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Understanding Adoption of Energy-Efficient Technologies: A Case Study of Battery Electric Vehicle Adoption in the U.S.

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Key Points

The adoption of energy-efficient technologies is a key factor in improving energy utilization. The ways in which consumers make their decisions – incorporating non-economic factors – is critical to understanding the pace and depth of adoption. We present a way of characterizing current and potential adopters of new technology and the factors that influence their decisions using battery electric vehicle (BEV) adoption in the U.S. as a case study.

- BEVs have the potential to secure up to ~2.4 percent of the U.S. automotive market.

- The costs of adding the features that potential BEV buyers require to change their purchase decisions, combined with the eventual removal of purchase subsidies, will likely offset the forecasted declines in battery costs.

- The biggest competitors to BEVs are fuel-efficient gasoline vehicles. Fuel economy instruments such as the Corporate Average Fuel Economy (CAFE) standards may work against BEV adoption targets despite BEV sales being strongly incentivized in the CAFE program.

Summary

Understanding what drives adoption of energy-efficient technologies is key to achieving success in improving energy utilization and reducing emissions. In order to promote higher penetration of energy-efficient technologies, stakeholders need a better understanding of what drives consumer uptake of such technologies. In particular, who are the current adopters, why are they adopting it, who are the next batch of potential adopters and what factors will induce them to adopt.

Revealed preference surveys can provide key insights on current adopters' reasons for purchase. For identifying potential adopters, stated-preference surveys are generally used. However, consumers generally tend to react differently to hypothetical choice experiments than they would facing the same alternatives in a real market. Thus, in this study, we present a novel data mining approach, "ex-post counterfactual inference," for understanding current and potential adopters of energy-efficient technologies using revealed preference survey data.

A proof-of-concept is demonstrated by analysing battery electric vehicle (BEV) technology adoption in the U.S. market, as it represents a topical policy matter. Ten U.S. states, including California, representing 28 percent of U.S. light duty vehicle sales, have set mandated sales targets for zero-emission vehicles (ZEVs) that could result in significant reductions in fuel consumption and carbon emissions. Battery electric vehicles (BEVs) represent the most widely adopted full ZEV technology and hence are key to achieving this mandate. For the targets to be successful, stakeholders need a better understanding of: (i) who buys BEVs, (ii) who might buy BEVs, and (iii) what factors can induce them to buy?

To answer these questions and others, KAPSARC carried out a novel segmentation-sizing study of the U.S. automotive market based on quantitative consumer profiling analysis, utilizing large-scale revealed preference survey data of 88,404 new car buyers. The nationally representative survey was carried out by Strategic Vision.

Using a combination of factors related to buyers' reasons for purchase, demographics and geographical characteristics, the analysis identifies different types of BEV buyers. Using these buyer-types as a reference, analysis then identifies and estimates potential BEV buyers from among the non-BEV buyers that "statistically resemble" the BEV buyer types. This is the first time such a methodology has been used in any field and has broad applications for the analysis of revealed preference survey data and technology adoption.

Our study found that BEV buyers are tech savvy and green enthusiasts who prefer to lease BEV as a second vehicle for their household, thus alleviating to some extent both range and resale anxiety issues. On the other hand, non-BEV buyers prefer an aesthetically pleasing vehicle with tried and tested powertrain technology, with good expected resale value, towing capability and handling ability in inclement weather.

Among BEV buyers, there are three types: (i) "price conscious buyers" who care about price, leasing terms and rebates; (ii) "affluent adopters" who care about styling, prestige and performance; and (iii) "demanding buyers" who are both price conscious and care about styling, prestige and performance. Demanding buyers also have fewer additional cars in their household and could thus be range conscious. According to consumer adoption theory, the affluent adopters show risk-tolerant characteristics representative of "innovators" and "early adopters." While the demanding buyers with their high expectations exhibit characteristics more representative of the "early majority adopters."

The demanding BEV buyer type also showed the maximum scope for growth. We found that under favorable conditions, the BEV market could secure up to 2.4 percent of the U.S. national market.

Since the potential BEV buyers are a tough group to attract, various measures are needed on the part of automakers and government entities, such as: providing BEVs with better handling in inclement weather, offering a better resale value proposition, extending electric drive range or offering loan programs that allow BEV buyers to borrow non-BEVs for long distance trips, better styling, offering flexible leasing terms and building more charging infrastructure where potential buyers live and/or work.

However, adding the above features and initiatives could increase the product/technology development and manufacturing costs associated with BEVs. If the costs get passed on to the consumers in the form of higher purchase price, it would have a negative effect on adoption. Thus, in the short term, it is important to keep the purchase price of BEVs competitive, wherein a decrease in battery costs and continuation of current federal tax credits and state incentive programs would both help.

To bring down battery costs, economies of scale are needed. However, it’s unclear if the potential BEV market share of 2.4 percent in the U.S., the second-largest automotive market in the world, would be enough to yield economies of scale given the different cell chemistries and configuration used by different battery suppliers.

Eventually, battery costs would have to fall even further to make-up for the inevitable termination of rebate and incentive programs as well as the cost of adding the suggested features.

BEV adoption also faces stiff competition from fuel-efficient gasoline vehicles, which currently is the preference of the majority of potential BEV buyers. Thus, policies promoting sales of these fuel-efficient gasoline vehicles, such as the federal Corporate Average Fuel Economy (CAFE) standards, may reduce the growth of BEV adoption. However, CAFE and ZEV are not necessarily mutually exclusive because BEV sales count favorably toward CAFE standards.

There is also a need to consider competition from other alternative fuel vehicles (AFVs) when promoting BEV adoption. Although total AFV market share can increase, our results show that promotion of BEVs could reduce hybrid and plug-in hybrid sales.

Introduction

Light duty vehicles (LDVs) in the United States account for about 42 percent of liquid fuel consumption and 17 percent of total U.S. energy related CO_2 emissions (EIA 2015). Although fully electric battery electric vehicles (BEVs) comprised only ∼0.38 percent of total new LDV sales in 2014 (Lutsey 2015), if adopted at a large scale, they could substantially reduce U.S. liquid fuel consumption and GHG emissions (Greene, Park, and Liu 2014, Chapin et al. 2013). Ten U.S. states, including California, representing 28 percent of total U.S. LDV sales (NRC 2015), have set a target of 3.3 million cumulative sales of zero-emission vehicles (ZEVs) by 2025. The target, known as the ZEV Mandate, could entail major techno-economic and policy spillovers for the rest of the U.S. and the world (Sperling and Eggert 2014) and could have an important impact on global liquid fuel consumption and carbon emissions. Among the different ZEVs considered, this paper focuses on BEV adoption, the most widely adopted pure zero tailpipe emission technology to date in the U.S.

For ZEV adoption to be successful, stakeholders need a better understanding of consumers: namely their preferences, attitudes and decision-making (Greene, Park, and Liu 2014, Chapin et al. 2013, Collantes 2010, NRC 2015). Historically, LDV adoption initiatives that did not address consumer needs proved to be unsustainable. In New Zealand during the 1980s, there was a push by the government to promote compressed natural gas vehicle (NGV) adoption. Incentive programs were able to achieve over 10 percent market share. Once policies were phased out, consumers stopped purchasing NGVs because they still preferred gasoline powered vehicles (Yeh 2007).

Literature tells us that as a new technology enters a market, different segments of buyers will adopt in phases; not all buyers switch at the same time (Rogers 2010). From a marketing perspective, a strategy to promote the adoption of new technology ought to target the segments of consumers who will be more inclined to use the new technology (Slater and Mohr 2006). Policies and targets promoting BEVs that do not take into account the relative size of potential likely buyers in the market and their needs and preferences risk being unsuccessful or unsustainable. Thus, there is a need to study potential buyers, along with current and mass-market buyers. Additionally, we must understand how BEVs and other alternative fuel vehicles (AFVs), such as hybrid electric vehicles (HEVs), compete for this crucial segment of the market.

Methods for Analyzing BEV Adoption

Studying potential buyers of BEVs can be done through a stated preference survey wherein consumers are asked about their interest in purchasing a BEV in the future. For example, stated preference surveys have been used to study adoption barriers for EVs among potential buyers (Egbue and Long 2012), lifestyle and preference heterogeneity among potential buyers (Axsen, Bailey, and Castro 2015), and what attributes of EVs car-buyers valued (Caulfield, Farrell, and McMahon 2010, Axsen and Kurani 2013). They have also been used to estimate consumer interest and willingness to pay (Carley et al. 2013, Hidrue et al. 2011, Potoglou and Kanaroglou 2007, Kihm and Trommer 2014).

However, in stated preference experiments, consumers might misrepresent their choices, as they tend to react differently to hypothetical choice experiments than they would facing the same alternatives in a real market (Brownstone, Bunch, and Train 2000). People may (consciously or unconsciously) overstate their intention to make purchases that are perceived to be in favor of the environment (Brownstone, Bunch, and Train 2000). Thus, results based on stated preference may be biased and overestimate the desirability of BEVs.

Instead of studying who wants to buy a BEV, some research analyze who could buy a BEV based on their travel needs relative to the range, size and performance of BEVs that are available (Lopes, Moura, and Martinez 2014, Tamor and Milačić 2015). This technique, known as the rule-based approach, defines the market of feasible BEV buyers and points to a likely upper bound of market opportunity given a set of vehicle attributes. But it does not explain why consumers who could have feasibly bought a BEV decided not to, i.e., what needs and preferences these buyers have that could not be met by current BEVs on the market.Revealed preference surveys of current BEV adopters capture needs and preferences without the biases associated with stated preference studies. For example, revealed preference surveys have been used to assess the motivations of actual AFV buyers (Ozaki and Sevastyanova 2011, Tal et al. 2013). Understanding people who have already purchased a BEV can provide useful context, but does not directly address nor identify potential adopters.

Because of the limitations of stated preference surveys and rule-based methods, we developed a novel data mining approach, "*ex-post* counterfactual inference," that can identify potential buyers using revealed preference data. This is the first time this method has been used in any field and has broad applications for the analysis of revealed preference survey data and technology adoption. We apply the approach to a nationally representative large-scale survey of 88,404 new car buyers that include respondents' geographic, demographic and psychographic characteristics (for a description of the data, see appendix A1). Among studies based on revealed preference survey data, this is the first nationally representative study of potential BEV buyers in the U.S. market. We seek to answer four main questions:

1. Who buys BEVs and for what reasons?
2. Who might buy BEVs and how many of them are in the market?
3. What factors can induce them to buy?
4. To what extent are BEVs competing with other AFVs and fuel-efficient gasoline vehicles for market share?

In order to address question 1, we segmented the current set of BEV buyers into different groups and looked at the factors that separate the different types of BEV buyers. In other words, we tried to identify what distinct characteristics and motivations define the different types of current BEV buyers.

In order to answer questions 2 and 3, we used ex-post counterfactual inference, the approach developed for this paper. Briefly speaking, we identified the current non-BEV buyers who “statistically resemble” the different types of current BEV buyers. Once identified, we looked at what aspects separate these potential buyers from the current buyers in order to infer the factors that would induce these potential buyers to adopt BEVs.

Finally, we address question 4 by looking at what these potential BEV buyers currently bought and estimate cannibalization that would happen when these potential BEV buyers would actually switch to BEVs. A schematic description of the approach for: (a) identifying different types of BEV buyers and (b) identifying potential BEV buyers, is shown in Figure 1.

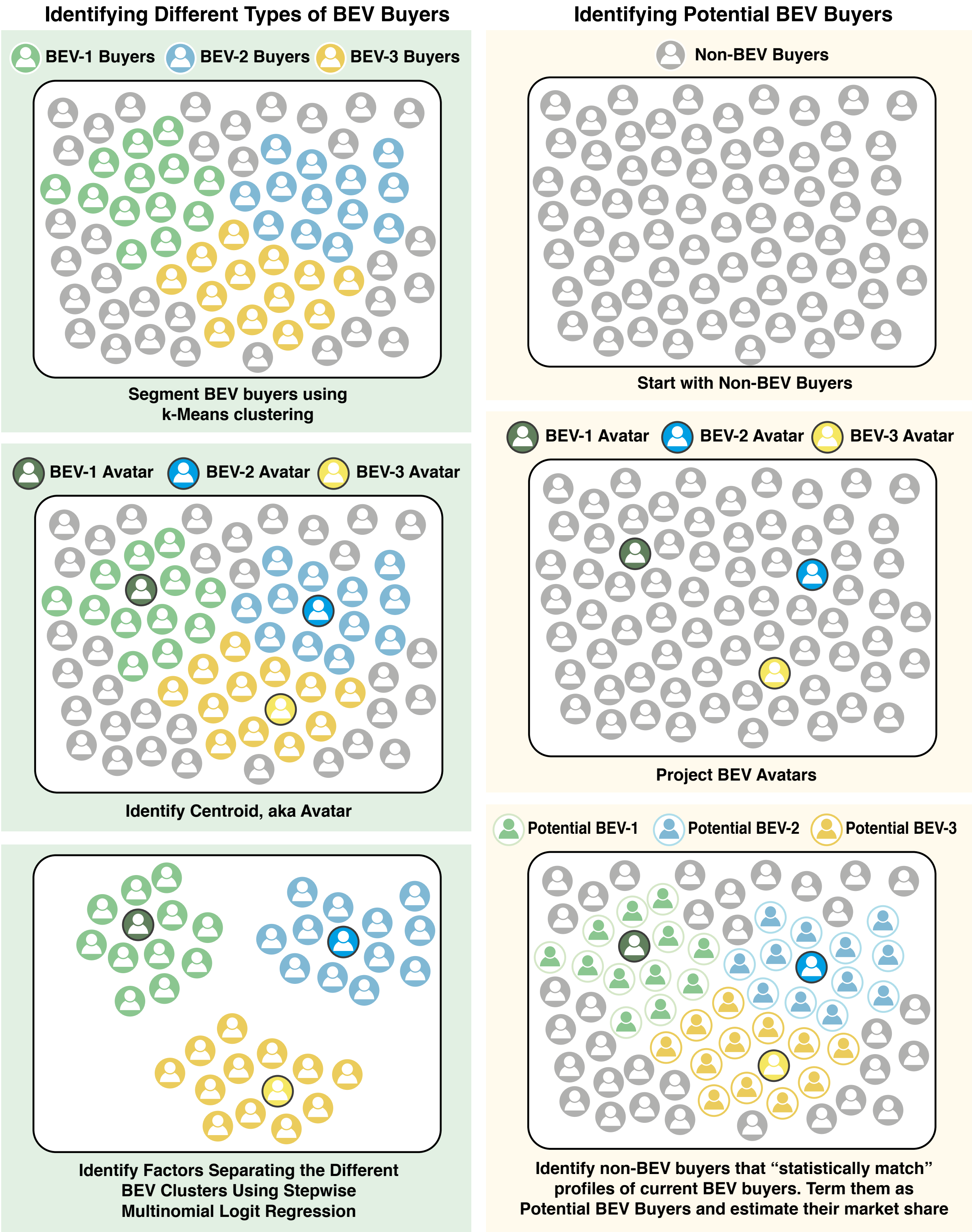

Figure 1. Schematic diagram for (a) identifying different types of BEV buyers, (b) identifying potential BEV buyers. Please see appendix A.2 for more details on the methodology.

