Electric Vehicle Explorer

Educating and Persuading Consumers with an Online Vehicle Energy Cost Calculator

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Abstract. Most HCI research related to electric vehicle adoption has focused on mitigating barriers related to vehicle range and charging infrastructure, while relatively less attention has been given to helping consumers recognize the benefits of electric vehicles. A significant benefit is reduced energy costs; however, the complexity of comparing gasoline and electricity prices makes it difficult for consumers to quantify. This paper describes and evaluates an online tool called EV Explorer that enables users to compare personalized estimates of annual energy costs for multiple vehicles. We assessed the tool through an online experiment, gauging users' perceptions—before and after using the tool—of their current energy costs, potential savings with electric vehicles, attitude toward electric vehicle charging, and intention to buy or lease an electric vehicle in the future. Statistically significant changes in each of these variables validate the tool as an educational and persuasive strategy to promote electric vehicle adoption.

Keywords: Eco-feedback · Electric vehicles · Vehicle cost calculator

1 Introduction

Vehicle electrification is an important strategy in moving toward a more sustainable transportation future. Replacing gasoline with electricity to power vehicles enables reduced dependence on fossil fuels. Depending on the mix of energy sources used to produce that electricity, electric vehicles can also dramatically reduce climate-altering greenhouse gas emissions.

There are two types of electric vehicles (EVs), also called plug-in electric vehicles (PEVs): (1) battery electric vehicles (BEVs), which are powered exclusively by electricity from rechargeable electric battery packs and have no direct (tailpipe) emissions, and (2) plug-in hybrid electric vehicles (PHEVs), which can run on gas and/or electricity via a rechargeable electric battery and an internal combustion (gas-powered) engine that is smaller relative to those in conventional gas vehicles. Both types of PEVs are more energy efficient and less expensive to operate and maintain compared to conventional gas vehicles and hybrids (HEVS). HEVs require gasoline; they have an internal combustion engine aided by a non-rechargeable electric motor that enables better fuel economy and less emissions compared to similar conventional gas vehicles [1].

Barriers to PEV adoption are well-studied; they include relatively higher purchase price and limitations in vehicle range and charging infrastructure [1–3]. These barriers are partly a function of consumers' lack of knowledge and experience with PEVs. For example, Jakobsson et al. [4] found that even prospective buyers of PEVs have very little knowledge regarding range performance, charging infrastructure, and the ability to plug-in at home. The phenomenon of "range anxiety"—fear of being unable to reach one's destination—is in many cases only a perceived barrier, since most drivers' regular commute travel range is lower than the modern electric vehicle's range [2, 3].

HCI research regarding PEV adoption has typically focused on addressing the barriers of range anxiety and lack of knowledge or access to charging infrastructure. For example, Lundström and colleagues [5–8] have developed and tested various interfaces for displaying remaining range to electric vehicle drivers, as well as mobile apps to simulate electrical vehicle range when driving a gas vehicle. Other examples of the latter strategy include BMW's EVolve App and Stanford researchers' Virtual EV Test Drive [9]. These apps are excellent educational tools for prospective PEV buyers, though they require a time commitment of several days or weeks to use properly.

There has been a lack of HCI research focused on conveying the benefits of PEVs to prospective buyers. There is a great need for such a focus given that consumers weigh perceived benefits more heavily than perceived risks when evaluating new technologies [10]. Moreover, increasing perceived benefits can have the effect of lowering perceived risk, likely to reduce cognitive dissonance created by negative aspects of technologies that one considers beneficial [11].

A significant benefit of PEVs can be lower energy costs. However, estimating potential savings is a complex endeavor [1]. Specifically, calculating potential energy savings to be gained with a PEV requires knowledge regarding current gas prices and electricity prices at each place the consumer may charge the vehicle (home, work, and/or public charging stations), as well as fuel economy of the consumer's current vehicle and the electricity consumption per mile of the particular PEV(s) the consumer is considering, all of which vary [12].

Vehicle cost calculators are one strategy to educate consumers about the benefits of PEVs, and perhaps even persuade them to adopt. In general, vehicle cost calculators handle three types of cost information: vehicle purchase, ongoing costs (taxes, insurance, and maintenance), and energy costs (gasoline and electricity). The present research provides an example of a calculator that focuses on energy costs.

