVs do not follow the same trend of higher pro-environmental lifestyle and values as those interested in PEVs. This observation suggests that respondents attracted to HFCVs may have distinct motivations from other PEV-interested respondents. To my knowledge, this finding has not been reported elsewhere in the literature. HFCVs were described in the survey as being similar to CVs in terms of how they are refueled (i.e., with a fuel pump at a station) and given the driving ranges provided, likely do not require changes to driving behaviour to operate in the same way as PEVs. Perhaps respondents interested in HFCVs are intrigued by the unconventional aspects of HFCVs alone, and are otherwise more similar to CV-interested respondents than those interested in ZEVs.

The LCM class membership model yielded similar results to the ANOVA comparison, in terms of underlying characteristics associated with vehicle preferences. I observe that respondents in the "PEV-enthusiast" class have greater environmental lifestyle engagement, stronger environmental concern, and lower traditional and openness to change values, while respondents in the "PHEV-oriented" class have stronger environmental concern and lower egoist values, compared to those in the "CV-oriented" class. Given these respondents' lower traditional and egoist values, coupled with heightened environmental concern, their strong preferences for PEVs could be in part motivated by a desire to help the environment. Other research has found that helping the environment was a motivating factor in some consumers' BEV purchases (Hardman et al., 2016) and that environmental concern is associated with PEV interest (Krause et al., 2013; Petschnig et al., 2014; Rezvani et al., 2015; Ziegler, 2012). Respondents in the "ZEV-curious" class also have greater environmental lifestyle engagement, stronger environmental concern, and lower traditional values compared to "CV-oriented" respondents. "ZEV-curious" respondents' environmental consciousness could in part explain their preferences for ZEVs. Perhaps growing Mainstream awareness around the environmental benefits of ZEVs relative to CVs could affect their preferences in the future. Observations from the LCM suggest that respondents with preferences for ZEVs (or potential interest in ZEVs) have pro-environmental characteristics, and are distinguishable in their lifestyles, values, and environmental concern from "CV-oriented" respondents.

The design exercise and LCM results specify several demographic characteristics associated with ZEV-interested consumers. Results from the chi-square test using the design exercise results reveal that respondents who selected a ZEV are younger, have higher education levels and earn more income on average, compared to those who selected a CV or HEV. The LCM class membership model also supports this finding, indicating that respondents with preferences for ZEVs (i.e., respondents in the "PHEV-oriented" and "PEV-enthusiast" classes) tend to be younger and have higher education levels, compared to those in the "CV-oriented" class. Research from the U.S., Canada, and Germany has also observed a trend of younger ages, and higher education (Egbue & Long, 2012; Hidrue et al., 2011; Higgins et al., 2012; Peters & Dütschke, 2014; Sheldon et al., 2017) and income levels (Egbue & Long, 2012) among consumers interested in PEVs, as well as adopters of PEVs (Axsen, Goldberg, & Bailey, 2016).

Both stated response methods demonstrate that respondents that are interested in ZEVs have different values, lifestyles, and environmental beliefs than those who express disinterest in ZEVs. These constructs could be indications of underlying motives for ZEV interest. Notably, analyses of the design exercise results differentiated respondents interested in HFCVs from respondents interested in PEVs in terms of their values and lifestyles, which is a unique finding of this study. The LCM class membership model linked respondent social characteristics to specific classes, where classes with ZEV preferences tended to have similar characteristics to one another. In applying both methods, I find that respondents' interest in ZEVs could be driven by concern for the environment, environmental- and technology-oriented lifestyles, as well as values related to helping the environment and others. ZEV-interested respondents also tend to be younger and more highly educated compared to respondents not currently interested in ZEVs.

4.3. Limitations

Although this study addresses important gaps in the literature, I acknowledge several key limitations of the study. Given these limitations (explained below), results must be interpreted with caution.

First, several forms of bias could be introduced in the data. Because I use stated response methods in which respondents make hypothetical choices, my results are potentially subject to hypothetical bias. Hypothetical bias refers to the extent that respondents may behave or respond inconsistently in a survey, when their choices have no consequences (Hensher, 2010). In other words, hypothetical bias describes one potential cause of systematic differences between what a respondent indicates they would choose and what they would actually choose, due to the hypothetical nature of the exercise. While the survey design was intended to reduce hypothetical biases by specifically framing the design exercises and stated choice experiment to add realism (i.e., using respondents' anticipated next vehicle purchase/lease as the base vehicle, incorporating respondents' actual home recharge access, etc.), I cannot be sure the hypothetical nature of the survey did not lead to a systematic bias in either or both stated response techniques. Related to this, some social desirability bias, where respondents provide answers that they think would be viewed as favourable (i.e., by society or by researchers), could also exist in the data. As such, concerns about the external validity of my findings may be raised, particularly because the results cannot be validated by revealed preference data. For example, the design exercise results suggest that 21% of respondents are interested in ZEVs, and yet sales data show that less than 1% of Canadian consumers have purchased a PEV (Klippenstein, 2017). However, this comparison between latent demand and sales is not appropriate as there are a variety of factors that prevent sales rates from realizing latent demand (e.g., lack of recharging/refueling access and lack of vehicle supply) (Wolinetz & Axsen, 2017). It is still unclear how these stated response results would relate to revealed preferences, if there existing a "full supply" of ZEVs in the Canadian market (e.g., comparable to CVs in terms of make and model availability and variety). Despite these concerns, I argue that stated response methods are still a useful way to elicit consumer preferences for ZEVs, given that they are emerging technologies.

Second, although I took extensive efforts in the survey approach to teach respondents about ZEVs and help them construct their preferences, it is possible that some respondents were still sufficiently unfamiliar with ZEVs to reliably express their preferences. For example, it is possible that many ZEV attributes did not emerge as significant in the LCM (e.g., workplace charging, DC fast charging, ZEV range) because respondents did not understand the practical meaning of these attributes. Consumer confusion about how ZEVs are operated and refueled is consistently observed in the literature (e.g., Axsen, Langman, et al., 2017; Caperello & Kurani, 2012), thus it is reasonable to conceive that respondents could be confused about the other ZEV attributes specified above. Conversely, it is possible that respondents are simply unaffected by these attributes. It should be noted that I removed some respondents (n = 16) from my analysis who expressed that they did not understand how to correctly complete both the design exercises and stated choice experiment to ensure I omitted erroneous data in my analysis.