Source: KAPSARC analysis.

Study of Current Adopters

In order to understand the main characteristics of current BEV buyers, we took a statistical comparison of BEV buyers in the survey to non-BEV buyers. A typical BEV buyer is a tech savvy, green enthusiast, who prefers to lease BEV as a second vehicle for their household, which alleviates range and resale anxiety. On the other hand, a typical non-BEV buyer prefers an aesthetically pleasing vehicle with proven powertrain technology, robust resale value, strong towing capability and reliable handling ability in inclement weather. Table 1 highlights some of the major differences between BEV and non-BEV buyers. For a detailed description of the results, please see Figure A4 and A5 in the appendix.

To account for heterogeneity among BEV buyers (Axsen, Bailey, and Castro 2015) we segmented current BEV buyers into three distinct profiles using k-means clustering, as shown in Figure 1(a) (please see appendix A.2.1 for more details on consumer segmentation). Figure 2 highlights the major differences and similarities between the three BEV segments vis-à-vis their respective reasons for purchase, demographics and geographical characteristics (please see Figure A6 and A7 in the appendix for detailed results).

Although all three BEV segments care strongly about environmental friendliness, technical innovation and fuel economy, there were the following differences among them. BEV-1 cares mainly about owning/operating costs; BEV-2 has a higher average income and cares mainly about performance and styling; and BEV-3 values style and performance while caring strongly about costs. BEV-3 also has a lower income than the average BEV buyer and owns fewer cars, thus having fewer alternatives to a BEV for long-range trips. Thus, BEV-3 type buyers are the most demanding of the consumer segments we identified.

Table 1. Summary of factors separating BEV and non-BEV buyers. The table explains what BEV and non-BEV buyers care more about relative to one another and how their preferences could have influenced their respective purchase.

BEV Buyers care more about	Non-BEV Buyers care more about
Leasing Terms: Leasing instead of buying lowers the risk associated with uncertain resale value, battery decay and rapid technology improvements (NRC 2015, Lim, Mak, and Rong 2014, Sheetz 2015), thus BEV buyers generally prefer to lease the vehicle (Sheetz 2015).	**Exterior Styling**: Due to lack of good exterior styling in BEV models (other than the Tesla Model S), consumers who care more about exterior styling tend to choose non-BEVs.
Technical Innovation: Since BEVs represent the most technically innovative fuel type currently available, consumers who care more about technical innovation tend to buy BEVs. Affinity for new technology is a typical trait of innovators and early adopters (Greene, Park, and Liu 2014, Axsen, Bailey, and Castro 2015, NRC 2015).	**Previous Experience with Manufacturing Brand**: Non-BEV buyers are risk averse and more loyal in nature, which is manifested in their preference for a familiar brand.
Environmental Friendliness: BEVs are viewed as one of the most environmentally friendly vehicles available. Consumers who care a lot about the environment tend to buy BEVs. This result is in-line with others' findings that BEV buyers are green enthusiasts (Axsen, Bailey, and Castro 2015).	**Expected Resale Value**: Because of the uncertainty of resale values for BEVs and battery decay rate, consumers who care a lot about expected resale value tend to buy non-BEVs (Lim, Mak, and Rong 2014).
Expected Costs of Operations/Repair: Operations and repair costs for BEVs are typically lower as compared to internal combustion engine vehicles (ICEVs) (Raustad and Fairey 2014), which explains the choice of BEVs by those who care more about costs of operations and repair.	**Towing Capability**: Due to the lack of towing capability in MY 2013 BEV models, consumers who care about towing tend to buy non-BEVs.
Other Cars in Household: BEV buyers own more cars in their household. Having a non-BEV present for occasional long trips could alleviate range anxiety concerns (Tamor and Milačić 2015). Thus, range anxiety may not act as a barrier to adoption for consumers that have other cars in their household.	**Handling ability in Inclement Weather**: BEVs lack all-wheel drive capability (other than the Tesla Model S), thus consumers who value handling ability in inclement weather tend to gravitate toward non-BEVs.
Winter Severity: BEV range can drop significantly on a cold weather day as stored electrical energy is used for heating the vehicle interior (NRC 2015, Vergis and Chen 2015). Thus, consumers are less likely to purchase a BEV in climates with severe winters.	

Results are obtained by applying a Kolmogorov–Smirnov equality-of-distributions test followed by a stepwise binary logit regression assuming BEV buyers as one group and all the non-BEV buyers as the other group.

Source: KAPSARC analysis.

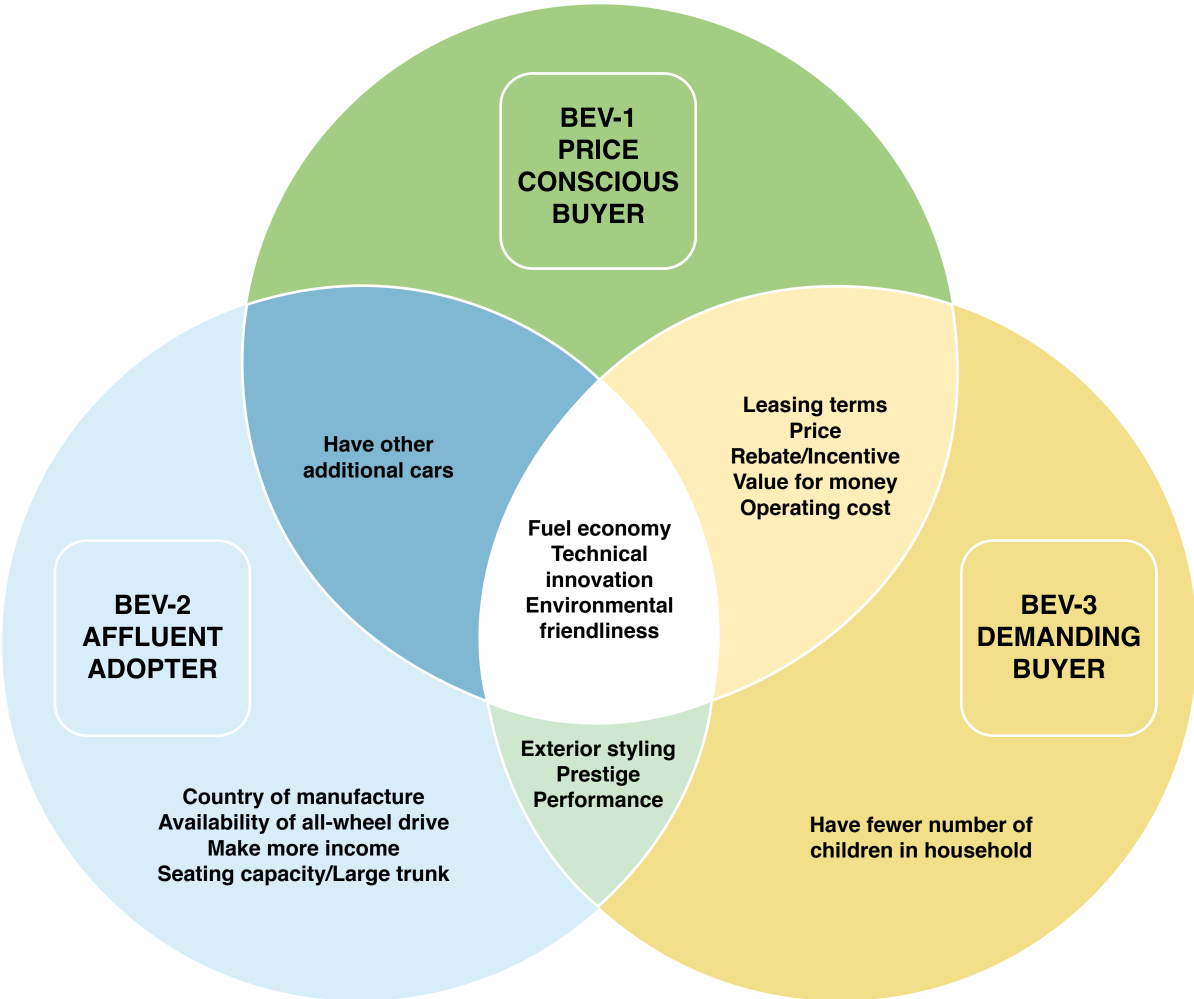

Figure 2. A Venn diagram describing the different types of BEV buyers, highlighting the similarities and differences between them. For a detailed description of factors separating the three types of BEV buyers, please see Table A2 in the appendix.

Source: KAPSARC analysis.

To see which consumer profiles purchased which type of BEV, the vehicle models breakup by the three BEV buyer segments is presented in Figure 3. The un-scaled BEV model breakup and the model breakup scaled to the U.S. national market are shown in Figure 3a and 3b, respectively.

As can be seen in Figure 3a, the BEV-1 segment is composed primarily of Nissan Leaf buyers. The BEV-2 segment is mainly dominated by Tesla Model S buyers followed by Nissan Leaf buyers.

Thus, there are some Nissan Leaf buyers who do not care much about price, leasing terms and incentives, contrary to the characteristics of BEV-1 and BEV-3 Nissan Leaf buyers. With regards to consumer adoption theory, the BEV-2 Nissan Leaf buyers are much more representative of “innovators” and “early adopters” because of their high risk tolerance, as indicated by the fact that they assign very low importance to leasing terms as compared to BEV-1 and BEV-3 buyers.

The BEV-3 segment is also composed mainly of Nissan Leaf buyers. However, as pointed out in Table A2, the BEV-3 buyers have greater expectations from their vehicle as compared to BEV-1 buyers and their expectations are much more aligned with an "early majority" type BEV buyer's expectations.

It is also important to note that the Tesla-Leaf segmentation between BEV-1 and BEV-2 and between BEV-2 and BEV-3 is identified purely through consumers' purchase reasons, demographics and geographical characteristics without providing any BEV model level details.

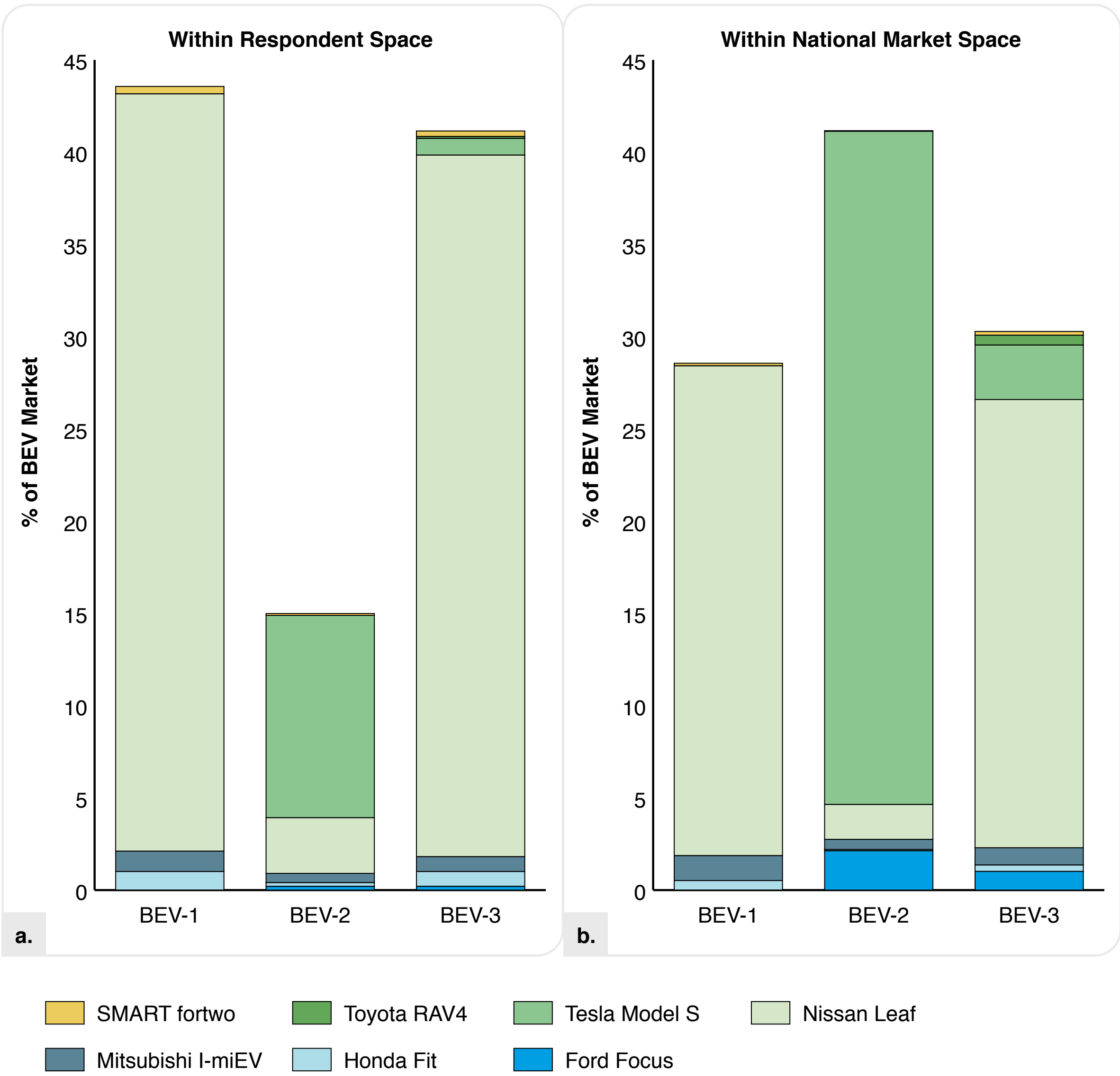

Figure 3. BEV model breakup for the three BEV buyer types within (a) respondent space, (b) U.S. national market.

Source: KAPSARC analysis.

Potential Buyers: Size of Market and Barriers to Adoption

Using a novel data mining approach, ex-post counterfactual inference, we identified non-BEV buyers that "statistically resemble" profiles of current BEV buyers (please see section A.2.2 in the appendix for more details on the methodology). We ran two scenarios: (i) where we assumed a pragmatic growth opportunity for BEVs and other fuel types; and (ii) where we assumed an optimistic growth opportunity for BEVs and pragmatic growth opportunity for other fuel types. The conditions that define pragmatic and optimistic growth opportunities are described in detail in appendix section A.2.2. The potential market shares for each BEV adopter profile in the two scenarios are shown in Figure 4.