There are many other examples of vehicle cost calculators that help users learn about PEV energy costs (Table 1). These calculators vary in terms of a number of features that are potentially important for user experience, education, and persuasion. For example, calculators may display cost information for only one vehicle at a time or multiple vehicles for comparison. The demand on users to input personal data before generating any output also varies, from no required inputs (which minimizes personalization of estimates) to many, which could be fatiguing to a user. The most commonly required input is miles the user drives per day, which, if unknown, may require the user to consult other tools such as mapping programs to estimate driving distance.

Table 1. Vehicle cost calculators that provide energy cost information for PEVs

Tool name[a]	Car comparisons	Required inputs	Destination charger
EV Explorer [18]	4; any type	Home address, destination address	Type, cost, hours parked
Alternative fuels data calculator [19]	8; any type	–	–
Go solar california [20]	2; 1 gas or HEV and 1 PEV	Miles/day	% public charger use, cost
Electric car calculator [21]	2; any type	Miles/weekday, miles/weekend day	–
My plug-in hybrid calculator [22]	–	Miles/day, miles/year, state	Type
PEV calculator (PG&E) [23]	–	Miles/day, zip code	–
PEV calculator (consumers energy) [24]	2; 1 gas or HEV and 1 PEV	–	–
Oncor EV savings calculator [25]	–	–	–
SMUD calculator [26]	2; 1 gas or HEV and 1 of 5 PEVs	–	–

Vehicle cost calculators also vary in terms of optional inputs that allow more tailored estimates of energy costs. For example, most allow the user to modify gas and electricity prices and customize some details about driving distances. Few tools allow the user to specify details regarding charging away from home. Given that 75% of workplace charging is free [13], the ability to specify destination charging costs in particular could increase energy savings estimates for many users, who might then be more persuaded to purchase or lease a PEV.

Finally, these tools vary in terms of the degree of interactivity with the output, i.e., the ease of exploration via modification of inputs. Some tools are highly structured such that the user must begin the entire process again if they wish to explore other inputs. Others allow for easier exploration by including multiple paths to change inputs, displaying results on the same page as inputs, and automatically updating results when inputs are changed.

Although many calculators exist, how they are used, whether they are effective, and which features influence consumer knowledge, attitudes, and intentions to adopt PEVs are not well-studied. Our research explores these questions in the context of one of these tools, called EV Explorer, which was created by members of our research team. EV Explorer utilizes several features that are less common in other existing tools, including a map-based interface for easily calculating commute distances within the site, comparison of up to four vehicles, and ability to customize variables related to charging at commute destination. The application is layered for ease of exploration; the user is only required to enter home address and commute destination address to start comparing energy costs; extensive tailoring can then be done as desired to increase the precision of estimates.

2   Methodology

We first describe the development and user interface design of EV Explorer, then detail the experiment conducted to evaluate its impact on users' knowledge, attitudes, and intention to buy or lease PEVs.

2.1   Website Development and Design

EV Explorer is written entirely in JavaScript. This means all calculations are done in the user's browser, which makes the tool very responsive to use. It uses Node.js [14] to power its webserver and API.

EV Explorer also makes use of several freely available public APIs. The map-driven content is powered by Google Maps [15]; this includes geocoding and route generation in addition to the standard map display. Vehicle information concerning fuel economy and range comes from an API available from the United States (US) Department of Energy Efficiency and Renewable Energy [16]. EV Explorer provides fuel prices relevant to the user by combining fuel price data from the US Energy Information Administration [1] with the user's location from freegeoip [17] based on their IP address. Electricity price was not created dynamically at the time of this study; it was set at $0.14 USD/kWh, which was slightly higher than average electricity price in the US in 2015; it can be customized by the user.