Third, it could be argued that the incremental prices employed in the design exercise price scenarios were inaccurate, where some may see the prices as too high and others may see them as too low. If this is the case, the external validity of my design exercise results could be further questioned if respondents selected their ideal vehicle under unrealistic assumptions. I consulted several reputable sources (at the time) in calculating the prices (National Research Council, 2013; Nykvist & Nilsson, 2015; Sakti et al., 2015; US Department of Energy, 2014; Wolfram & Lutsey, 2016), although I note that any estimate of ZEV prices is speculative by nature. Estimating “current” prices is even speculative, as I calculated prices for ZEV sizes that are not currently available (e.g., pickup truck BEV). Automakers also do not report the full costs (and markup rates) of the models they sell, making it difficult to validate calculations. However, I emphasize that the design exercise results are not intended to be an assessment of current sales – rather they provide an indication of latent demand (i.e., demand that is not realized due to constraints such as limited awareness and supply). I explore overall interest in ZEVs – and different ZEV types – under various technological and policy conditions (i.e., varying levels of vehicle supply and price), which may or may not be realized in the future.

Furthermore, the design exercises are only one method used to elicit respondent preferences. The stated choice experiment was price neutral, where price attributes were systematically varied across choice sets, leading to the estimate of a choice model that can simulate WTP or latent demand under a range of price and technology scenarios. Because the stated choice experiment (and accompanying choice model) is not vulnerable to this weakness, it is complementary to the design exercises (and consequently provides a validation of design exercise results).

Fourth, the design exercise scenarios that measured the impact of vehicle supply on preferences seemed to be ineffective by design. This outcome could be due to the complexity of the instructions for this aspect of the design exercise (which may have dissuaded respondents from engaging with it). Likewise, it could be due to my simplistic treatment of vehicle classes; only five broad classes of vehicle body sizes (i.e., compact car, sedan, mid-size SUV, full-size SUV/minivan, and pickup truck) were considered in my exploration of supply constraints and ZEV preferences. There are several other vehicle supply constraints that may impact consumer preferences for ZEVs (Wolinetz & Axsen, 2017). For example, I did not consider within-class model diversity, meaning the availability of multiple model options within a vehicle class. I also did not account for dealership availability, where individual dealerships' may or may not keep ZEVs in stock or on the lot, or even be certified to sell ZEVs. Lastly, I did not consider automaker manufacturing constraints, where automakers may be limited in their production of ZEVs to due to scarcity of resources (e.g., lithium for lithium-ion batteries) or lack of factory capacity (e.g., as is the case with Tesla Motors). However, I emphasize that my examination of vehicle supply and its impact on preferences was largely exploratory. Carrying out this type of simulation within a survey is difficult and rarely done (i.e., only by one other study to my knowledge, Kurani et al., 2016).

Lastly, there are two key limitations related to my statistical analyses. The correlational nature of the analyses (i.e., in the ANOVA and class membership model) makes causal statements impossible. For this reason, I cannot say that certain constructs motivate respondents' ZEV interest (e.g., environmental concern motivates interest in BEVs), rather I can only make statements about their association (e.g., environmental concern is associated with interest in BEVs). Related to this, the many pairwise comparisons undertaken in the ANOVA leads to an increased likelihood of Type I error (i.e., false positives). Thus, the associations between ZEV interest and values, lifestyles, and environmental concern are vulnerable to Type I error, especially given that I applied fairly generous p-values (i.e., from a statistician's point of view) when determining significant associations. Again, I emphasize that this research is exploratory and is not intended to make definitive statements about respondent motivations for ZEV interest.

4.4. What are the implications of these findings for ZEV policy in Canada?

As Canada is developing a national ZEV strategy to help reach its GHG reduction targets outlined in the *Pan Canadian Framework on Climate Change and Clean Growth,* the findings of this study are relevant to current discussions of ZEV policy. As explained in Section 1.5, there are two broad categories of ZEV policy – demand-focused and supply-focused – which differ according to their emphasis on stimulating either consumers or suppliers. By design, my approach is not intended to analyze how supply-focused policies, such as a sales mandate or fuel efficiency standard, could impact ZEV sales. My assessment of latent demand for ZEVs lends itself better to discussion of demand-focused policies, which the following section will primarily focus on. However, given the above limitations and exploratory nature of this study, results should be interpreted carefully.

My results indicate that consumers are highly varied in their preferences and underlying motivations for ZEV interest; thus, policymakers would be wise to consider these differences when implementing certain ZEV-supportive policies. Given that there are limited resources to support ZEV uptake, policy ought to focus on areas likely to have the greatest impact. For instance, policy could encourage ZEV adoption among certain consumer segments, such as those similar to "PHEV-oriented" and "ZEV-curious" respondents, as these consumers may be open to purchasing ZEVs if provided the right information and incentives. Conversely, focusing on consumers like those in the "PEV-enthusiast" and "CV-oriented" classes may be an inefficient use of resources because the first segment may purchase a ZEV in any event (i.e., they may freeride off ZEV policy), and the latter may not purchase a ZEV regardless of policy. As one example, simulations with the LCM results from this study found that latent demand among "PHEV-oriented" respondents responded more strongly to a purchase subsidy for ZEVs than the other four segments (Axsen, Kormos, Goldberg, & Long, under review).

Concentrating policy initiatives on key consumer segments, for example through targeted messaging campaigns appealing to consumer environmental beliefs and lifestyles, could potentially help receptive consumers consider ZEVs. Such targeted messaging campaigns could also benefit from utilizing the demographic characteristics I have associated with ZEV preferences. However, my results suggest that a "one size fits all" policy approach to information and messaging campaigns is unlikely to connect with all consumers. For example, outreach that emphasizes the environmental aspects of ZEVs may resonate with some consumers (e.g., respondents who selected a PHEV or BEV in the design game) but could be less effective with others (e.g., respondents who selected a HFCV). The LCM results demonstrate that consumer segments also value policies differently, where WTP values for a CAD $1,000 ZEV subsidy ranged from around $460 to over $7,000. The same is likely to be true for other ZEV-supporting policies, such as free parking or high occupancy vehicle lane access, which could impact a given policy's efficacy. Policymakers ought to consider the range of possible motivations and policy valuations when designing and implementing ZEV policy initiatives.