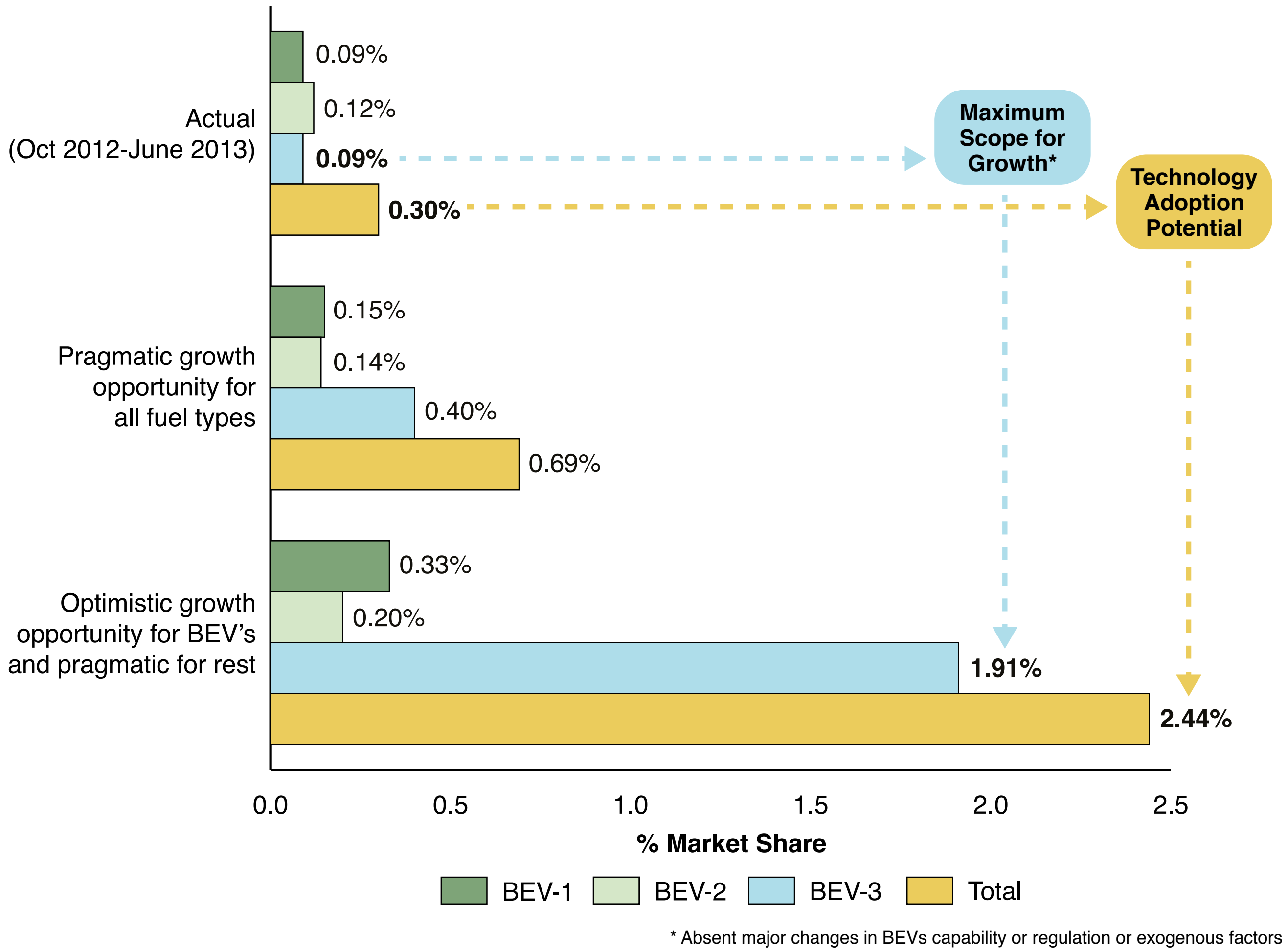

Figure 4. Potential BEV market share for two different scenarios: (i) pragmatic growth opportunity for all fuel types, (ii) optimistic growth opportunity for BEVs and pragmatic growth opportunity for the other fuel types.

Source: KAPSARC analysis.

In our optimistic scenario, the BEV market has the potential to grow up to an equilibrium market share of 2.44 percent, provided appropriate measures are taken. The maximum scope for growth exists in the BEV-3 segment, which, as demonstrated in the earlier sections, is the most demanding BEV buyer type. To put things in perspective, the BEV market share within the U.S. over the last three years is provided in Table A3. The estimated market share in California for both scenarios along with the likely compliance targets as per the ZEV mandate are presented in Figure A8.

To identify factors that can induce potential BEV buyers to adopt BEVs and increase market share from 0.3 percent (in October 2012-June 2013) to the equilibrium level of 2.44 percent, we compare actual BEV buyers to potential BEV buyers. Comparing the traits of potential BEV buyers with actual BEV buyers helps in identifying further actions that need to be taken by the private and public sector entities to nudge potential BEV buyers into becoming actual BEV buyers. For discussion purposes, we focus our attention on BEV-3 buyers, because they have the maximum scope for growth. Figure 5 and Table A4 summarize the differences between potential and actual BEV-3 buyers in addition to actions that can be taken by private and public sector to facilitate adoption.

It is important to note that potential BEV-3 buyers are even more demanding, caring more about added features such as exterior styling and all-wheel-drive (AWD) while simultaneously being more cost-conscious. This may be because potential BEV-3 buyers own even fewer additional cars on average, and thus their vehicle must satisfy a wider range of needs. Having fewer alternatives for long-distance travel also indicates that potential BEV-3 buyers will require BEVs to have longer driving range than current buyers do. The detailed results comparing each of the potential BEV buyer segment with its respective actual BEV buyer segment are provided in the appendix (Figures A9 through A11).

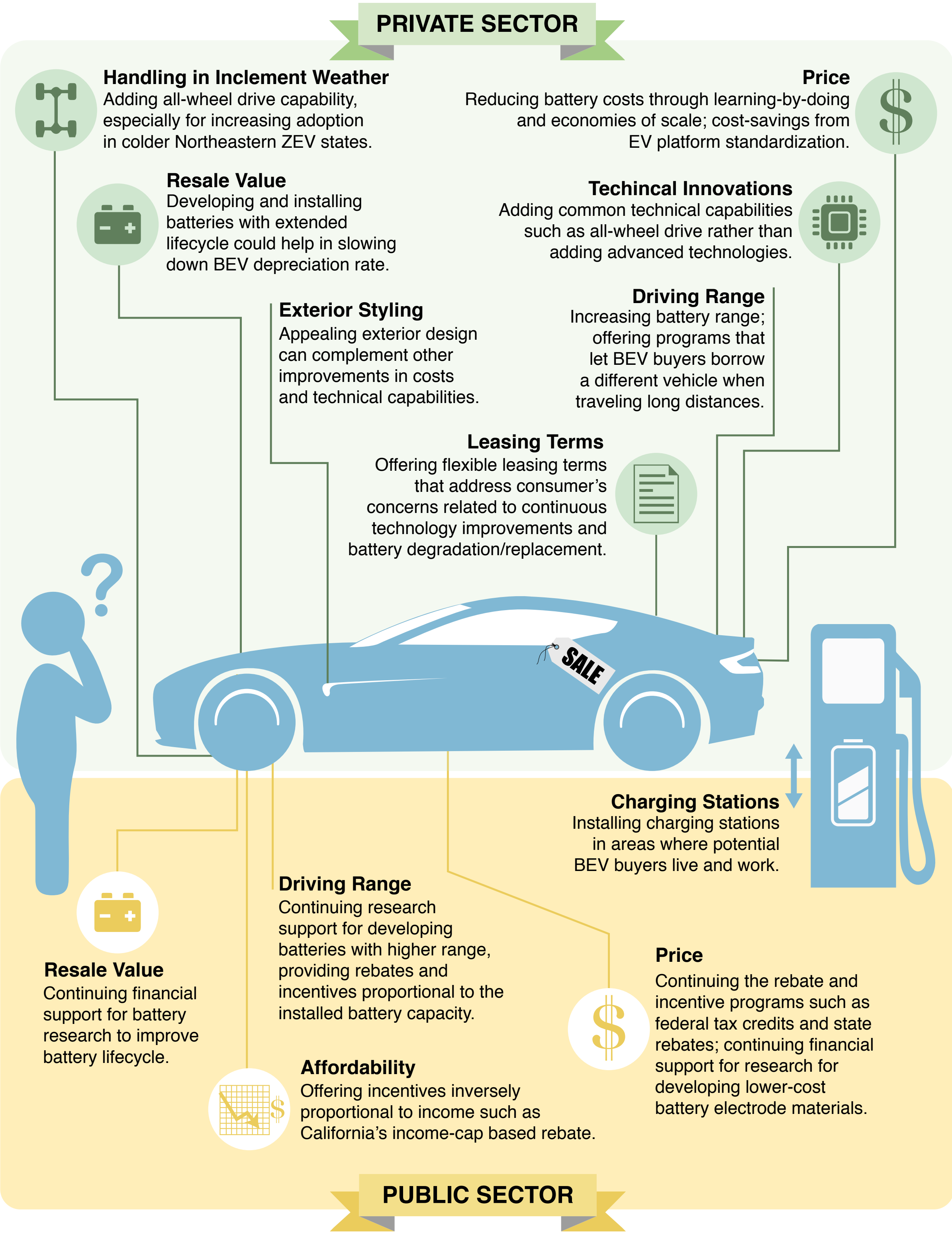

Figure 5. Factors that can induce potential BEV-3 buyers to adopt BEVs, obtained by comparing potential BEV-3 buyers with actual BEV-3 buyers. For more details, please see Table A4 in the appendix.

Source: KAPSARC analysis.

Time-frame and Exogenous Factors

Our approach predicts an equilibrium market share, i.e., the market share that would eventually be reached provided the suggested set of measures are taken. For a particular senario, it is an equilibrium (saturation level) estimate in the sense that in order to achieve market share above the predicted level, factors exogenous to our current model would have to be favorably altered. The model predictions are in line with a scenario analysis, not a forecast. The timeframe within which the predicted levels of market share is achieved depends upon the enactment of suggested measures.

We identify two primary exogenous factors that could affect the size of the potential market for BEVs: vehicle choice and retail gasoline prices. Expanding the vehicle choice available to buyers by introducing BEV models significantly different from the models available on sale during the survey period (October 2012-June 2013) would be expected to increase the size of the potential market. For example, the introduction of a BEV minivan or pickup truck could lead to the creation of an additional BEV buyer profile that is distinct from the profiles identified in this study. Most of the economical BEVs planned or announced in the near future such as the Chevy Bolt or Tesla Model 3 have features that would be in line with the preferences of potential BEV-3 buyers, such as higher electric driving range, better exterior styling, availability of all-wheel drive and affordable pricing. Whether or not upcoming BEV SUV/CUV (cross over utility vehicle) models such as the Tesla Model X will appeal to significantly different buyers or whether they will appeal to the same buyers of luxury BEV sedans, such as the Tesla Model S, remains to be seen.

The gasoline price, exogenous to our model, has dropped significantly since the considered timeframe (October 2012-June 2013). Low gasoline prices have already led to a boom in sport utility vehicle (SUV) sales and a drop in sales of fuel efficient vehicles including BEVs (Shepardson and Lienert 2015). Thus, with current low gasoline prices, the optimistic scenario in our study seems even more so.

Intra-AFV Competition for Market Share

BEV adoption does not occur in a vacuum but in the context of various competing fuel technologies, many of them directly or indirectly encouraged by government policies. The federal CAFE program in the U.S., which mandates improving fuel economy of LDVs over time, encourages the development and sale of fuel efficient vehicles including internal combustion and electric vehicles. Thus, BEV adoption policies must take into account how different fuel types compete over market share. To the extent that AFV types and fuel-efficient gasoline vehicles compete with one another over similar consumers, simultaneously fulfilling mandates such as CAFE and ZEV can be difficult. In this section, we look directly at cannibalization (i.e., competition for market share) of different fuel-type technologies through our data mining analysis.

The results from the potential buyer analysis can be extended to other fuel types to show the extent to which BEVs, HEVs, plug-in hybrid electric vehicles (PHEVs) and fuel-efficient gasoline vehicles compete with each other for similar consumers. As discussed in Appendix A.2.2, identifying potential BEV adopters entailed simultaneously identifying potential adopters for all fuel types represented in our survey. The fuel type that potential buyers actually purchased can be used to estimate cannibalization rates between fuel types, i.e., what percentage of a particular fuel-type's sales growth came at the expense of another fuel type. For example, if a large portion of potential BEV buyers have currently purchased a HEV, we can infer that growth in BEV sales will cannibalize HEV sales. Figure 6 shows the results of this analysis under an optimistic growth scenario for BEVs and pragmatic growth for all other fuel types.

In a scenario where BEV market share increases to 2.44 percent, total AFV market share (HEV + PHEV + BEV) will increase from 4 percent to 5.64 percent (see Figure 6 top). However, HEV and PHEV market share will decrease from current levels. This reduction can partly be attributed to cannibalization from BEV sales. Among potential BEV buyers, 6.29 percent and 3.26 percent of them purchased a HEV or PHEV, respectively (see Figure 6 bottom left), resulting in a cannibalization rate of 3.87 percent and 25.8 percent, respectively (see Figure 6 bottom right). Current BEV buyers in the survey often stated that they considered purchasing a HEV (e.g., Toyota Prius) or a PHEV (e.g., Chevy Volt) in lieu of a BEV (see Appendix Table A5). Often, these buyers would also already own a HEV (e.g., Toyota Prius) in their household (see Appendix Table A6). These facts suggest that many current BEV buyers were previous hybrid buyers and decided that in lieu of buying another hybrid (or PHEV), opted for a BEV.

As strong as intra-AFV competition is, the highest level of competition for market share comes from gasoline vehicles. Gasoline buyers constitute the biggest source of sales growth for all AFV types (see Figure A12(b) in the appendix). In addition, current AFV buyers switching to gasoline vehicles result in double-digit sales cannibalization for all non-gasoline fuel types (see Figure A12(c)). Plus, potential AFV buyers predominantly purchased fuel-efficient gasoline vehicles, such as the Honda Civic (see Table 2). Growth in AFV market share, whether it came from BEVs or otherwise, would come at the expense of fuel-efficient gasoline vehicles.

Alternatively, improvements in fuel-efficient gasoline vehicles would mitigate gains for AFVs. Not only are all three AFV types competing against fuel-efficient gasoline vehicles, but they are competing against similar models of fuel-efficient gasoline vehicles (see Table 2). For example, the Nissan Altima and the Honda Civic were commonly owned by all three types of potential AFV buyers. As HEVs, PHEVs and BEVs are also competing directly for market share with fuel-efficient gasoline vehicles, they are also competing indirectly with each other as well. A buyer that switches from a fuel efficient gasoline vehicle to a BEV is one that did not switch to a PHEV.