Upon entering the site, EV Explorer prompts the user through two steps. 'Step 1' is to enter a home address (Fig. 1). 'Step 2' is to enter a commuting destination by either typing it in or dragging a marker to the location on the map in the background. Upon completion of these two steps, a stacked bar chart comparison of annual energy costs (distinguishing between electricity and gasoline costs) for four vehicles is presented: one gasoline vehicle, two PHEVs, and one BEV (Fig. 2). A meter at the bottom of the screen shows required range for the user's roundtrip commute compared to total range for the BEV displayed in the cost comparison chart.
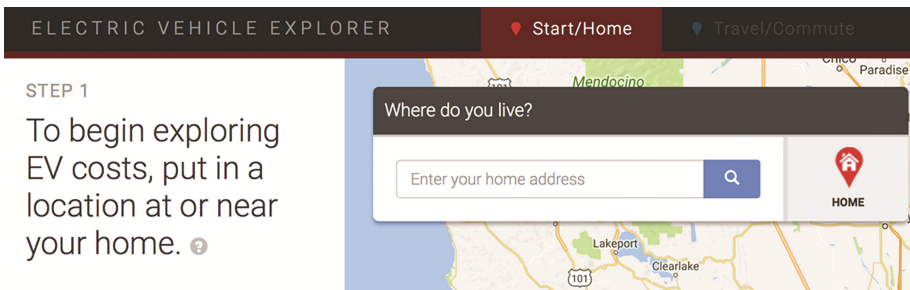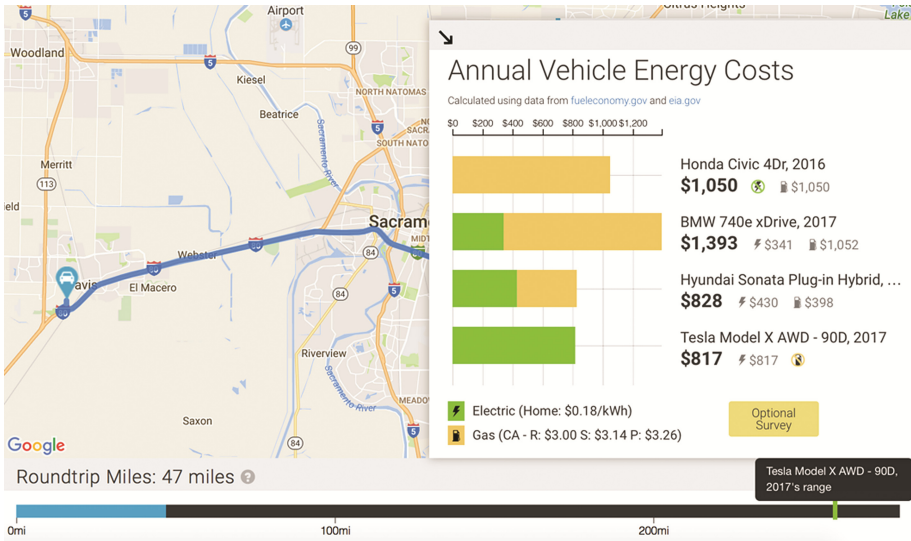

Fig. 1. Step 1: enter home address

Fig. 2. Main output with annual energy cost comparisons and BEV range information

Fig. 3. (Left) Travel/commute settings: commute frequency and charging at destination

Fig. 4. Modifiable energy prices

The user can then explore other features and further customize their annual fuel cost estimates. Specifically, the user can modify the frequency of their commute (default is 5 days per week) and charging opportunities at destination (Fig. 3). Another feature allows the modification of gas and electricity prices (Fig. 4). A feature called 'Car Manager' allows the user to select up to four different vehicles to compare, and allows modification of each vehicle's mileage, range, and time to charge (Fig. 5).

Fig. 5. Car manager: choose a new car and modify vehicle MPG/range/time to charge

2.2 Online Experiment

We conducted an online pretest-posttest experiment to evaluate the impact of EV Explorer on users. We used SurveyMonkey to develop our test instrument and recruited participants via Amazon Mechanical Turk. We asked 108 Mechanical Turk "workers" a series of identical questions before and after visiting EV Explorer via a link embedded in the online survey instrument. Participants were paid $0.65 USD. Average time spent exploring the site and answering questions was approximately 15 min.

At the start of the posttest when participants were asked to answer the same questions they answered in the pretest, there was a prompt noting that the questions were the same and their responses may or may not have changed after using EV Explorer. This design provided a measurement of change in the following variables via corresponding before-and-after questions.