As clearly indicated by my results, and the literature more generally, financial incentives would likely help increase ZEV uptake in Canada. I observe that vehicle purchase price affected respondents' preferences in the design exercises, where 21% of respondents selected a ZEV in the lower price scenario, compared to 14% in the higher price scenario. In the LCM, all five classes value both purchase price and ZEV incentives. Additionally, several classes in the LCM have negative WTP values (based on the ASCs interacted with range only) near the rate of current Canadian ZEV subsidies (i.e., BC, Ontario and Quebec offer purchase rebates for ZEVs between $1,000 and $14,000); thus, consumers like those in the "HEV-oriented", "PHEV-oriented", "ZEV-curious" classes could be more receptive to purchasing a ZEV with the right subsidy conditions. Simulations with the LCM data presented in this study found that a $7,500 purchase subsidy could increase potential latent ZEV demand from 29% to 45% of consumers, and that a subsidy had the largest impact on demand of simulated policies (Axsen, Kormos, Goldberg, & Long, under review). Other research suggests that persistent and substantial financial incentives (i.e., $12,000 per ZEV for 15 years) could increase Canadian ZEV market share by 10% by 2040 (Melton et al., 2017). A recent review of 35 studies investigating the effect of financial purchase incentives on PEV adoption found that financial incentives are effective at increasing PEV sales (Hardman, Chandan, Tal, & Turrentine, 2017). Results from this study and others demonstrate that purchase subsidies could be important in the Canadian ZEV policy-scape.

Policy aimed at increasing ZEV home-based recharging infrastructure may also support ZEV adoption in Canada. Results from both the design exercises and LCM indicate that home recharging is important to some respondents interested in ZEVs – potentially more important than public charging – and may be a factor influencing consumer interest. In the design exercises, I observe that PEV selections are most frequent and include PEVs with longer electric driving ranges among respondents with potential Level 2 home recharge access. A similar trend was also exhibited by new vehicle buying households in California (Axsen & Kurani, 2013) and Canada (Axsen, Goldberg, et al., 2015). In the LCM, “PHEV-oriented” respondents strongly value home recharging, as these respondents’ WTP values for PHEVs are highest when including their valuation of home recharging. While some research has found stronger valuation of PEV charging infrastructure among some consumer segments (Axsen, Bailey, et al., 2015), this study and another suggest that home recharging is more important to consumers than “public” charging (Bailey, Miele, & Axsen, 2015). Supporting home recharging availability could be an area for policy focus, especially given that over one-third of the population lives in attached homes and apartments (shown in Table 5) where accessing charging can be difficult (e.g., accessing a reliable parking space or installing a charger in a strata-operated building). Examples of policy actions in this area include amending building codes to require PEV chargers in new buildings and offering subsidies to building managers and homeowners who install chargers.

Although the results of this study are not intended to evaluate the long-term effectiveness of supply-focused policies, the design exercise results have implications regarding the impact of ZEV supply on vehicle preferences. Results from the unconstrained vehicle supply scenarios suggest that there is latent demand for ZEVs that are not currently sold in Canada (i.e., in terms of ZEV drivetrains in certain size classes), where up to 11% of respondents selected a ZEV that is not presently available in Canada. However, when design selections were constrained to only vehicle types currently for sale in Canada, the proportion of overall ZEV designs was largely unchanged from when vehicle supply was unconstrained; when their ideal ZEV was “unavailable”, most respondents selected an available ZEV. A study of American new vehicle buyers also observed that constraining ZEV supply in a design exercise had a marginal impact on vehicle design selections (Kurani et al., 2016). While lack of ZEV supply is cited as inhibiting large scale ZEV adoption (Greene, Park, & Liu, 2014; Wolinetz & Axsen, 2017), the present findings from the design exercises indicate that constraining ZEV supply does not meaningfully limit respondent interest in ZEVs. However, as mentioned above, I only assessed the effect of limiting vehicle supply on respondent preferences crudely, and did not consider several other important aspects of vehicle availability (e.g., model variety and dealership availability), which may prevent many consumers from purchasing a ZEV. A ZEV sales mandate, which would increase ZEV supply and diversity, will undoubtedly increase ZEV market share, but my findings do not suggest that this type of policy would necessarily increase consumer interest in ZEVs. Nonetheless, a ZEV mandate could result in reduced purchase prices (i.e., through automaker cross-subsidization or by cost savings through increased production volume) and increased ZEV refueling/recharging infrastructure (i.e., as market share increases and demands expanded infrastructure), thus indirectly impacting policy areas I have identified as important for supporting ZEV adoption (Axsen, Goldberg, & Wolinetz, 2017).

4.5. Future research directions

Although I have gained a deeper understanding the Canadian Mainstream consumer market for ZEVs, research should endeavour to continue uncovering insights into consumer preferences and motivations – and how these constructs relate to overall demand – for ZEVs. It would be useful to understand how individual and household travel behaviour are related to ZEV preferences; for instance, researchers could explore how travel behaviour characteristics are associated with preferences in a LCM (as is currently planned for a next stage in analysis using the data from CZEVS). It is also imperative to further explore consumer motivations for ZEVs through more sophisticated survey questions. A growing body of literature in psychology and economics studies why individuals perform pro-environmental behaviours, and including ZEV use in that research would be beneficial to academics and policymakers. Given my finding that respondents interested in HFCVs are distinct from those interested in PEVs, research should also advance the understanding of how and why consumers interested in HFCVs are different. Additionally, it is pertinent to improve behavioural realism in models of ZEV demand. Data from the LCM could be used to improve consumer dynamics in models estimating and forecasting ZEV demand in Canada, which other researchers in START are doing (e.g., Wolinetz & Axsen, 2017). To address some limitations of this study, it would be useful to follow up with respondents who indicate they are interested in ZEVs to discover their eventual purchase decisions. This type of study could contribute to measuring hypothetical bias as well as to improving stated response methods to reduce biases. Continuing to refine and progress methods to evaluate the impact of vehicle supply on preferences in stated response methods is also worthy of further study. Lastly, it is crucial to continue studying the Mainstream Canadian consumer vehicle market to assess how preferences for ZEVs change over time, given the changing technology and policy conditions occurring.