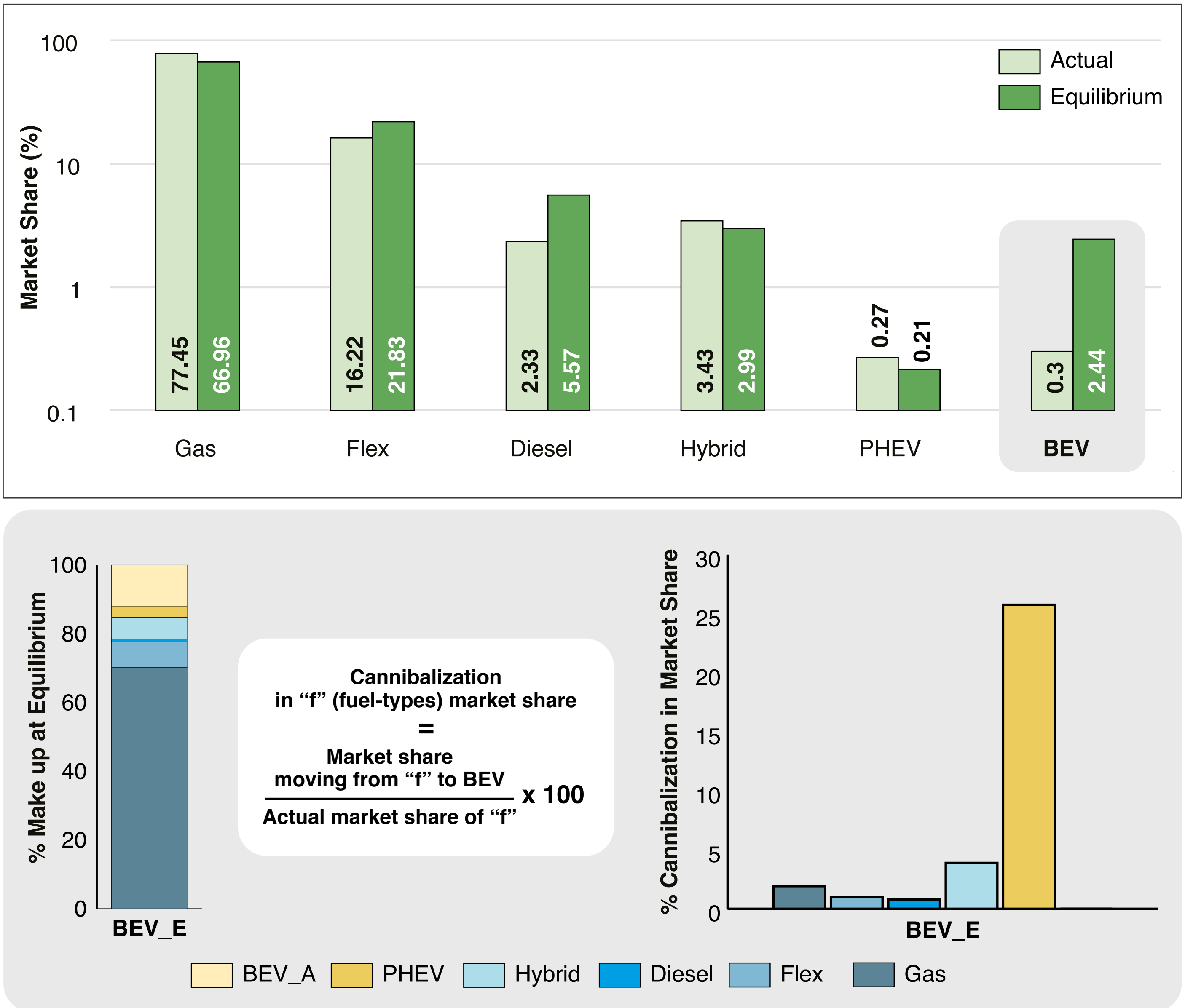

Figure 6. (Top) Actual and equilibrium market share for different fuel types for the scenario assuming optimistic growth for BEVs and pragmatic growth for rest, (bottom-left) percent makeup at equilibrium for BEV and (bottom-right) percent cannibalization for each fuel type due to out flux of market share from the respective fuel type to BEV.

Source: KAPSARC analysis.

Table 2. Top 10 models actually purchased by potential alternative fuel type buyers.

Potential Hybrid	Potential PHEV	Potential BEV
Volkswagen Passat	Nissan Leaf	Honda Civic Sedan
Honda Accord Sedan	Ford C-MAX	Volkswagen Jetta (Sedan)
Honda Civic Sedan	Nissan Altima Sedan	Nissan Altima Sedan
Nissan Altima Sedan	Acura RDX	Volkswagen Passat
Honda CR-V	Dodge Dart	Honda Accord Sedan
Volkswagen Jetta Sedan	Fiat 500	BMW 3 Series Sedan
Volkswagen Golf	Ford Fiesta Sedan	Nissan Sentra
Volkswagen Jetta (Wagon)	Ford Fusion	Chevrolet Volt
Volkswagen New Beetle	Honda Civic Sedan	Honda CR-V

Source: KAPSARC analysis.

Policy Implications

Under favorable conditions, the BEV market has potential to reach an annual U.S. market share of 2.44 percent. The key to achieving this level of growth is to target the relatively demanding potential BEV-3 buyers. To appeal to these buyers, BEVs will need to include more features such as better exterior styling, longer driving range and AWD for handling in inclement weather. Potential BEV-3 buyers also care more about price and resale value than current buyers. In short, to achieve the market share predicted in the analysis, BEVs offering more features in a greater range of platforms/vehicle types must be sold at lower prices.

The current financial support, in the form of public subsidies and incentives, for promoting BEV adoption is expected to be phased out as battery costs come down. However, it is important to take into account that declining battery costs will also be offset by the added costs of including better features needed to attract more buyers. Moreover, whether a 2.44 percent BEV market share in the U.S. (second largest automotive market in the world) would be sufficient to generate economies of scale to achieve significant battery cost reductions, remains to be seen. The fact that different battery suppliers produce batteries with different cell chemistries, configurations and sizes (Menahem 2014), makes it further difficult to achieve economies of scale. Moreover, recent research suggests that economies of scale in battery manufacturing are reached quickly, at a production volume of ~200–300 MWh annually and increased volume does little to reduce unit costs (Sakti et al. 2015). To put things in perspective, the approximate sales of both the Chevy Volt and the Nissan Leaf through 2013 were about 23,000 vehicles each (Shahan 2014) or a total of about 900 MWh.

Thus, in the short term, publically funded rebate and incentive programs would have to be maintained to support BEV adoption to keep retail prices competitive without further burdening consumers and automotive manufacturers. And in the long term, battery costs would have to come down enough to not only offset the cost of adding the above features and capabilities, but also to account for the effect of removing state and federal rebate and incentive subsidies, if and when that happens. Current subsidies in a state like California amount to roughly $10,000 ($7,500 federal tax credit and $2,500 state rebate) for a typical BEV such as the Nissan Leaf. Removing these incentives can have a significant effect on BEV sales as was recently seen in Georgia. The recent termination of Georgia's state tax credit of $5,000 was followed by a more than 80 percent drop in BEV sales between June, the last month the credit was in effect, to August (Gould 2015).

There is also a need to consider intra-AFV competition when promoting adoption. Although total AFV market share can increase, promotion of BEVs can cannibalize HEVs and PHEVs. Not only do AFV buyers significantly overlap, they also compete over a similar segment of fuel-efficient gasoline vehicle buyers. Thus, policies promoting development and sale of fuel-efficient gasoline vehicles, such as the Federal CAFE standards, may reduce the growth of BEV adoption. However, CAFE and ZEV are not necessarily mutually exclusive because BEV sales count favorably toward CAFE standards because of their high fuel efficiency and low emissions (EPA/NHTSA 2012).

Conclusion

In summary, we have demonstrated a novel data mining approach for promoting consumer adoption of energy-efficient technologies. The approach, "ex-post counterfactual inference," can identify potential adopters of novel energy-efficient technologies using revealed preference data. It is centered on identifying the next set of potential adopters that "statistically resemble" current adopters. A proof-of-concept study involving the application of the developed approach for understanding BEV adoption in the U.S. has also been demonstrated. This is the first time such a method has been used in any field and has applications in other consumer-centric energy challenges such as adoption of residential solar, energy-efficient appliances such as HVAC systems, refrigerators, cloth dryers, lighting, water heaters, and smart meters.

As next steps, we are currently analyzing the hybrid market in the U.S. using the last 10 years of consumer profile data. We are also planning to do a follow-up survey study with the identified potential hybrid buyers, guaging their interest in hybrids. The follow-up survey study would serve twin purposes. It will help us calibrate our potential market share estimate for hybrids. It will also help us identify what factors are preventing these potential hybrid buyers that have high statistical resemblance with current hybrid buyers, from purchasing a hybrid. Thus, the follow-up survey study would help in identifying the barriers to adoption.

We are also planning to launch a nationally representative survey of new car buyers in Saudi Arabia. The aim of this study would be to understand the current buyers of fuel-efficient vehicles in Saudi and identify and estimate the size of potential market. The study will also focus on identifying factors that could induce the identified potential buyers to switch to buying more fuel-efficient vehicles.

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Appendix

A.1 Data

This study relies on data from a large-scale, nationally representative revealed preference survey of new car buyers. The size and scale of the survey allows for a rich, nationally representative analysis of current and potential adopters of BEVs. The dataset used is a subset of the 2013 New Vehicle Experience Survey (NVES) conducted by Strategic Vision Inc. (SV). The survey was sent out to car buyers who purchased a new vehicle from October 2012 - June 2013. There were 162,701 respondents who completed at least part of the survey, but for this analysis 88,404 entries were used based on respondents who answered all the questions used in this analysis.

Our study primarily utilizes two sets of elements from the NVES data; (i) consumers' reasons for purchase; (ii) their demographic characteristics. Along with the above two sets of variables, another set of variables related to geographical conditions corresponding to the state where the vehicle was purchased is also considered. A descriptive list of all the variables used in this analysis is provided in Table A1. The NVES data also provides weights that correspond to the ratio of the number of buyers for each make and model in the national market to the number of respondents for the same make and model in the survey. Additionally, respondents in the survey are asked to state which car model they most seriously considered (but did not purchase) and to list the other vehicles owned by their household. These data were used specifically in the cannibalization section.

Table A1. List of variables used for the analysis.

Purchase Reason				Demographics	Geography
Quality of Workmanship	Interior Versatility	Reliability	Large Trunk/ Cargo Space	Total Number of Children	Charging Station Density
Availability of RWD	Leasing Terms	Expected Resale Value	Manufacturers Reputation	Total Other Vehicles Owned/ Leased	Winter Severity
Availability of 4WD	Overall Seating Capacity	Previous Experience with Brand	Fun to Drive	Income	
Handling in Inclement Weather	Exterior Styling	Car Reviews	Discount/Rebate Incentive	Age	
Towing Capability	Price/Monthly Payment	Prestige	Advertising Promotion		
Advice of Friends/ Relatives	Warranty/ Guarantee	Value for Money	Dealer Reputation		
Environmentally Friendly	Technical Innovations	Power Pickup	Safety Design Features		
Country of Manufacture	Interior Roominess	Engine Performance	Navigation System		
Ease of Customizing	Fuel Economy	Expected Costs of Operation/Repairs	Interior Options/ Accessories		
			Interior Storage		

Source: KAPSARC analysis.

The *purchase reason* set of variables represents respondents' responses to the survey questions related to reasons for buying a particular vehicle. In particular, the respondents are asked a series of questions related to their reasons for purchasing the vehicle they bought, which they have to rate on a scale of 1 to 5. As an example, the respondents are asked – on a scale of 1 to 5 – how important is fuel economy to your purchase decision and so on. The original Strategic Vision NVES 2013 questionnaire had 52 questions (and thus 52 variables) related to reasons for purchase. Among these 52, variables with a pairwise correlation of less than 0.6 were automatically selected for the analysis. Among groups of variables that have a pairwise correlation of more than 0.6, only one representative variable is selected.

The *demographic* set of variables corresponds to questions related to respondents' age, income and children and total other vehicles in their household. The reported age is transformed to a continuous scale to have a range from 1 to 5. The reported income is put on a logarithmic scale and then transformed to a continuous scale to have a range from 1 to 5. The geography variable charging station density is related to the electric vehicle charging infrastructure in the state where the vehicle was purchased. It is defined as the number of charging stations within the state divided by the state's urban area. In order to make it comparable to other variables, the above calculated charging station density is transformed using a logarithm function and then scaled to a range from 1 to 5. The information about number of electric charging stations within the state is obtained from the U.S. Department of Energy's alternative fuels and advanced vehicles website (AFDC). The data for state urban area is obtained from the U.S. Census Bureau website (Census.gov). The variable *winter severity* is calculated using the average winter temperature for the three winter months (December, January and February) obtained from NOAA National Centers for Environmental Information (NOAA) and is scaled to a range from 1 to 5, with the state having the lowest winter temperature having the value 5.

A.2 Methodology

The methodology involves two main steps: (i) segmentation of respondents into different fuel type subgroups; (ii) identification and estimation of non-members who *ex post* could be categorized into a specific fuel type subgroup-of-interest.

A.2.1 Consumer segmentation

The objective of the consumer segmentation analysis is to divide the consumers into different groups based on similarity of features. Consumers in the same group have a high degree of similarity to each other, and consumers in different groups have a high degree of dissimilarity. A flowchart describing the segmentation process is provided in Figure A1. Briefly, we first divide consumers based on the fuel type of the vehicle they purchased. Then we further segment the consumers within each fuel type using k-means clustering. For each fuel type, clusters of consumers with similar attributes (purchase reasons, demographics and geographical characteristics) are identified. The correlation distance metric, as shown in equations 1 and 2, is used for the k-Means clustering. The Calinski-Harabasz criterion is used to determine the optimum number of clusters for each fuel type. Once the clustering step is complete, variables separating the different fuel type clusters are identified using a stepwise multinomial logistic regression (MLR). The objective is to eliminate variables that do not have any explanatory power with regards to separating the different fuel type clusters.

The different fuel type clusters are considered as the dependent categorical variables, while the variables defined in Table A1 are considered as the set of independent variables for the stepwise-MLR. A backward elimination scheme is used for the stepwise regression. The stopping criterion for the stepwise-MLR is until all coefficients have p-values less than 0.05. Once the stopping criterion has been met, the clustering is repeated for each fuel type using the new, reduced set of variables. A subsequent stepwise-MLR is performed using a new set of fuel type clusters and this iterative (clustering)-(stepwise MLR) is performed until convergence. Convergence is achieved when no more variables are eliminated during stepwise-MLR between two consecutive iterations.