Awareness of Long-term Fueling Costs. Since the focal output of EV Explorer is an estimate of annual fuel costs and users are able to input their current vehicle, we hypothesized that using the tool would increase participants' awareness of their current annual fuels costs. To test this hypothesis, we asked the following question before and after participants' explored the website: *About how much money do you spend on gas and/or electricity to fuel your vehicle(s)? Please enter both a dollar amount and unit of time (e.g., $100/week).*

Knowledge of Potential Savings. Since the focal output of EV Explorer juxtaposes annual energy cost estimates for a gas vehicle, two PHEVs, and a BEV, we hypothesized that using the tool would increase participants' knowledge of potential personal savings with PEVs compared to gas vehicles. To test this hypothesis, we asked the following question before and after participants' explored the website: *Given your driving patterns, how much would/do you save in fueling costs by driving the following vehicle types compared to a gas only vehicle? (Hybrid, Plug-in hybrid electric, Electric; response options: Not sure, No savings, Some Savings, Significant Savings).* We hypothesized that knowledge of savings for PHEVs and BEVs would increase in terms of both (a) fewer "Not sure" responses and (b) an increase in the perceived amount of potential savings.

Attitude Concerning Charging. Since EV Explorer includes a variety of customizable variables for charging infrastructure, we hypothesized that using the tool would result in an increase in participants' understanding of charging requirements and a positive shift in attitudes about the convenience of charging. To test this hypothesis, we asked the following question before and after participants' explored the website: *Given your driving patterns, how (in)convenient are the charging requirements of the following vehicle types compared to fueling a gas only vehicle? (Plug-in hybrid electric, Electric; response options: Not sure, Much more inconvenient, Somewhat more inconvenient, No more or less (in)convenient, Somewhat more convenient, Much more convenient).* Similar to the previous question, greater understanding of charging requirements would be evidenced by fewer "Not sure" responses after using the tool.

Intention to Purchase or Lease. We hypothesized that the above changes in knowledge of potential savings and attitude toward charging as a result of using the tool would lead to an increase in intention to purchase or lease PHEVs and BEVs. To test this hypothesis, we asked the following question before and after participants' explored the website: *How likely are you to buy/lease the following vehicle types in the future? (Gas only, Hybrid, Plug-in hybrid electric, Electric; response options: Very likely, Likely, Neutral, Unlikely, Very unlikely).*

Intervening Variables. In order to help explain any observed changes in knowledge, attitudes, and intentions, and to gain insights for the design of electric vehicle cost calculators, we asked participants which website features they used and what calculations they made while exploring the site (i.e., how much they would spend or save by driving their current vehicle or a different vehicle). In the posttest, participants were encouraged to go back and use features that they may not have noticed independently and they were asked to report whether they noticed the feature or not, thus the results yielded implications for improving the saliency of some features.

We also asked demographic questions to explore relationships between user characteristics and dependent variables. Participants included 63 males, 44 females, and 1 other; average age was 32 ($SD = 10$ years), ranging from 19 to 62. Participants' median household income was $25,000 to $49,999 and their median level of education was a Bachelor's degree. Participants indicated the type(s) of vehicles they drove on a regular basis; 100 out of the 108 participants indicated that they drove a gas vehicle, 8 drove an HEV, 5 drove a PHEV, and 0 drove a BEV.

Data Analysis. We conducted McNemar's or Wilcoxon signed-rank tests to detect paired differences in participants' responses before and after using EV Explorer, for each of our dependent variables. We conducted Mann Whitney U tests to analyze differences in change scores for each dependent variable based on whether or not the participant used each key feature of the website. These tests are appropriate for comparing central tendencies (or proportions) for ordinal variables. To assess our hypothesis that increasing knowledge of savings and knowledge and attitudes regarding charging requirements would increase intention to purchase or lease PEVs, we explored correlations between change scores for these variables. We used an alpha level of .05 to claim significance.

3   Results and Discussion

Results are organized first according to EV Explorer's potential impacts on consumer PEV education and persuasion to adopt. We then examine relationships between consumer knowledge, attitudes, and intentions, followed by an assessment of participant characteristics that influenced user response to EV Explorer. Finally, we consider the influence of specific features of EV Explorer on our outcomes.