4.6. Concluding remarks

Extensive ZEV deployment is likely essential for Canada to achieve its ambitious GHG reduction targets, and understanding the consumer market that will purchase ZEVs is imperative for implementing effective ZEV policy. To effectively promote ZEVs, it is critical to understand the factors that influence interest in ZEVs. In this study, I surveyed over 2,000 Mainstream Canadian consumers, employing two complementary stated response methods to develop insights into preferences and motivations for using ZEVs. The design exercises reveal that up to 21% of respondents are interested in ZEVs (i.e., a proxy for latent demand), where interest is primarily in PHEVs followed by BEVs and HFCVs. ZEV-interested respondents tend to be younger and have higher education and income levels, and are different from those who are disinterested in ZEVs in their lifestyles, values, and environmental concern. The design exercises allowed for a comparison between respondents interested in each drivetrain, finding that those interested in HFCVs are also distinct from respondents interested in PEVs in terms of their values and possible underlying motivations. Using data from the stated choice experiment, I estimated a LCM and identified five unique respondent segments based on vehicle preferences and other characteristics. Thirty-six percent of respondents fall probabilistically into classes which have strong preferences for ZEVs (“PHEV-oriented” and “PEV-enthusiast” classes), 20% of respondents are undecided about ZEVs but remain open to them (“ZEV-curious” class) and 44% of respondents prefer CVs and HEVs over ZEVs (“CV-oriented” and “HEV-oriented” classes). Each of these classes has a unique valuation of ZEVs, revealed by the breadth of WTP values ranging from -$45,000 to over $162,000. The LCM indicates that respondents who prefer ZEVs are younger and have higher education levels, and have greater environmental concern, higher engagement in environmental-oriented lifestyles, and stronger pro-social values, compared to respondents who prefer CVs alone.

Globally, ZEV sales are increasing, battery and fuel cell costs are falling (International Energy Agency, 2017), and yet consumer ZEV awareness in North America appears stagnant (Axsen, Goldberg, et al., 2015; Axsen & Kurani, 2013; Kurani et al., 2016). More PEVs were sold in Canada in 2017 than ever before (Klippenstein, 2017), but sales are not expected to continue rising without policy to alleviate barriers to mass market ZEV uptake (Melton et al., 2017). Policy is indispensable to facilitate and sustain a societal transition towards ZEVs, which is essential to achieve Canadian and international climate change mitigation goals. This study has implications for ZEV policy in Canada, as I find a broad diversity in preferences and potential underlying motivations for using ZEVs. Given this heterogeneity, policies are unlikely to connect with all consumer segments equally, and policymakers ought to focus efforts in areas expected to have the greatest impact. Vehicle subsidies and home recharging support may be important policy areas to target, as indicated by attribute valuation in the LCM and design frequencies in the design exercises.

References

Al-Alawi, B. M., & Bradley, T. H. (2013). Review of hybrid, plug-in hybrid, and electric vehicle market modeling studies. *Renewable and Sustainable Energy Reviews*, *21*, 190–203. http://doi.org/10.1016/j.rser.2012.12.048

Axsen, J. (2013). The "Design Space" approach: Observing disaggregated consumer response and preference formation. [PowerPoint slides]. Presented January 13th, 2013 at the Transportation Research Board Conference, Workshop: "New Perspectives in Stated-Response Experiments: Facing up to Complexity, Subtlety and Practicality". Slides provided by author.

Axsen, J., Bailey, J., & Castro, M. A. (2015). Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics*, *50*, 190–201. http://doi.org/10.1016/j.eneco.2015.05.003

Axsen, J., Cairns, J., Dusyk, N., & Goldberg, S. (under review). Consumer lifestyle and response to low-carbon technologies: structured interviews with plug-in electric vehicle owners. *Energy Research & Social Science*.

Axsen, J., Goldberg, S., & Bailey, J. (2016). How might potential future plug-in electric vehicle buyers differ from current “Pioneer” owners? *Transportation Research Part D: Transport and Environment*, *47*, 357–370. http://doi.org/10.1016/j.trd.2016.05.015

Axsen, J., Goldberg, S., Bailey, J., Kamiya, G., Langman, B., Cairns, J., … Miele, A. (2015). *Electrifying vehicles: Insights from the Canadian Plug-in Electric Vehicle Study*. Simon Fraser University, Burnaby, BC.

Axsen, J., Goldberg, S., & Wolinetz, M. (2017). *Accelerating the transition to electric mobility in Canada: The case for a zero-emission vehicle mandate*. Equiterre, Montreal, Quebec. Retrieved from https://equiterre.org/sites/fichiers/repac_en.pdf

Axsen, J., Kormos, C., Goldberg, S., & Long, Z. (under review). Which types of zero-emissions vehicles do Canadian consumers want, why do they want them, and under what conditions? *Submitted to Transportation Research Part D*.

Axsen, J., & Kurani, K. S. (2013). Hybrid, plug-in hybrid, or electric - What do car buyers want? *Energy Policy*, *61*, 532–543.

Axsen, J., Kurani, K. S., Turrentine, T., & Sovacool, B. K. (working paper). Anticipating consumer response to low-carbon, transformative technologies: The Reflexive Participant Approach to survey research.