From the segmentation described, representative buyer profiles are created using the centroid (mean) for each respective cluster. Only the variables that have a non-zero coefficient in the converged clustering-stepwise MLR for the respective fuel type clusters are considered. This representative buyer is termed as an avatar for the rest of the discussion.

$$Distance = 1 - Correlation(x, y) \tag{1}$$

$$Correlation(x, y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{2}$$

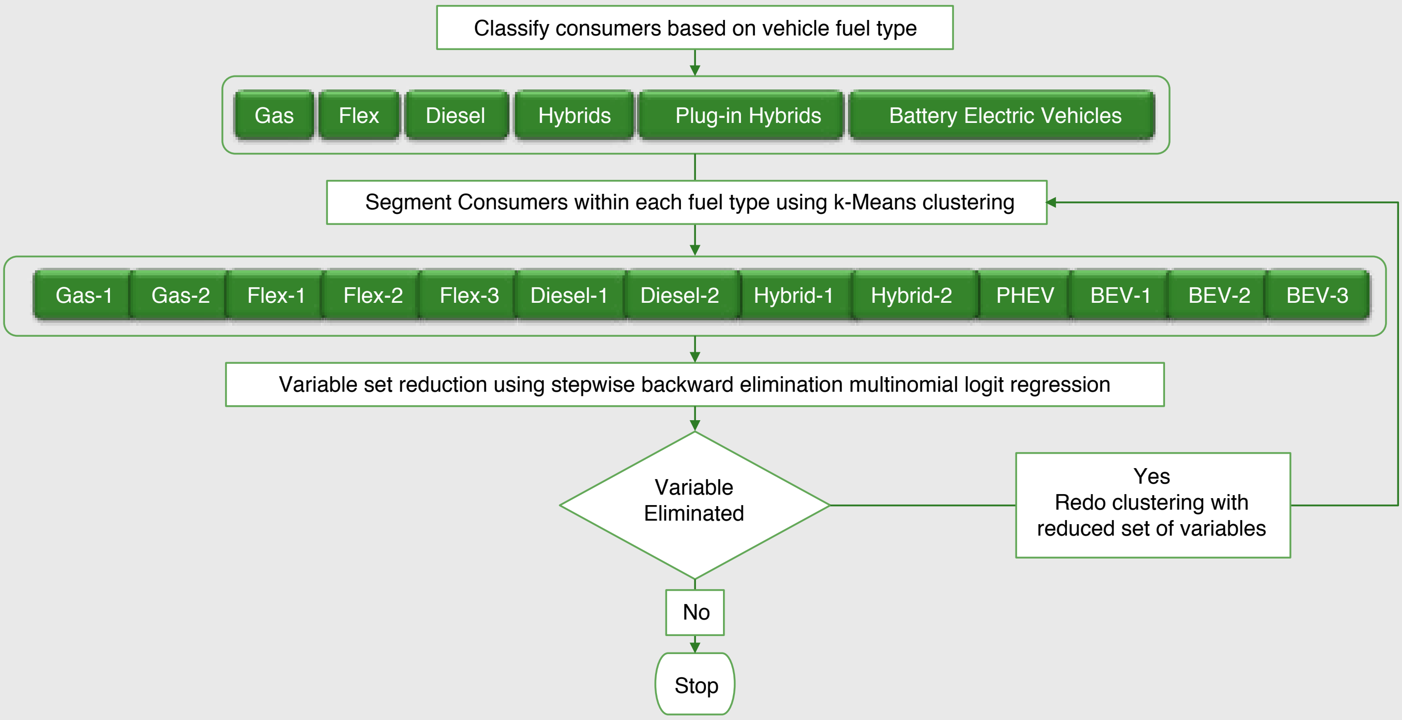

Figure A1. Flowchart for segmentation analysis.

Source: KAPSARC analysis.

A.2.2 Market Sizing - Identifying Potential Buyers

Conceptually, identifying potential buyers is equivalent to identifying non-members of a group who counterfactually could be categorized into said group based only on their observable characteristics. In other words, the idea is to identify buyers who currently have not bought the fuel type-of-interest, but still have characteristics that “statistically resemble” the avatars of the fuel type-of-interest buyer segments. The “statistical resemblance” is measured using a combination of clustering and categorical regression techniques and is described in detail below. Once the potential buyers for each fuel type cluster are identified, the corresponding market share can be calculated. A flowchart describing the potential market sizing process is provided in Figure A2 and all the steps are described in detail below.

Step 1: Defining a scenario

The first step in the potential market sizing estimation is to define a scenario. In our analysis, we defined two different scenarios, pragmatic and optimistic. The definitions of these scenarios are given in Step 2.

Step 2: Assigning buyer population to a training dataset and hold-out dataset

The entire population is separated into the training set and the hold-out dataset. Hold-out datasets are identified by fuel type cluster and then merged together to form a single hold-out dataset for the scenario. All the members that are not present within the hold-out dataset are assigned to the training dataset. A schematic diagram describing how the hold-out dataset is identified for a particular fuel type cluster is presented in Figure A3.

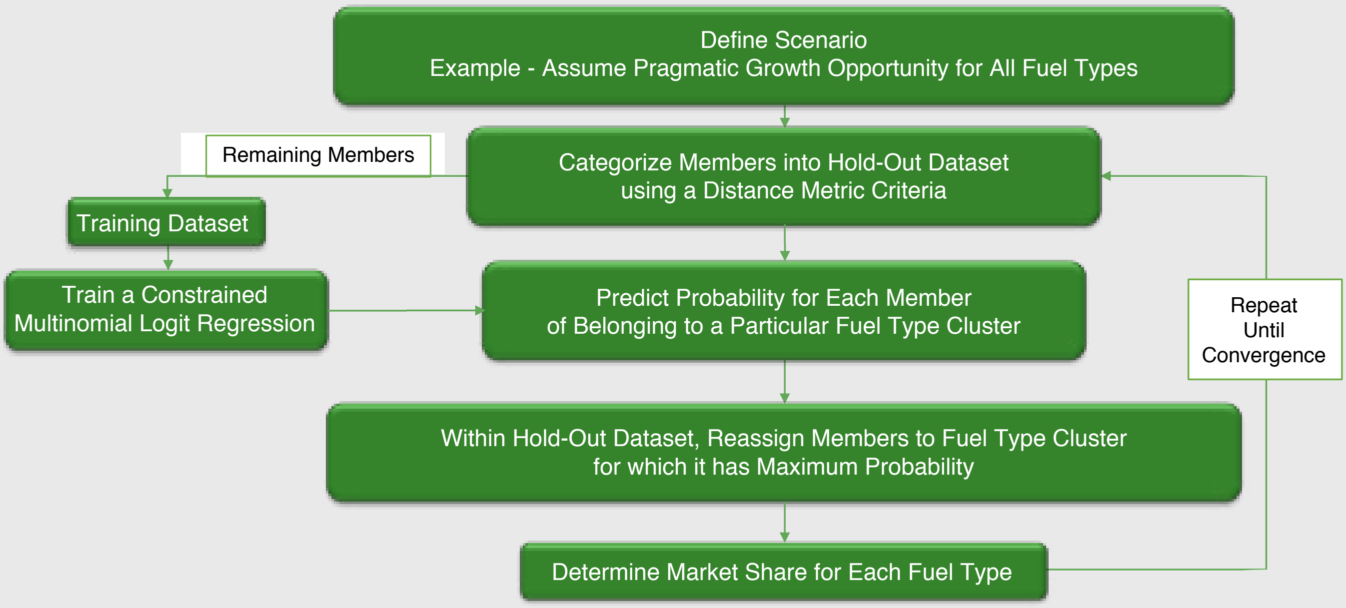

Figure A2. Flowchart for market sizing analysis.

Source: KAPSARC analysis.

Consider the process of identifying the holdout dataset for a BEV cluster, referred to as "BEV-1." First, the distance of each BEV-1 member and the BEV-1 centroid is measured. The distance metric is defined as *1-correlation(x, y)*, where the correlation is measured between the BEV-1 centroid's responses (x) and a BEV-1 member's responses (y). Let the distribution of distances between each BEV-1 member and the BEV-1 centroid be denoted by D_1. Then the distances within which 50 percent and 75 percent of the BEV-1 population lie are measured. The corresponding distances are used to define two different cases termed as pragmatic growth case and optimistic growth case respectively. Let the distances be denoted by r_{Prag_1}, r_{Opt_1} respectively. Let's for discussion purposes consider the pragmatic growth case for BEVs. For this case, all the non-BEV members who are closer to the BEV-1 centroid than any other centroid and have a distance from the BEV-1 centroid less than r_{Prag_1} are selected for the holdout dataset.

The above steps are repeated for each avatar (fuel type cluster centroid) to identify the hold-out dataset. In any case, the hold-out dataset for the analysis is the union of the hold-out datasets identified for each fuel type centroid. For the two sets of results presented in Figure 4 and Figure A8, we ran two scenarios. For the first scenario, we assumed pragmatic growth opportunity for all fuel types and for the second scenario, we assumed optimistic growth opportunity for BEVs and pragmatic growth opportunity for the remaining fuel types.

Step 3: Determining probability of each member of belonging to each fuel type cluster

For a particular scenario, once the members going into the hold-out dataset have been identified, all the remaining members are assigned to the training dataset. By design, the members in the training dataset will be "closest" to their respective centroid. Once the data have been partitioned, the MLR model identified at the end of the consumer segmentation part is fitted to the training set. The trained MLR model is then applied on the hold-out dataset to determine the probabilities for each of the member to belong to each fuel type cluster. Let P^H_{ijf} denote the probability of the i^{th} member of belonging to the j^{th} cluster of f^{th} fuel type. Then, within the hold-out dataset, we reassign members to the fuel type cluster for which it has maximum probability and the fuel type for each member in the hold-out dataset is accordingly updated. For example, let's say a particular member in the hold-out dataset was originally in the Gas-2 cluster. Now, let's say its probability of belonging to BEV-3 cluster came out to be the highest. Thus, now this member will be assigned to the BEV-3 cluster and it will be assumed that this member bought a BEV fuel type.

Step 4: Determining market share for each fuel type

The market share for each fuel type is computed using the following equation:

$$MS_f = \frac{N_f^T + \sum_j \left(\sum_{i=1}^{N^H} w_i P^H_{ijf}\right)}{\left(\sum_f N_f^T + \sum_{i=1}^{N^H} w_i\right)}, \tag{3}$$

where, MS_f denotes the market share for f^{th} fuel type,
N_f^T represents total number of buyers of f^{th} fuel type in the training set,
N^H represents the total number of members in the hold-out dataset
w_i represents the weight associated with each member in the hold-out dataset
P^H_{ijf} denote the probability of the i^{th} member of belonging to the j^{th} cluster of f^{th} fuel type in the hold-out dataset

Finally steps 2-4 are repeated until convergence, which is when no appreciable change occurs in the predicted market share for BEV fuel type between two consecutive iterations

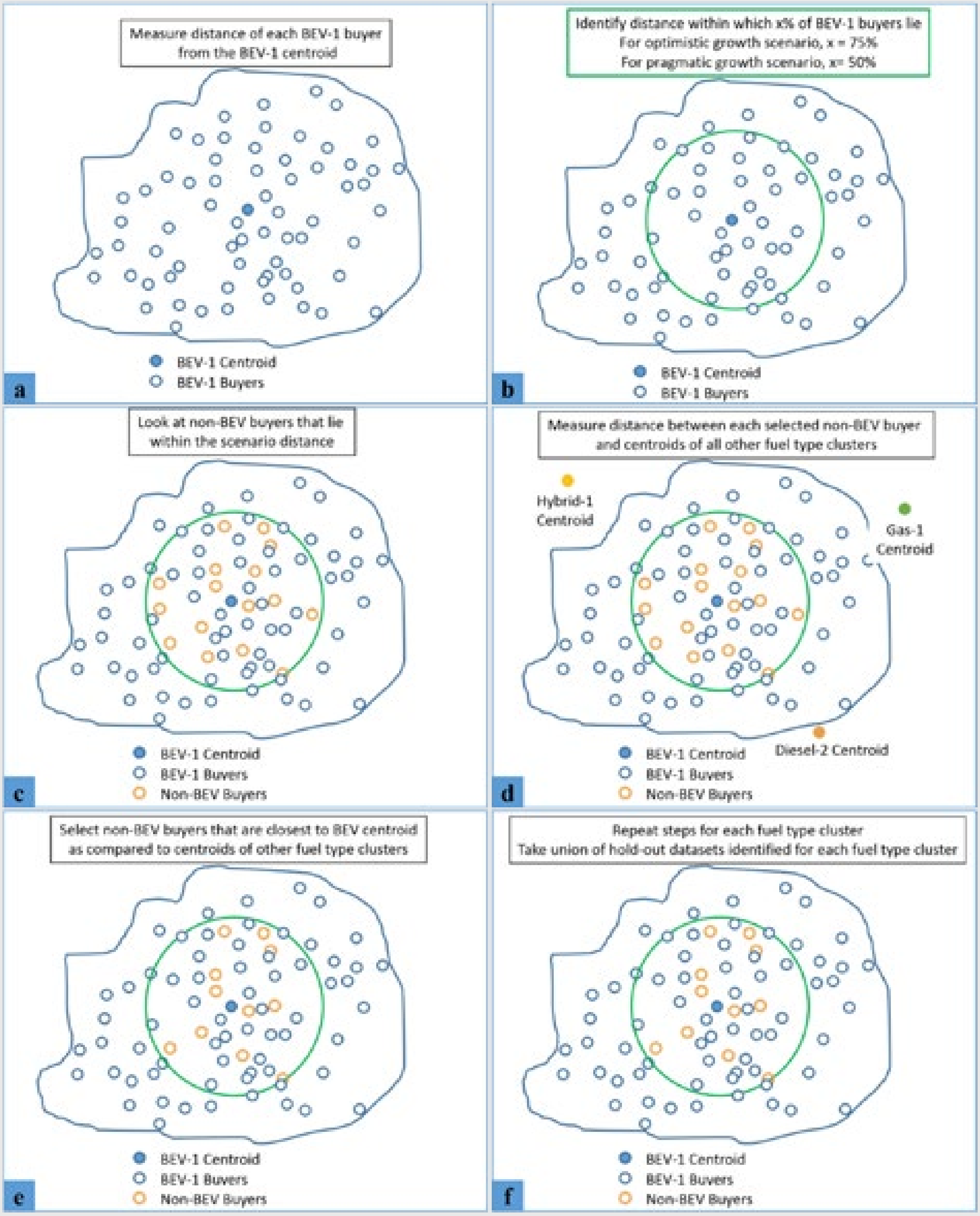

Figure A3. Schematic diagram showing the various steps involved in determining the hold-out dataset.
For demonstrative purposes, steps (a) to (e) show how to identify the hold-out dataset for BEV-1 fuel type cluster.

Source: KAPSARC analysis.