3.1   Education

When asked to report personal fuel costs in their own terms, participants framed costs over longer periods of time after using EV Explorer compared to before. Specifically, after using the tool more participants reported fuel costs in terms of years (McNemar's test $p < .031$) and fewer reported fuel costs in terms of weeks (McNemar's test $p = .001$); Table 2. This supports our hypothesis that EV Explorer raised awareness of long-term energy costs.

Table 2.   Awareness of long-term fuel costs, savings potential, and charging requirements

		Before EV Explorer	After EV Explorer
Percentage of respondents who reported their fuel cost in terms of each unit of time	1–2 Week(s)	57%	47%*
	Month	39%	45%
	Year	1%	7%*
Percentage "Not sure" of savings potential with each alternatively-fueled vehicle type	HEV	15%	6%*
	PHEV	19%	6%**
	BEV	20%	6%**
Percentage "Not sure" of (in)convenience of charging	PHEV	13%	10%
	BEV	16%	9%

*$p < .05$ **$p < .01$

After using EV Explorer, significantly fewer participants reported being "Not sure" about the savings associated with HEVs (McNemar's test $p = .013$), PHEVs (McNemar's test $p < .0001$), and BEVs (McNemar's test $p < .0001$). Similarly, fewer participants reported being "Not sure" about the (in)convenience of charging PHEVs

and BEVs, but the differences were not significant. Overall, these findings suggest EV Explorer has an educational function; users learn about their personal long-term fueling costs and potential savings with alternatively-fueled vehicles.

3.2 Persuasion

For participants who had some perception about savings before and after using EV Explorer (i.e., excluding those who were "Not sure"), their estimation of the amount of potential savings significantly increased for each: HEVs ($Z = -3.889, p < .0001$), PHEVs ($Z = -3.812, p < .0001$), and BEVs ($Z = -3.567, p < .0001$); Table 3. For participants who had some perception about the (in)convenience of charging before and after using EV Explorer (i.e., excluding those who were "Not sure"), their attitudes became more positive for BEVs ($Z = -2.010, p = .044$), but not PHEVs ($Z = -0.989, p = .322$); Table 3.

Table 3. Participant attitudes before and after using EV Explorer

		Before EV Explorer		After EV Explorer	
		Median	Mean (SD)	Median	Mean (SD)
Perceived savings *(No savings = 2; Significant savings = 4)*	BEV[**]	Some savings	3.38 (0.65)	Significant savings	3.63 (.054)
	PHEV[**]	Some savings	3.28 (0.58)	Significant savings	3.57 (0.55)
	HEV[**]	Some savings	3.12 (0.46)	Some savings	3.38 (0.55)
Attitude toward charging *(Much more inconvenient = 2; Much more convenient = 6)*	BEV[*]	Somewhat more inconvenient	3.16 (1.24)	Somewhat more inconvenient	3.40 (1.35)
	PHEV	Somewhat more inconvenient	3.38 (1.25)	Somewhat more inconvenient	3.52 (1.31)
Intention to buy or lease *(Very unlikely = 1; Very likely = 5)*	BEV[**]	Neutral	2.85 (1.22)	Neutral	3.20 (1.24)
	PHEV[**]	Neutral	2.91 (1.14)	Neutral	3.31 (1.23)
	HEV[*]	Likely	3.49 (0.96)	Likely	3.66 (1.02)
	Gas[*]	Likely	3.79 (1.13)	Likely	3.67 (1.17)

[*]$p < .05$
[**]$p < .0001$

Participants reported a significantly greater intention to buy or lease HEVs ($Z = -2.107, p = .035$), PHEVs ($Z = -4.890, p < .0001$), and BEVs ($Z = -4.255, p < .0001$), and a significantly lower intention to buy or lease gasoline vehicles ($Z = -2.408, p = .016$) after using EV Explorer; Table 3. For both PHEVs and BEVs, mean scores in intention to buy or lease crossed over the line of neutrality from the negative side, "Unlikely", before using EV Explorer to the positive side, "Likely", after using EV Explorer, though the median stayed the same ("Neutral"). Overall, these findings suggest EV Explorer has a persuasive function, increasing users' perception of the amount of potential savings with alternatively-fueled vehicles, promoting more favorable attitudes toward BEV charging, and increasing

stated intention to purchase or lease alternatively-fueled vehicles (while decreasing intention to purchase or lease gas vehicles).