Axsen, J., Langman, B., & Goldberg, S. (2017). Confusion of innovations: Mainstream consumer perceptions and misperceptions of electric-drive vehicles and charging programs in Canada. *Energy Research and Social Science*, *27*, 163–173. http://doi.org/10.1016/j.erss.2017.03.008

Axsen, J., Orlebar, C., & Skippon, S. (2013). Social influence and consumer preference formation for pro-environmental technology: The case of a U.K. workplace electric-vehicle study. *Ecological Economics*, *95*, 960–107. http://doi.org/10.1016/j.ecolecon.2013.08.009

Axsen, J., TyreeHageman, J., & Lentz, A. (2012). Lifestyle practices and pro-environmental technology. *Ecological Economics*, *82*, 64–74. http://doi.org/10.1016/j.ecolecon.2012.07.013

Bahn, O., Marcy, M., Vaillancourt, K., & Waaub, J. P. (2013). Electrification of the Canadian road transportation sector: A 2050 outlook with TIMES-Canada. *Energy Policy*, *62*, 593–606. http://doi.org/10.1016/j.enpol.2013.07.023

Bailey, J., Miele, A., & Axsen, J. (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. http://doi.org/10.1016/j.trd.2015.02.001

Bettman, J. R., Luce, M. F., & Payne, J. W. (1998). Constructive consumer choice processes. *Journal of Consumer Research*, *25*(3), 187–217. http://doi.org/10.1093/cje/bem005

Bliemer, M. C. J., & Rose, J. M. (2011). Experimental design influences on stated choice outputs: an empirical study in air travel choice. *Transportation Research Part A: Policy and Practice*, *45*, 63–79.

Brand, C., Cluzel, C., & Anable, J. (2017). Modeling the uptake of plug-in vehicles in a heterogeneous car market using a consumer segmentation approach. *Transportation Research Part A: Policy and Practice*, *97*, 121–136. http://doi.org/10.1016/j.tra.2017.01.017

Browne, D., O'Mahony, M., & Caulfield, B. (2012). How should barriers to alternative fuels and vehicles be classified and potential policies to promote innovative technologies be evaluated? *Journal of Cleaner Production*, *35*, 140–151. http://doi.org/10.1016/j.jclepro.2012.05.019

Brownstone, D., Bunch, D. S., & Train, K. (2000). Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. *Transportation Research Part B: Methodological*, *34*(5), 315–338. http://doi.org/10.1016/S0191-2615(99)00031-4

Bunch, D. S., Bradley, M., Golob, T. F., Kitamura, R., & Occhiuzzo, G. P. (1993). Demand for clean-fuel vehicles in California: A discrete-choice stated preference pilot project. *Transportation Research Part A: Policy and Practice*, *27*(3), 237–253. http://doi.org/10.1016/0965-8564(93)90062-P

Caperello, N. D., & Kurani, K. S. (2012). Households' Stories of Their Encounters With a Plug-In Hybrid Electric Vehicle. *Environment and Behavior*, *44*(4), 493–508. http://doi.org/10.1177/0013916511402057

Carley, S., Krause, R. M., Lane, B. W., & Graham, J. D. (2013). Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. *Transportation Research Part D: Transport and Environment*, *18*, 39–45. http://doi.org/10.1016/j.trd.2012.09.007

Coad, A., de Haan, P., & Woersdorfer, J. S. (2009). Consumer support for environmental policies: An application to purchases of green cars. *Ecological Economics*, *68*(7), 2078–2086. http://doi.org/10.1016/j.ecolecon.2009.01.015

Cordano, M., Welcomer, S. A., & Scherer, R. F. (2003). An Analysis of the Predictive Validity of the New Ecological Paradigm Scale. *The Journal of Environmental Education*, *34*(3), 22–28. http://doi.org/10.1080/00958960309603490

Daziano, R. A., & Bolduc, D. (2013). Incorporating pro-environmental preferences towards green automobile technologies through a Bayesian hybrid choice model. *Transportmetrica A: Transport Science*, *9*(1), 74–106. http://doi.org/10.1080/18128602.2010.524173

Dimitropoulos, A. (2014). *The Influence of Environmental Concerns on Drivers ' Preferences for Electric Cars.*Tinbergen Institute Discussion Paper (TI 2014-128/VIII), Amsterdam, the Netherlands.

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*, *48*(2012), 717–729. http://doi.org/10.1016/j.enpol.2012.06.009

Environment and Climate Change Canada. (2017). *Greenhouse gas emissions by Canadian economic sector*. Retrieved from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions/canadian-economic-sector.html

Ewing, G. O., & Sarigöllü, E. (1998). Car fuel-type choice under travel demand management and economic incentives. *Transportation Research Part D: Transport and Environment*, *3*(6), 429–444. http://doi.org/10.1016/S1361-9209(98)00019-4

Giddens, A. (1984). *The Constitution of Society - Outline of the Theory of Structuration*. Berkeley, CA: University of California Press.

Giddens, A. (1991). *Modernity and Self-identity: Self and Society in the Late Modern Age*. Stanford, CA: Stanford University Press.

Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., & Stannard, J. (2012). Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. *Transportation Research Part A: Policy and Practice*, *46*(1), 140–153. http://doi.org/10.1016/j.tra.2011.09.008

Greene, D., & Ji, S. (2016). *Policies for Promoting Low-Emission Vehicles and Fuels: Lessons from Recent Analyses*. The Howard H. Baker Jr. Center for Public Policy, Baker Report (4:16), Knoxville, Tennessee.

Greene, D., Park, S., & Liu, C. (2014). Analyzing the transition to electric drive vehicles in the U.S. *Futures*, *58*, 34–52. http://doi.org/10.1016/j.futures.2013.07.003

Greene, D., Park, S., & Liu, C. (2014). Public policy and the transition to electric drive vehicles in the U.S.: The role of the zero emission vehicles mandates. *Energy Strategy Reviews*, *5*, 66–77. http://doi.org/10.1016/j.esr.2014.10.005

Greene, W. H., & Hensher, D. A. (2003). A latent class model for discrete choice analysis: contrasts with mixed logit. *Transportation Research Part B: Methodological*, *37*(8), 681–698.