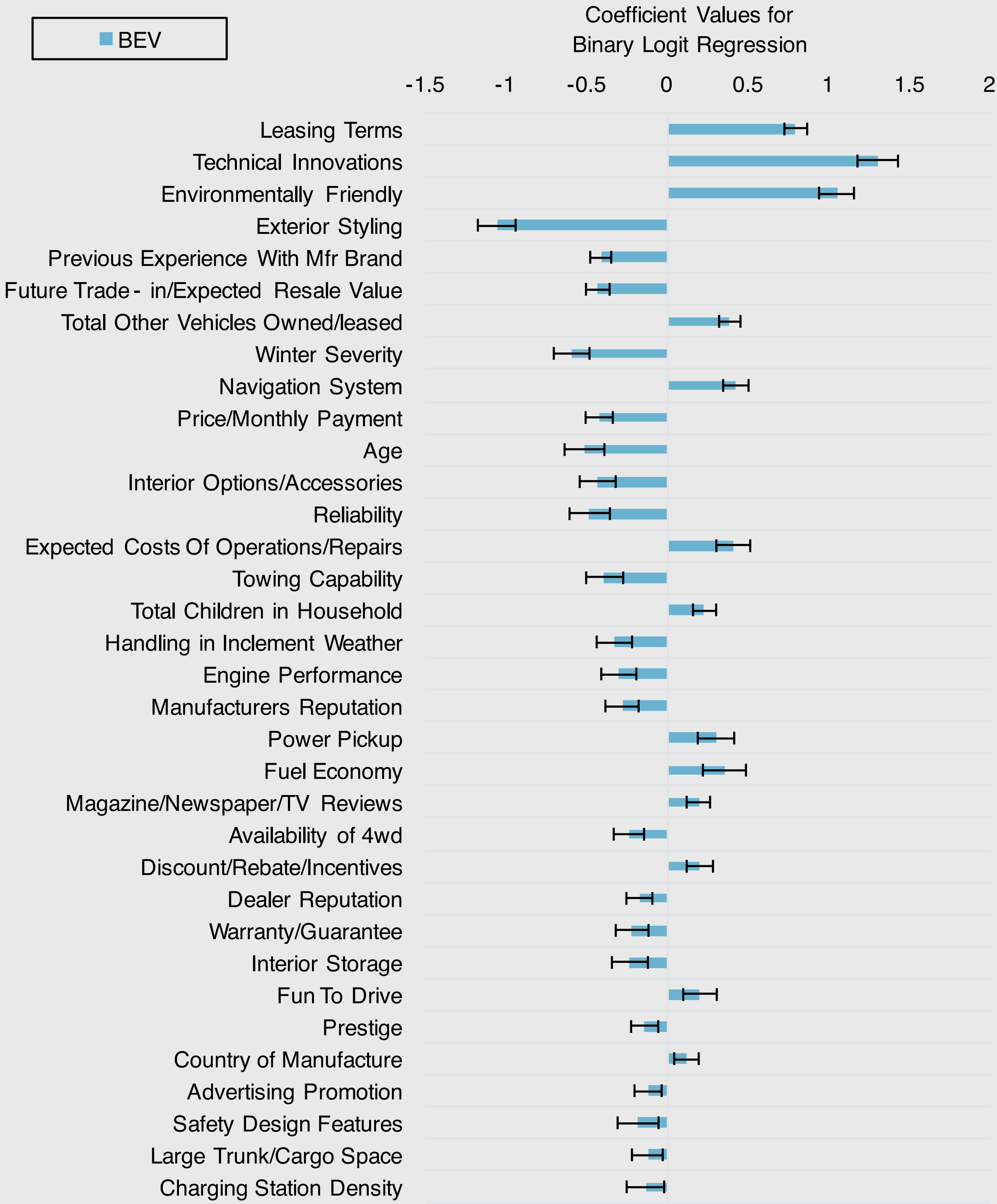

Figure A4. Coefficient values from a stepwise binary logit regression, assuming non-BEV buyers as the base outcome, p-value for all variables is less than 0.05 and variables are arranged in increasing order of p-value.

Source: KAPSARC analysis.

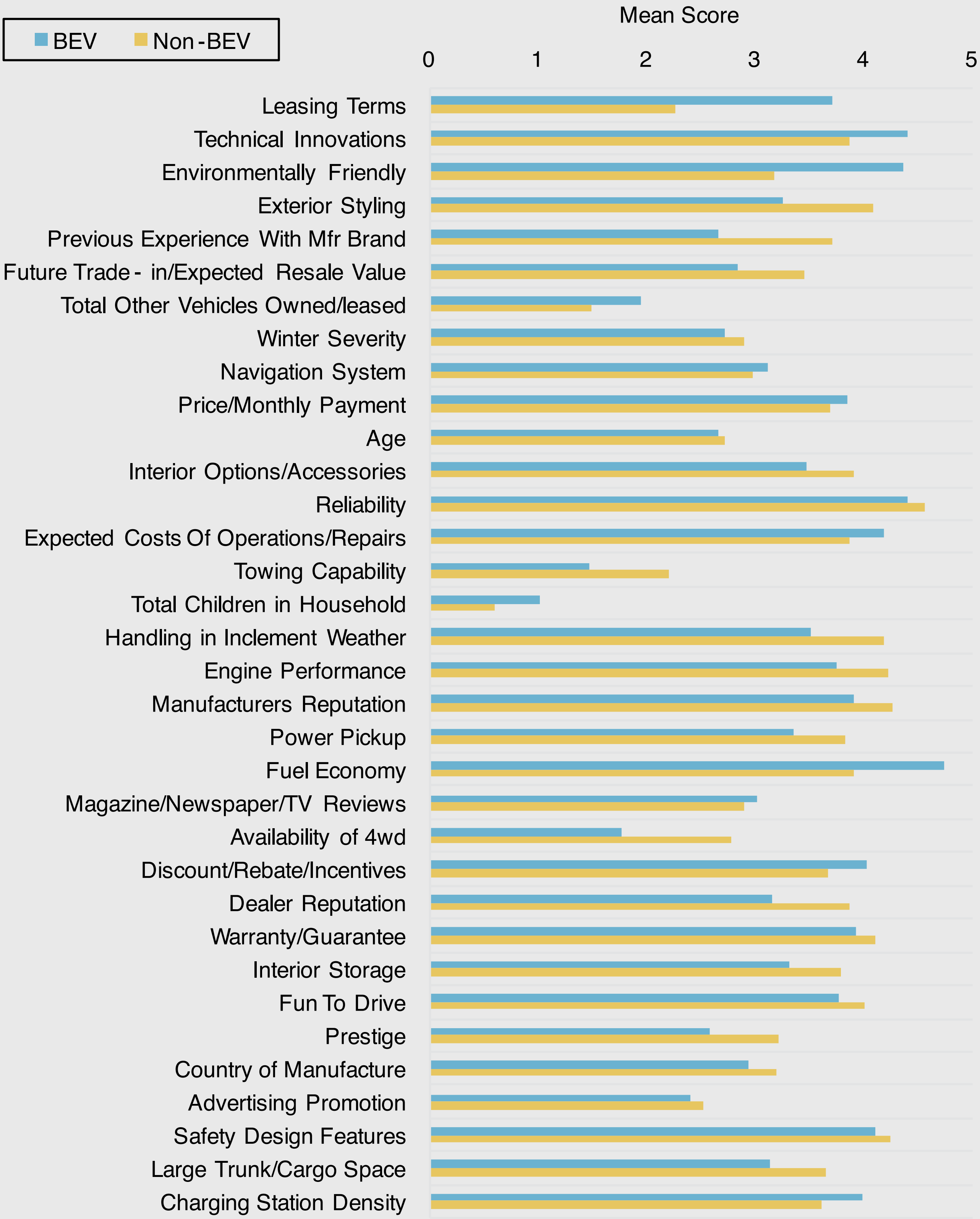

Figure A5. Mean score values for BEV and non-BEV buyer groups for each variable listed in Figure A4.

Source: KAPSARC analysis.

Table A2. Summary of factors separating the three types of BEV buyers. The table explains what they care more about relative to one another. Results were obtained through a stepwise multinomial logit regression.

BEV-1: Price Conscious Buyer	BEV-2: Affluent Adopter	BEV-3: Demanding Buyer
Care more about	**Care more about**	**Care more about**
Leasing Terms: This buyer type wants to minimize their risk through leasing instead of buying; flexible leasing terms are important for this buyer segment.	**Exterior Styling:** Wants to buy an aesthetically appealing BEV.	Cares almost the same as BEV-1 about: (i) Leasing Terms (ii) Discount and Rebate (iii) Price/Monthly Payment (iv) Operations/Repair Cost (v) Value for Money
Discount/Rebate/Incentive: Implies federal tax credit and state rebate positively affect BEV purchase for this buyer type.	**Prestige:** Owning a status symbol is an important motivator for this buyer type, which, in certain contexts, BEVs may convey. (Eisenstein 2013).	Cares more than BEV-1, but less than BEV-2 about: (i) Exterior Styling (ii) Prestige (iii) Performance (iv) Country of Manufacture
Price/Monthly Payment: Implies lowering BEV prices can have a favorable effect on adoption of BEVs by this buyer type.	**Availability of RWD &/or 4WD:** The need for this attribute possibly relates to the desire for better performance or the ability to drive in inclement weather.	**Other Cars in Household:** Have fewer other cars in household as compared to BEV-1 and BEV-2 buyers; thus could have range anxiety concerns.
Expected Costs of Operations/ Repair: High fuel economy and the absence of a combustion engine reduce BEVs operating and maintenance costs. These cost reductions positively affect adoption for this buyer type.	**Country of Manufacture:** Certain BEVs such as the Tesla Model S are manufactured in the U.S., which may be a motivator for this buyer type.	
Value for Money: Want good value for money from their vehicle.	**Performance:** Superior performance associated with certain BEVs acts as a positive determinant for adoption.	
Have Other Cars in Household: Implies this buyer type has other vehicles in household for trip requirements that cannot be met by BEVs.	**Seating capacity & Large Trunk:** The size of the trunk and seating capacity is important to this buyer.	
	Income: Earn more income as compared to the other two BEV types.	

Source: KAPSARC analysis.

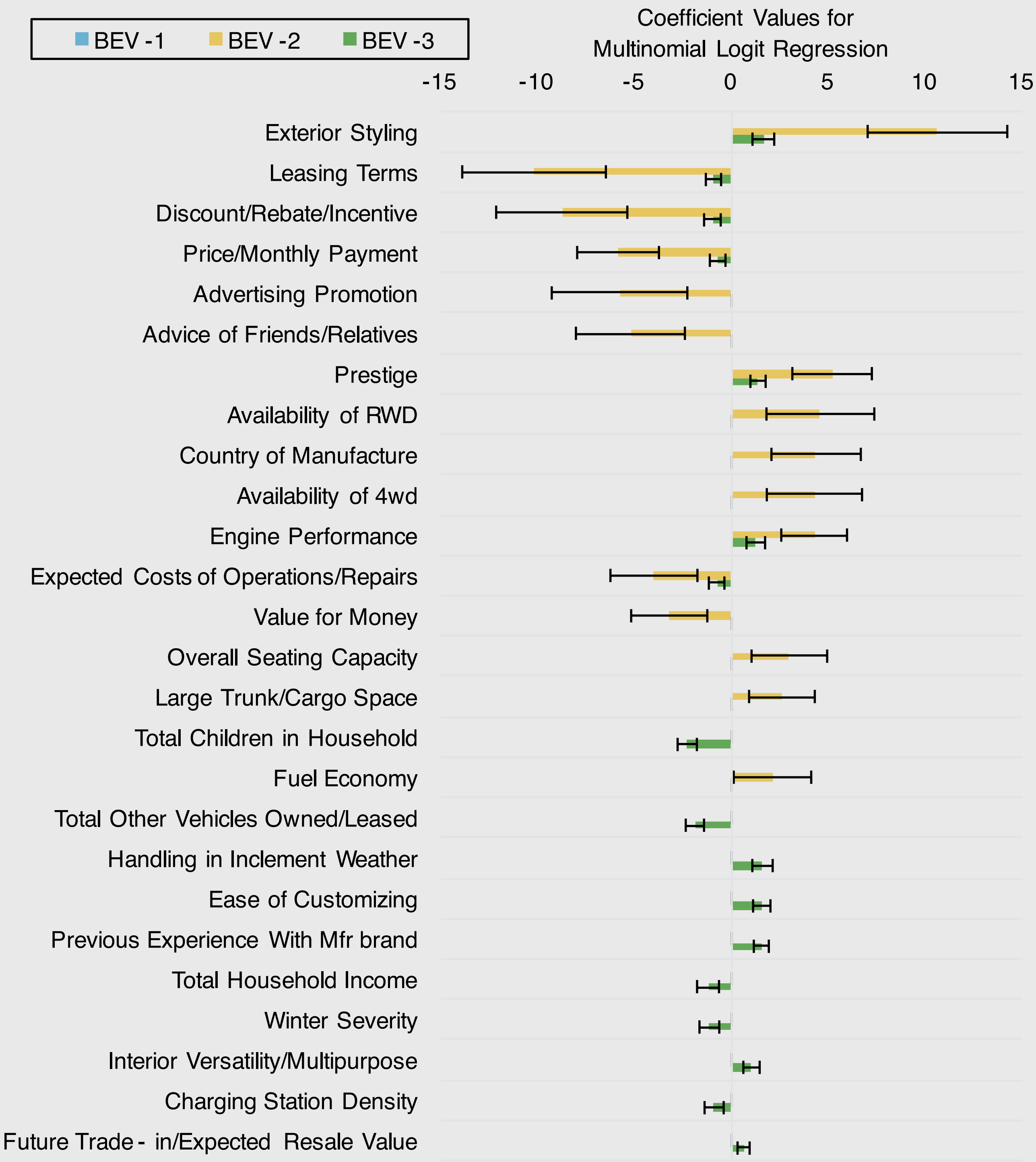

Figure A6. Coefficient values from a stepwise multinomial logit regression, assuming BEV-1 as the base outcome, p-value for all variables is less than 0.05, variables are arranged in decreasing order of difference between maximum and minimum coefficient value for the three buyer types.

Source: KAPSARC analysis.