Hackbarth, A., & Madlener, R. (2013). Consumer preferences for alternative fuel vehicles: A discrete choice analysis. *Transportation Research Part D: Transport and Environment*, *25*, 5–17. http://doi.org/10.1016/j.trd.2013.07.002

Hafner, R. J., Walker, I., & Verplanken, B. (2017). Image, not environmentalism: A qualitative exploration of factors influencing vehicle purchasing decisions. *Transportation Research Part A: Policy and Practice*, *97*, 89–105. http://doi.org/10.1016/j.tra.2017.01.012

Hardman, S., Chandan, A., Tal, G., & Turrentine, T. (2017). The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence. *Renewable and Sustainable Energy Reviews*, *80*, 1100–1111. http://doi.org/10.1016/j.rser.2017.05.255

Hardman, S., Shiu, E., & Steinberger-Wilckens, R. (2016). Comparing high-end and low-end early adopters of battery electric vehicles. *Transportation Research Part A: Policy and Practice*, *88*, 40–57. http://doi.org/10.1016/j.tra.2016.03.010

Hardman, S., Shiu, E., Steinberger-Wilckens, R., & Turrentine, T. (2017). Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters attitudes. *Transportation Research Part A: Policy and Practice*, *95*, 166–182. http://doi.org/10.1016/j.tra.2016.11.012

Heffner, R. R., Kurani, K. S., & Turrentine, T. S. (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research Part D: Transport and Environment*, *12*(6), 396–413. http://doi.org/10.1016/j.trd.2007.04.003

Helveston, J. P., Liu, Y., Feit, E. M., Fuchs, E., Klampfl, E., & Michalek, J. J. (2015). Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the U.S. and China. *Transportation Research Part A: Policy and Practice*, *73*, 96–112. http://doi.org/10.1016/j.tra.2015.01.002

Hensher, D. A. (2010). Hypothetical bias, choice experiments and willingness to pay. *Transportation Research Part B: Methodological*, *44*(6), 735–752. http://doi.org/10.1016/j.trb.2009.12.012

Hensher, D. A., Rose, J. M., & Greene, W. H. (2005). *Applied Choice Analysis: A Primer*. Cambridge, UK: Cambridge University Press.

Hidrue, M. K., Parsons, G. R., Kempton, W., & Gardner, M. P. (2011). Willingness to pay for electric vehicles and their attributes. *Resource and Energy Economics*, *33*(3), 686–705. http://doi.org/10.1016/j.reseneeco.2011.02.002

Higgins, A., Paevere, P., Gardner, J., & Quezada, G. (2012). Combining choice modelling and multi-criteria analysis for technology diffusion: An application to the uptake of electric vehicles. *Technological Forecasting and Social Change*, *79*(8), 1399–1412. http://doi.org/10.1016/j.techfore.2012.04.008

Hoen, A., & Koetse, M. J. (2014). A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. *Transportation Research Part A: Policy and Practice*, *61*, 199–215. http://doi.org/10.1016/j.tra.2014.01.008

International Energy Agency. (2015). *Energy and Climate Change: World Energy Outlook Special Report*. OECD/IEA, Paris, France.

International Energy Agency. (2017). *Global EV Outlook 2017*. OECD/IEA, Paris France. Retrieved from https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

Jaccard, M., Hein, M., & Vass, T. (2016). *Is Win-Win Possible? Can Canada's Government Achieve Its Paris Commitment...and Get Re-Elected?* Simon Fraser University, Burnaby, BC.

Jansson, J. (2011). Consumer eco-innovation adoption: Assessing attitudinal factors and perceived product characteristics. *Business Strategy and the Environment*, *20*(3), 192–210. http://doi.org/10.1002/bse.690

Jensen, A. F., Cherchi, E., & Mabit, S. L. (2013). On the stability of preferences and attitudes before and after experiencing an electric vehicle. *Transportation Research Part D: Transport and Environment*, *25*, 24–32. http://doi.org/10.1016/j.trd.2013.07.006

Klippenstein, M. (2017). Canadian EV sales. Retrieved November 29, 2017, from www.tinyurl.com/CanadaEVSales

Krause, R. M., Carley, S. R., Lane, B. W., & Graham, J. D. (2013). Perception and reality: Public knowledge of plug-in electric vehicles in 21 U.S. cities. *Energy Policy*, *63*, 433–440.

Krupa, J. S., Rizzo, D. M., Eppstein, M. J., Brad Lanute, D., Gaalema, D. E., Lakkaraju, K., & Warrender, C. E. (2014). Analysis of a consumer survey on plug-in hybrid electric vehicles. *Transportation Research Part A: Policy and Practice*, *64*, 14–31. http://doi.org/10.1016/j.tra.2014.02.019

Kuhfeld, W. F. (2005). *Marketing Research Methods in SAS: Experimental Design, Choice, Conjoint, and Graphical Techniques*. Cary, NC.

Kurani, K. S., Caperello, N., & TyreeHageman, J. (2016). *New car buyers' valuation of zero-emission vehicles: California*. University of California, Davis, Davis, CA.

Kurani, K. S., Turrentine, T., & Sperling, D. (1994). Demand for electric vehicles in hybrid households: an exploratory analysis. *Transport Policy*, *1*(4), 244–256. http://doi.org/10.1016/0967-070X(94)90005-1

Kurani, K. S., Turrentine, T., & Sperling, D. (1996). Testing electric vehicle demand in "hybrid households" using a reflexive survey. *Transportation Research Part D: Transport and Environment*, *1*(2), 131–150. http://doi.org/10.1016/S1361-9209(96)00007-7

Kyle, P., & Kim, S. H. (2011). Long-term implications of alternative light-duty vehicle technologies for global greenhouse gas emissions and primary energy demands. *Energy Policy*, *39*(5), 3012–3024. http://doi.org/10.1016/j.enpol.2011.03.016

Lee-Gosselin, M. (1990). The dynamics of car use patterns under different scenarios: A gaming approach. *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, 250–271.

Lee-Gosselin, M. (1996). Scope and Potential of Interactive Stated Response Data Collection Methods. In *Conference on Household Travel Surveys: New Concepts and Research Needs, Transportation Research Board Conference Proceedings* (pp. 115–133). Irvine, CA.

Louviere, J., Hensher, D. A., & Swait, J. (2000). *Stated Choice Methods: Analysis and Applications*. Cambridge, UK: Cambridge University Press.

McCollum, D., & Yang, C. (2009). Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications. *Energy Policy*, *37*(12), 5580–5596. http://doi.org/10.1016/j.enpol.2009.08.038

Melton, N., Axsen, J., & Goldberg, S. (2017). Evaluating plug-in electric vehicle policies in the context of long-term greenhouse gas reduction goals: Comparing 10 Canadian provinces using the "PEV policy report card." *Energy Policy*, *107*, 381–393. http://doi.org/10.1016/j.enpol.2017.04.052

National Research Council. (2013). *Transitions to Alternative Vehicles and Fuels*. The National Academies Press, Washington, DC.

Natural Resources Canada. (2017). 2016 Fuel Consumption Ratings (2017-01-04). Retrieved from http://open.canada.ca/data/en/dataset/98f1a129-f628-4ce4-b24d-6f16bf24dd64

Noppers, E. H., Keizer, K., Bolderdijk, J. W., & Steg, L. (2014). The adoption of sustainable innovations: Driven by symbolic and environmental motives. *Global Environmental Change*, *25*, 52–62. http://doi.org/10.1016/j.gloenvcha.2014.01.012

Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. *Nature Climate Change*, *5*(4), 329–332. http://doi.org/10.1038/nclimate2564

Peters, A., & Dütschke, E. (2014). How do Consumers Perceive Electric Vehicles? A Comparison of German Consumer Groups. *Journal of Environmental Policy & Planning*, *16*(3), 359–377. http://doi.org/10.1080/1523908X.2013.879037

Petschnig, M., Heidenreich, S., & Spieth, P. (2014). Innovative alternatives take action - Investigating determinants of alternative fuel vehicle adoption. *Transportation Research Part A: Policy and Practice*, *61*, 68–83. http://doi.org/10.1016/j.tra.2014.01.001

Plötz, P., Funke, S. A., Jochem, P., & Wietschel, M. (2017). CO2 Mitigation Potential of Plug-in Hybrid Electric Vehicles larger than expected. *Scientific Reports*, *7*(16493), 1–6. http://doi.org/10.1038/s41598-017-16684-9

Potoglou, D., & Kanaroglou, P. S. (2007). Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment*, *12*(4), 264–274. http://doi.org/10.1016/j.trd.2007.03.001

Requia, W. J., Adams, M. D., Arain, A., Koutrakis, P., & Ferguson, M. (2017). Carbon dioxide emissions of plug-in hybrid electric vehicles: A life-cycle analysis in eight Canadian cities. *Renewable and Sustainable Energy Reviews*, *78*, 1390–1396. http://doi.org/10.1016/j.rser.2017.05.105

Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D: Transport and Environment*, *34*, 122–136. http://doi.org/10.1016/j.trd.2014.10.010

Ricci, M., Bellaby, P., & Flynn, R. (2008). What do we know about public perceptions and acceptance of hydrogen? A critical review and new case study evidence. *International Journal of Hydrogen Energy*, *33*(21), 5868–5880. http://doi.org/10.1016/j.ijhydene.2008.07.106

Romejko, K., & Nakano, M. (2017). Portfolio analysis of alternative fuel vehicles considering technological advancement, energy security and policy. *Journal of Cleaner Production*, *142*(1), 39–49. http://doi.org/10.1016/j.jclepro.2016.09.029

Sakti, A., Michalek, J. J., Fuchs, E. R. H., & Whitacre, J. F. (2015). A techno-economic analysis and optimization of Li-ion batteries for light-duty passenger vehicle electrification. *Journal of Power Sources*, *273*, 966–980. http://doi.org/10.1016/j.jpowsour.2014.09.078

Schwartz, S. H. (1992). Universals in the content and structure of values: Theory and empirical tests in 20 countries. In M. Zanna (Ed.), *Advances in experimental social psychology (Vol. 25)* (pp. 1–65). New York, NY: Academic Press.

Sheldon, T. L., Deshazo, J. R., & Carson, R. T. (2017). Electric and plug-in hybrid vehicle demand: Lessons for an emerging market. *Economic Inquiry*, *55*(2), 695–713. http://doi.org/10.1111/ecin.12416

Shen, J. (2009). Latent class model or mixed logit model? A comparison by transport mode choice data. *Applied Economics*, *41*(22), 2915–2924.

Sovacool, B. K., & Hirsh, R. F. (2009). Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. *Energy Policy*, *37*(3), 1095–1103. http://doi.org/10.1016/j.enpol.2008.10.005

Steg, L. (2005). Car use: Lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice*, *39*(2–3 SPEC. ISS.), 147–162. http://doi.org/10.1016/j.tra.2004.07.001

Stern, P. C., Dietz, T., & Guagnano, G. A. (1998). A brief inventory of values. *Educational and Pyschological Measurement*, *58*(6), 984–1001.

Sykes, M., & Axsen, J. (2017). No free ride to zero-emissions: Simulating a region's need to implement its own zero-emissions vehicle (ZEV) mandate to achieve 2050 GHG targets. *Energy Policy*, *110*, 447–460. http://doi.org/10.1016/J.ENPOL.2017.08.031

Tarigan, A. K. M., Bayer, S. B., Langhelle, O., & Thesen, G. (2012). Estimating determinants of public acceptance of hydrogen vehicles and refuelling stations in greater Stavanger. *International Journal of Hydrogen Energy*, *37*(7), 6063–6073. http://doi.org/10.1016/j.ijhydene.2011.12.138

Train, K. (1986). *Qualitative choice analysis - theory, econometrics, and an application to automobile demand.* Cambridge, MA: The MIT Press.

Tran, M., Banister, D., Bishop, J. D. K., & McCulloch, M. D. (2013). Simulating early adoption of alternative fuel vehicles for sustainability. *Technological Forecasting and Social Change*, *80*(5), 865–875. http://doi.org/10.1016/j.techfore.2012.09.009

Turrentine, T. S., & Kurani, K. S. (1998). Adapting Interactive Stated Response techniques to a self-completion survey. *Transportation*, *25*(2), 207–222.

Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T., Borrego, C., … Schmid, S. (2010). Transport impacts on atmosphere and climate: Land transport. *Atmospheric Environment*, *44*(37), 4772–4816. http://doi.org/10.1016/j.atmosenv.2010.01.002

US Department of Energy. (2014). *Record 14014: Fuel Cell System Cost - 2014*.

Vass, T., & Jaccard, M. (2017). *Driving Decarbonization: Pathways and Policies for Canadian Transport*. Simon Fraser University, Burnaby, BC.

Vermunt, J., & Magidson, J. (2013). Latent Gold 5.0. Belmont, MA: Statistical Innovations Inc.

White, L. V., & Sintov, N. D. (2017). You are what you drive: Environmentalist and social innovator symbolism drives electric vehicle adoption intentions. *Transportation Research Part A: Policy and Practice*, *99*, 94–113. http://doi.org/10.1016/j.tra.2017.03.008

Williams, J. H., Debenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Iii, W. R. M., … Torn, M. S. (2012). 2050: The Pivotal Role of Electricity. *Science*, *335*, 53–60.

Wolfram, P., & Lutsey, N. (2016). *Electric vehicles: Literature review of technology costs and carbon emissions*. The International Council on Clean Transportation, Washington, DC. http://doi.org/10.13140/RG.2.1.2045.3364

Wolinetz, M., & Axsen, J. (2017). How policy can build the plug-in electric vehicle market: Insights from the respondent-based preference and contraints (REPAC) model. *Technological Forecasting and Social Change*, *117*, 238–250. http://doi.org/10.1017/CBO9781107415324.004

Yetano Roche, M., Mourato, S., Fischedick, M., Pietzner, K., & Viebahn, P. (2010). Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications. *Energy Policy*, *38*(10), 5301–5310. http://doi.org/10.1016/j.enpol.2009.03.029

Ziegler, A. (2012). Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: A discrete choice analysis for Germany. *Transportation Research Part A: Policy and Practice*, *46*(8), 1372–1385. http://doi.org/10.1016/j.tra.2012.05.016

Zito, P., & Salvo, G. (2012). Latent class approach to estimate the willingness to pay for transit users information. *Journal of Transportation Technologies*, *2*(3), 193–203.

Appendix.

Method of Grouping Vehicle Classes

In this section, I describe my method for grouping the vehicles in Natural Resource Canada's (NR Can) 2016 fuel economy database into five vehicle class sizes for the purposes of the design exercises and stated choice experiment. I used NR Can's 2016 fuel economy database when respondents indicated the make, model, and expected purchase price of their anticipated next vehicle purchase or lease, prior to the design exercises and stated choice experiment. Incremental prices were then added to the expected purchase price in the design exercises, when presenting respondents with HEV, PHEV, BEV, and HFCV versions of their "base" vehicle. In calculating these incremental prices, I estimated prices for five vehicle sizes (or classes): compact cars, sedans, mid-size SUVs, full-size SUVs/minivans, and pickup trucks. Calculating prices for these five classes, which are primarily differentiated according to engine power and secondarily by the number of engine cylinders, allowed the price to reflect the battery power/fuel cell size required for different size vehicles. This allowed for a sufficient level of detail to improve the accuracy of the calculations, but was not too detailed to make the task overly arduous.

The NR Can database categorized vehicles into 15 size classes, based on interior volume and weight, therefore we "nested" the 15 classes into my five classes in order to assign each vehicle in the database a price. NR Can's database provided data on the number of engine cylinders for each vehicle, but not engine power. Given the available information, I decided to group the 15 NR Can classes into my five classes according to the number of engine cylinders in the vehicle. To justify this assumption, I explored the validity of treating the number of engine cylinders as a proxy for engine power. Using data from a European vehicle database, I ran an analysis that showed a strong correlation (r = 0.62) between the number of engine cylinders in a vehicle and the vehicle's power. This correlation provides rationale for using the number engine cylinders in a vehicle as a proxy for the vehicle's power; however, I acknowledge that it is not a perfect correlation.

To group the 15 classes into my five classes, I carried out the following steps:

1. I roughly grouped the NR Can classes into anticipated likely groupings based on vehicle size (e.g., I expected that NR Can's subcompact, two-seater, compact and minicompact classes would fall into our compact class).

2. I calculated the mode number of engine cylinders (i.e., the number of engine cylinders that occurred most frequently) in each NR Can class.

3. I compared the mode number of engine cylinders in each NR Can class with the number of engine cylinders in each of my five vehicle classes (i.e., I compared the number of engine cylinders in my compact class with the mode number of engine cylinders in the NR Can classes roughly grouped into the compact class).

4. I adjusted the initial rough categorization based on the comparison in 3., recategorizing NR Can classes where the rough categorization in 1. was incorrect.

5. In cases where the above steps did not result in a logical assignment of NR Can classes into one of my five classes, I reassigned these classes to an appropriate class based on body style. For example, small high-performance sport cars (found in the NR Can two-seater class) have a high number of engine cylinders, and so the above method would erroneously result in them being assigned into the full-SUV/minivan class. In such cases, I reassigned NR Can classes to a more appropriate size class for our purposes.

Table A1 displays the grouping of NR Can classes into my five vehicle classes.

Table A1. Grouping of NR Can vehicle size classes into my five vehicle classes by number of engine cylinders.

My Classes	Number of engine cylinders	NR Can Classes	Mode number of engine cylinders
Compact	4	Subcompact	4
		Two-Seater	4
		Compact	4
		Minicompact	4
Sedan	4	Mid-Size	4
		Full-Size	6
		Station wagon-small	4
		Station wagon-mid-size	4
Mid-SUV	4	SUV-small	4
		Special purpose vehicle	4
Full-SUV/minivan	6	SUV-standard	8
		Minivan	6
Truck	8	Pickup truck-small	4
		Pickup truck-standard	8
		Van-passenger	8

Given that I grouped 15 vehicle classes into five, there are many permutations that could exist. Although my method is not perfect, the grouping I arrived at is an informed estimate, as were the incremental prices, and neither are likely to be perfect estimations.