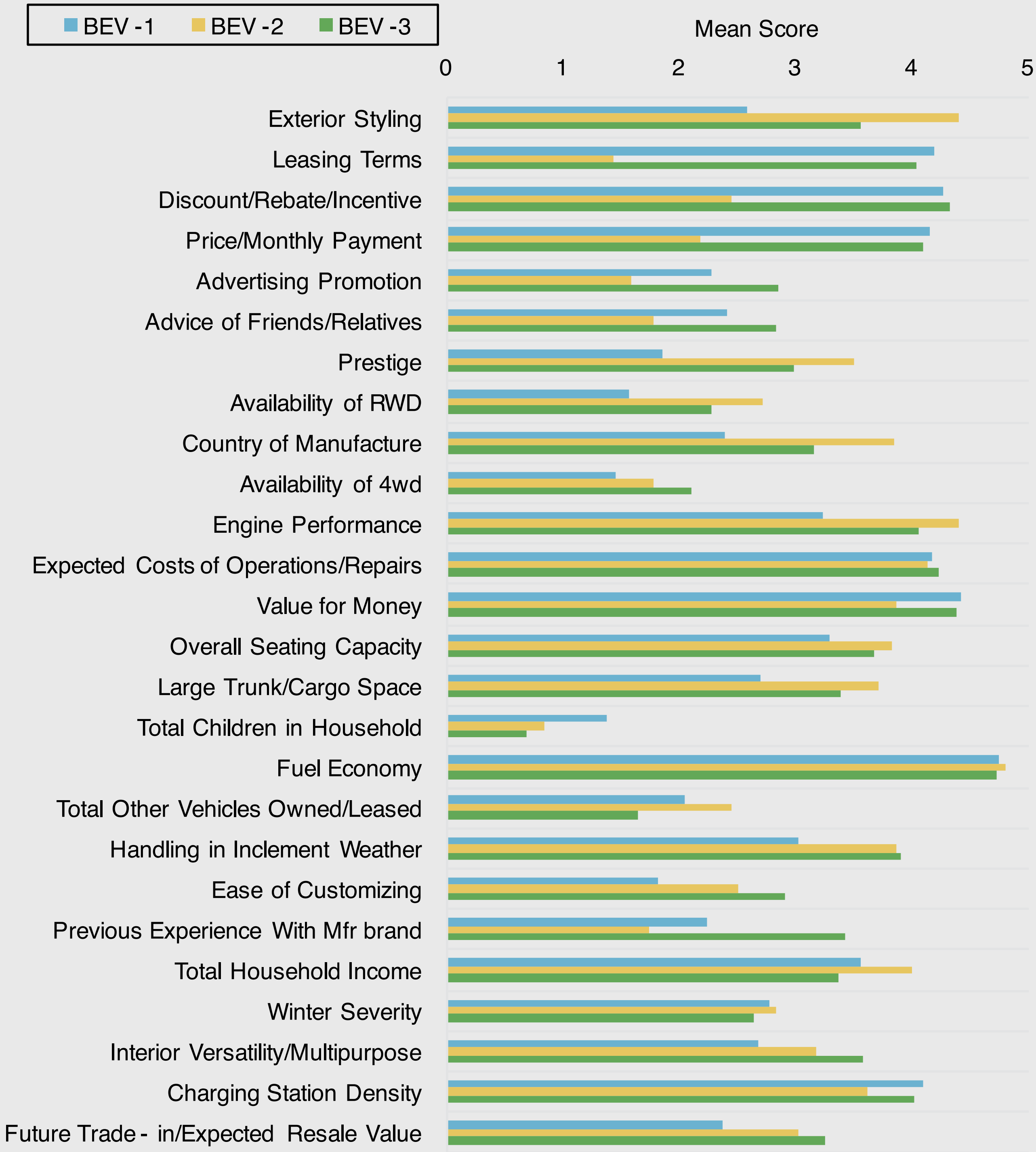

Figure A7. Mean score values for the three BEV buyer types for each variable listed in Figure A6.

Source: KAPSARC analysis.

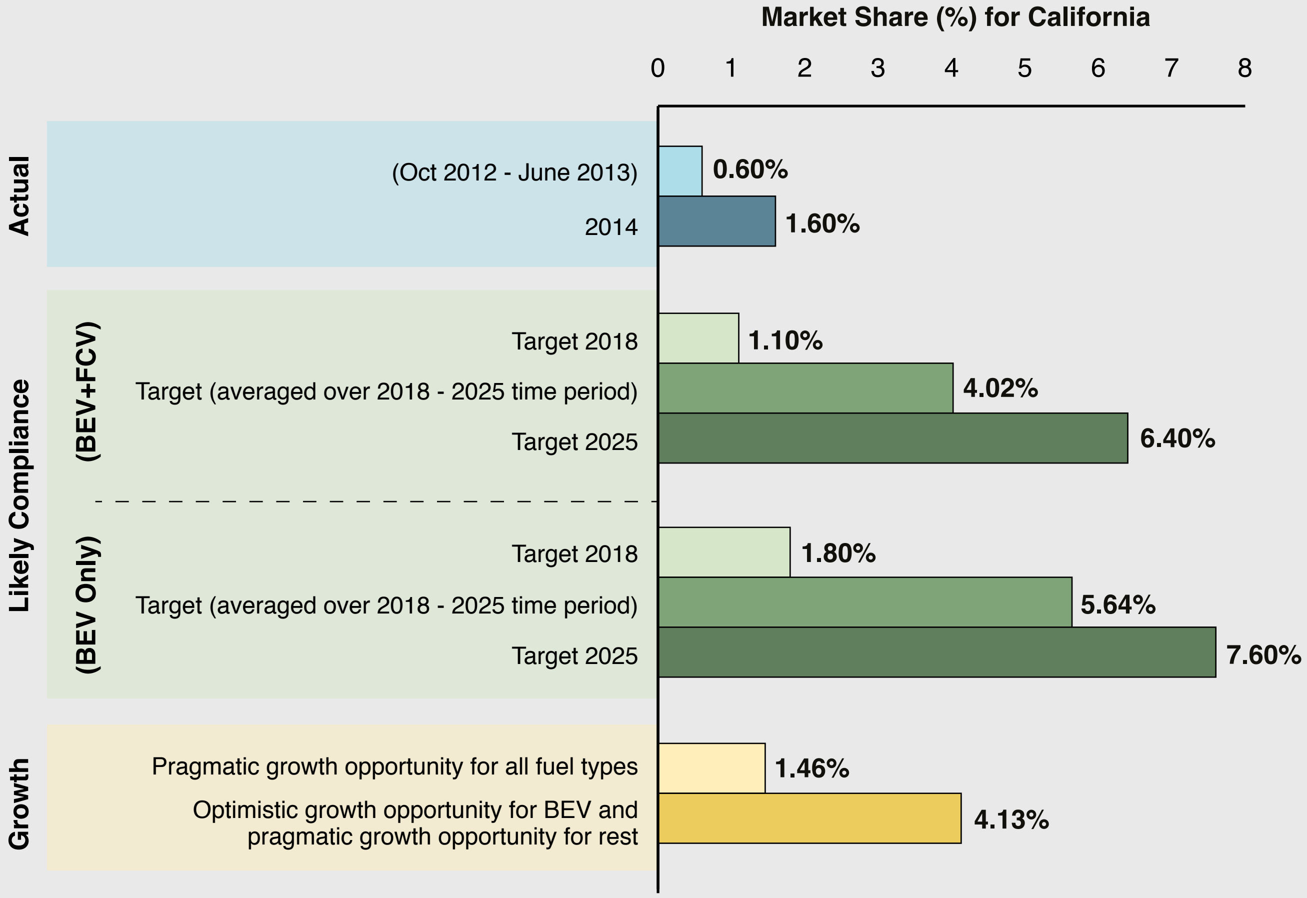

Figure A8. Potential BEV market share for CA: (i) actual market share for the time period Oct 2012-June 2013 and 2014 (CNCDA 2015); (ii) likely compliance target (CARB 2011) as per the ZEV mandate assuming sales for both BEVs and FCVs for different years (2018 and 2025) and averaged over the 2018-2025 time period; (iii) likely compliance target as per the ZEV mandate assuming sales for BEVs only for different years (2018 and 2025) and averaged over the 2018-2025 time period; (iv) for two different estimation scenarios: (a) pragmatic growth for all fuel types, (b) optimistic growth for BEVs and pragmatic growth for the other fuel types.

Source: KAPSARC analysis.

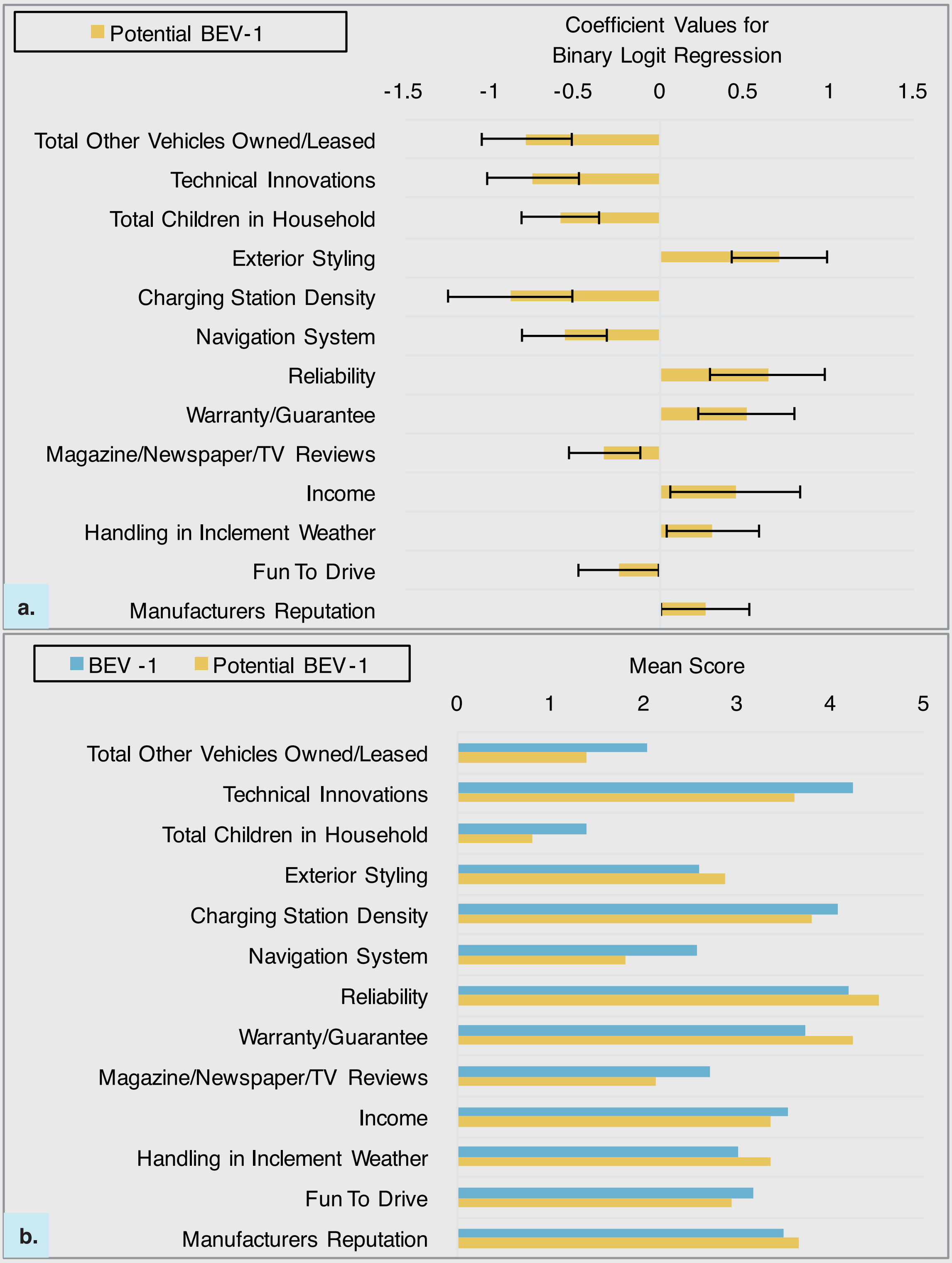

Figure A9. (a) Coefficient values from a stepwise binary logit regression, assuming BEV-1 buyer type as the base outcome, p-value for all variables is less than 0.05 and variables are arranged in increasing order of p-value, (b) Mean score values for BEV-1 and Potential BEV-1 buyer groups for each variable listed in Figure A9 (a).

Source: KAPSARC analysis.

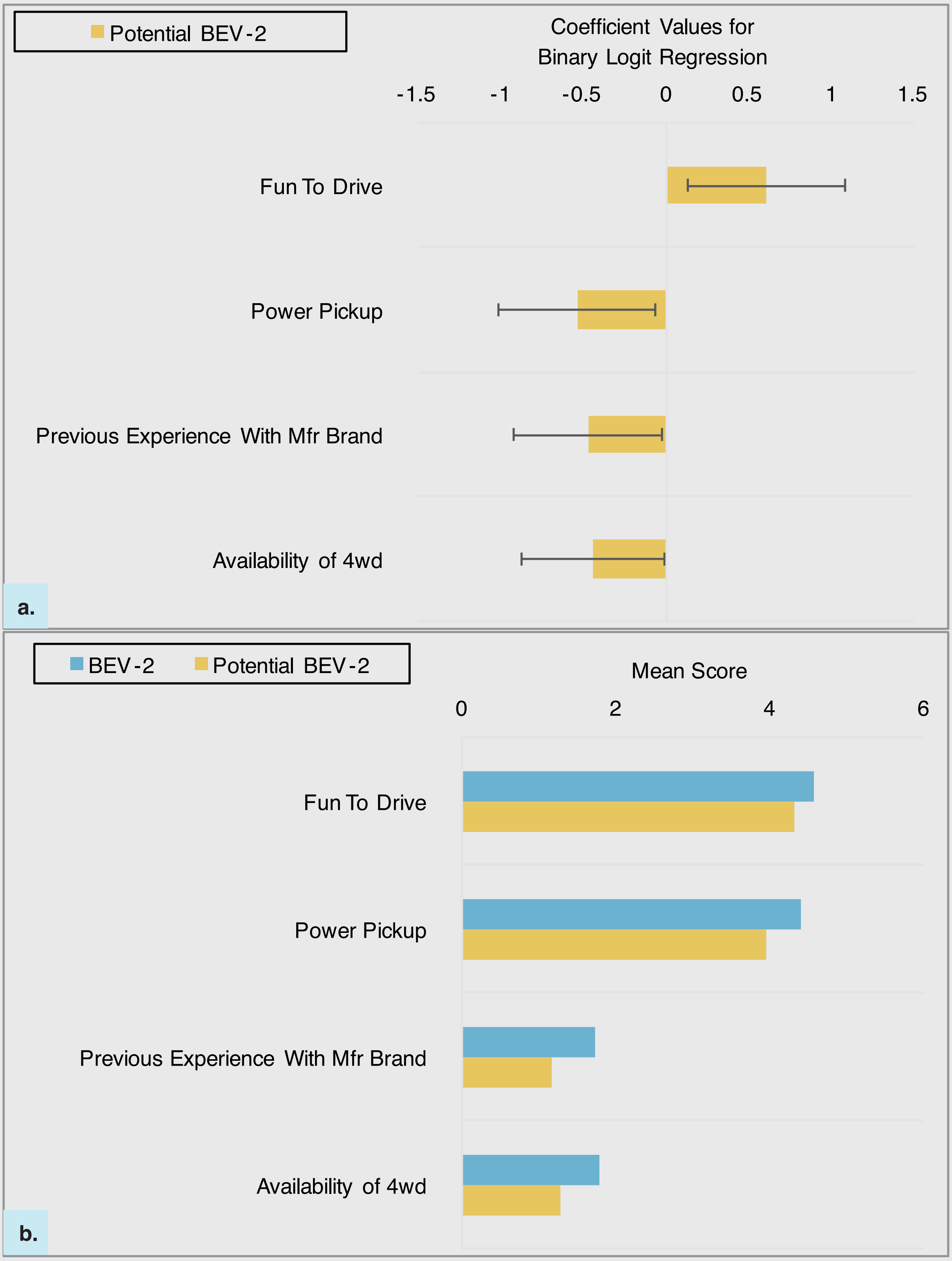

Figure A10. (a) Coefficient values from a stepwise binary logit regression, assuming BEV-2 buyer type as the base outcome, p-value for all variables is less than 0.05 and variables are arranged in increasing order of p-value, (b) Mean score values for BEV-2 and Potential BEV-2 buyer groups for each variable listed in Figure A10 (a).

Source: KAPSARC analysis.

Figure A11. (a) Coefficient values from a stepwise binary logit regression, assuming BEV-3 buyer type as the base outcome, p-value for all variables is less than 0.05 and variables are arranged in increasing order of p-value, (b) Mean score values for BEV-3 and Potential BEV-3 buyer groups for each variable listed in Figure A11 (a).

Source: KAPSARC analysis.

Table A3. Market share of BEVs in the U.S.

U.S. BEV Market Share (%)	
2012	**0.10**
2013	**0.31**
2014	**0.39**
2015	**0.41**

Source: Electric Drive Transportation Association Sales Dashboard (EDTA 2015.

Table A4. Factors that can induce potential BEV-3 buyers to adopt BEVs, obtained by comparing potential BEV-3 buyers with current BEV-3 buyers.

	Actionable Insights	
Potential BEV-3 (relative to BEV-3)	**For Private Sector (Suppliers, Original Equipment Manufacturers, Automotive Financial Institutions)**	**For Public Sector Government Entities**
Want better handling ability in inclement weather.	Adding all-wheel drive (AWD) capability could help, especially for increasing adoption in some of the colder Northeastern ZEV states, which in general have higher percentage of AWD in their drivetrain market share (CARB 2015).	
Want better resale value proposition.	As battery performance degradation is one of the major reasons for higher BEV depreciation rate, developing and installing batteries with extended lifecycle could help in slowing down BEV depreciation rate. Also providing options similar to Tesla's Guaranteed Resale Value program could also boost customer's confidence. The resale value issue needs careful attention and handling as the retention value for used BEVs is 15-20 percent lower than the retention value for similar sized used gasoline vehicles (Sheetz 2015).	Providing funding for battery research to improve battery lifecycle.
Want better exterior styling.	Appealing exterior design can complement other improvements in costs and technical capabilities.	

Potential BEV-3 (relative to BEV-3)	Actionable Insights: For Private Sector (Suppliers, Original Equipment Manufacturers, Automotive Financial Institutions)	Actionable Insights: For Public Sector Government Entities
Care more about leasing terms.	Leasing terms that address the consumer's concern related to continuous technology improvements and battery degradation/replacement could help (Sheetz 2015). Thus, flexible leasing terms offering consumers the choice to trade in the leased model for a higher range model (if available) at the end of the lease and/or buy the leased model under a guaranteed resale value program could help.	
Are more price conscious.	(i) Reductions in battery cost through learning-by-doing (Weiss et al. 2012), supply chain integration and economies of scale (Tesla 2014, Nykvist and Nilsson 2015) could help, although the estimated U.S. demand may not warrant operation at such high scale. (ii) Cost savings through using the same platform for pure electric and other powertrain models could also help (Edelstein 2015c, a).	(i) Continuing the rebate and incentive programs such as the federal tax credit and state rebate could help. (ii) Continued financial support for research aimed at developing lower cost battery electrode materials (Nykvist and Nilsson 2015).
Care less about technical innovations. Implies the potential buyers are less intrigued by novel technological features.	Adding more common technical capabilities such as all-wheel drive could help, rather than advanced features such as autonomous driving capability (although that would reinforce interest from current BEV buyers or create a new distinct avatar of BEV buyers).	
Have fewer other additional cars in household. Implies their vehicle must satisfy a wider range of needs, such as longer driving range as compared to current BEV buyers. However, 65 percent of potential BEV buyers have one other car in their household. Thus, the importance of range anxiety for potential buyers remains to be seen.	(i) Installation of batteries with higher range; (ii) offering programs that let BEV buyers borrow a different vehicle when they need to travel long distances such as the BMW i3 flexible mobility program and loaner program offered for Fiat 500e (Voelcker 2014) could help.	Offering incentives inversely proportional to the number of other additional cars in household could help. Also, providing subsidies and rebates in proportion to the installed battery capacity could also help encourage sales and support for higher range BEVs.
Live in areas with slightly lower charging station density.	Installing charging stations in areas where potential BEV buyers live and/or work could also help boost consumer confidence.	
Make lower income.		Offering incentives inversely proportional to income such as California's income-cap based rebate program could help (Edelstein 2015b).

Comparison between potential BEV-3 buyer segment and the actual BEV-3 buyer segment was made by carrying out a Kolmogorov–Smirnov equality-of-distributions test followed by a stepwise binary logit regression.

Source: KAPSARC analysis.

Table A5. Top 10 vehicles most seriously considered, but not purchased, by the three BEV buyer types.

BEV-1	BEV-2	BEV-3
Chevrolet Volt	Chevrolet Volt	Chevrolet Volt
Ford Focus	Ford Focus	Ford Focus
Toyota Prius	Audi A5 / S5	Toyota Prius
Toyota Prius Plug-in	Nissan Leaf	Toyota Prius Plug-in
Tesla All Models	Audi A8 / S8	Honda Fit
Honda Fit	BMW 5 Series	Tesla All Models
Nissan Leaf	Fiat Other / Unspecified	Nissan Leaf
Mitsubishi i-MiEV	Lexus RX	Toyota Prius c
Ford Other / Unsp	Toyota Prius	Ford Fusion
Toyota Prius c	Toyota RAV4	Fiat 500 / 500L

Source: KAPSARC analysis.

Table A6. Top 10 other vehicles in household for the three BEV buyer types.

BEV-1	BEV-2	BEV-3
Toyota Prius	Toyota Prius	Toyota Prius
Honda Odyssey	Lexus RX	Honda Accord
Honda Civic	Toyota Highlander	Honda CR-V
Ford Fullsize F-Series Pickup	Honda Odyssey	Toyota Camry
Toyota Highlander	Toyota Camry	Honda Odyssey
Acura MDX	Acura MDX	Honda Civic
Honda Pilot	Chevrolet Silverado Fullsize Pickup	Lexus RX
Toyota Camry	Ferrari (All Models)	Toyota RAV4
Volkswagen Jetta	Ford Fullsize F-Series Pickup	Acura MDX
Chrysler Town & Country	Honda Accord	Chevrolet Volt

Source: KAPSARC analysis.

Table A7. Top 10 models actually purchased by the three potential BEV buyer types

Potential BEV-1	Potential BEV-2	Potential BEV-3
Honda Civic Sedan (LX, EX / EX-L, Hybrid)	Volkswagen Passat (TDI, SEL, SE)	Honda Civic Sedan (LX, EX / EX-L, Hybrid)
Chevrolet Volt	Ford C-MAX (Hybrid SEL, Energi Plug In SEL)	Nissan Altima Sedan (SV, SL, S)
SMART fortwo Coupe	BMW 3 Series Sdn	Volkswagen Jetta Sdn (SE, S, TDI, Hybrid SE)
Volkswagen Jetta Sdn (S, TDI, Hybrid SEL, SE)	BMW X1	Volkswagen Passat (SE, S, SEL, SE TDI, SEL TDI)
Nissan Altima Sedan (S, SL, SV)	Dodge Dart	Honda Accord Sedan (LX, Sport, EX / EX-L, EX-L 6-Cyl)
Nissan Versa Sdn (SL, SV, S)	Jeep Grand Cherokee (Laredo 4WD, Overland Series)	BMW 3 Series Sdn
BMW 3 Series Sdn	Audi Q5 (2.0T Quattro)	Nissan Sentra (SR, SV, SL)
Fiat 500 (Pop, Sport 2 Dr Hatchback)	BMW 5 Series Sdn	Honda CR-V (EX/EX-L, LX)
Ford C-MAX (Hybrid SE, Energi (Plug In) SEL)	Chevrolet Volt	Nissan Rogue (S FWD, SV AWD, SL AWD, SL FWD)
Honda Accord (EX / EX-L, LX) Sedan	Honda Accord Sedan (EX / EX-L, Touring	Mini Cooper (Hardtop, Countryman, Clubman)

Source: KAPSARC analysis.

Table A8. Top 10 models actually purchased by potential alternative fuel type buyers

Potential Flex	Potential Diesel	Potential Hybrid	Potential PHEV	Potential BEV
Ram 1500 Pickup	Ram 1500 Pickup	Volkswagen Passat	Nissan Leaf	Honda Civic Sedan
Nissan Altima Sedan	Jeep Grand Cherokee	Honda Accord Sedan	Ford C-MAX	Volkswagen Jetta Sdn
Nissan Rogue	Jeep Wrangler	Honda Civic Sedan	Nissan Altima Sedan	Nissan Altima Sedan
Honda Accord Sedan	Nissan Pathfinder	Nissan Altima Sedan	Acura RDX	Volkswagen Passat
Dodge Dart	Nissan Altima Sedan	Honda CR-V	Dodge Dart	Honda Accord Sedan
Honda CR-V	Honda Pilot	Volkswagen Jetta Sdn	Fiat 500	BMW 3 Series Sdn
Honda Civic Sedan	Honda CR-V	Volkswagen Golf	Ford Fiesta Sedan	Nissan Sentra
Volkswagen Passat	Nissan Frontier	Volkswagen Jetta Wgn	Ford Fusion	Chevrolet Volt
Nissan Sentra	Nissan Titan	Volkswagen New Beetle	Honda Civic Sedan	Honda CR-V

Source: KAPSARC analysis.

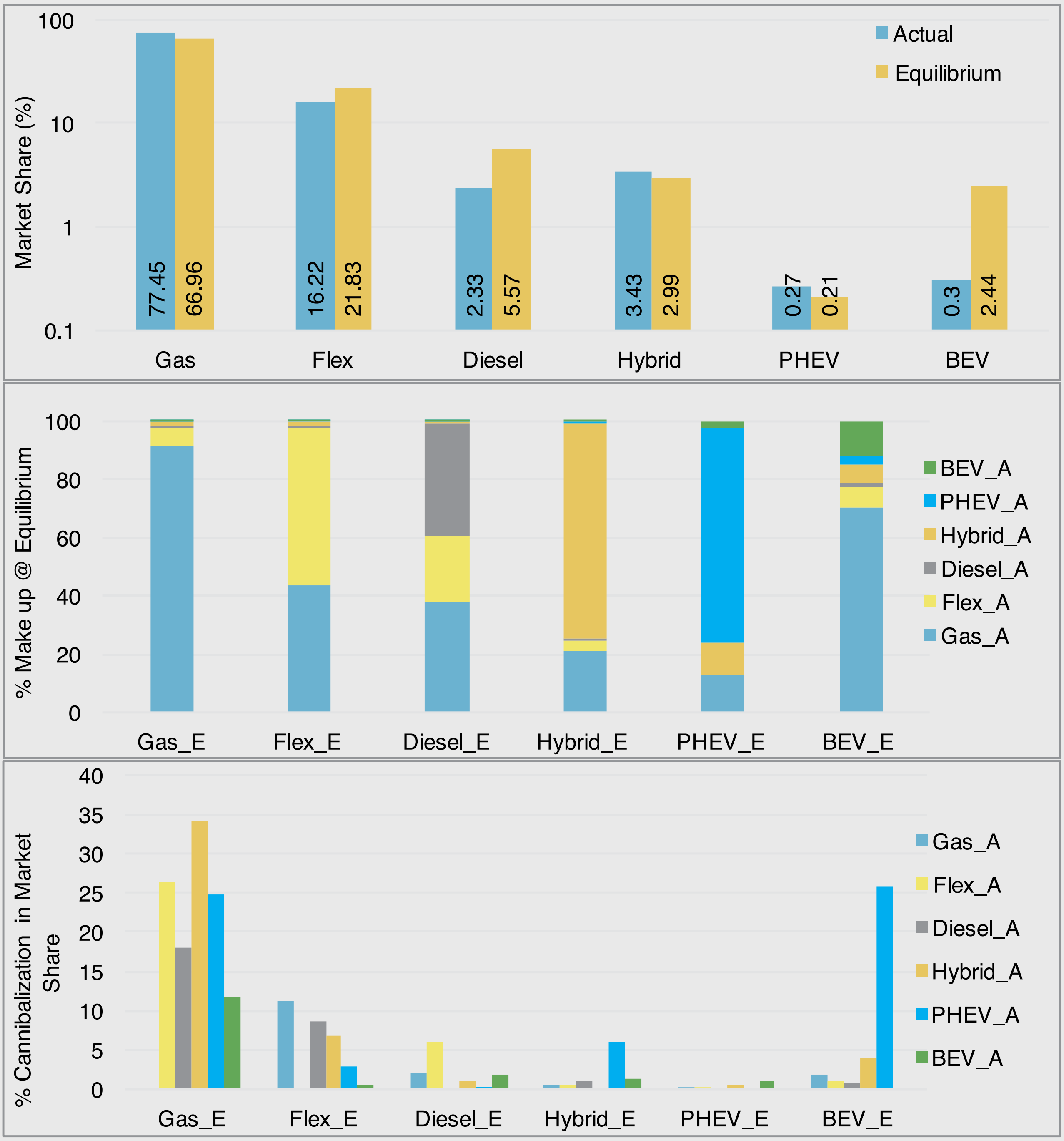

Figure A12. (a) Actual and equilibrium market share for different fuel types for the scenario assuming optimistic growth for BEVs and pragmatic growth for rest, (ii) percent makeup at equilibrium for each fuel type shown on the x-axis ("_E" stands for equilibrium and "_A" stands for actual), (iii) percent cannibalization of each fuel type due to out flux of market share from respective fuel type to other fuel types ("_E" stands for equilibrium and "_A" stands for actual).

Source: KAPSARC analysis.

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Notes

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About the Project

Promoting adoption of energy-efficient vehicles has become a key policy imperative in both developed and developing countries. Understanding the impact of various factors that affect adoption rates, such as: (i) consumer related factors – demographics, behavioral, psychographics; (ii) regulatory factors – policies, incentives, rebates, perks; and (iii) geo-temporal factors – weather, infrastructure, network effects; forms the backbone of KAPSARC's efforts in the transportation field. Our team is currently developing models at different levels of resolution – micro level models using large-scale data comprising of new car buyers' profiles and macro level models using aggregated adoption data, to understand and project the effects of various factors at play for the adoption of energy-efficient vehicles.

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