3.3 Relationships Between Knowledge, Attitude, and Intention

To test our hypothesis that increased knowledge of potential for personal savings with alternatively-fueled vehicles would correspond to increased intention to adopt, we explored correlations between change scores in each variable, for each vehicle type, before-and-after using EV Explorer. In general, we did find that increases in perceived potential energy cost savings were correlated with increased intention to purchase or lease alternatively-fueled vehicles, but not always in a straightforward fashion (see Table 4).

Table 4. Correlations between Change in Intention to Purchase or Lease and each: Change in Perceived Savings, and Change in Attitude toward Charging. Postive correlations are interpreted as an increase in Perceived Savings, or positive shift in Attitude toward Charging, corresponds to an increase in Intention to Purchase or Lease.
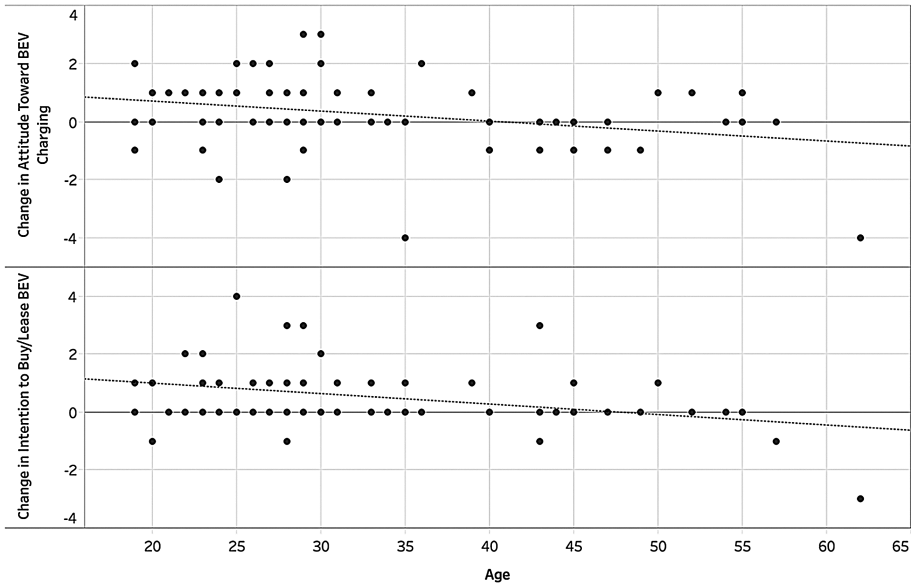
		Change in Intention to purchase or lease			
		Gas	HEV	PHEV	BEV
Change in perceived savings	HEV	−.75	.233[*]	.275[**]	.078
	PHEV	.011	.268[*]	.173	.030[*]
	BEV	−.106	.030[*]	.237[*]	.056
Change in attitude toward charging	PHEV	N/A	N/A	.127	.143
	BEV	N/A	N/A	.034	.361[**]

[*]$p < .05$ [**]$p < .01$

Similarly, we explored correlations between changes in attitude toward charging and changes in intention to purchase or lease PEVs pre- and post-EV Explorer. Our hypothesis was that EV Explorer would engender more positive attitudes toward charging by educating consumers about charging requirements, and that this shift would correspond to increased intention to buy or lease PEVs. Our hypothesis was supported for BEVs but not for PHEVs (Table 4).

3.4 Participant Characteristics Related to Outcomes

We explored correlations between demographic variables (sex, age, and income) and change scores in perceived savings, attitude toward charging, and intention to buy or lease each vehicle type. Participant sex did not correlate significantly with any change score. Age correlated negatively with change in attitudes toward BEV charging ($r = -.274, p = .011$) and change in intention to buy or lease BEVs ($r = -.230, p = .017$); Fig. 6. This suggests that younger participants' attitudes and intentions toward BEVs were more malleable compared to older participants; younger participants were more heavily influenced by EV Explorer.

Fig. 6. Negative correlation between age and each: positive shift in attitude toward BEV charging and increase intention to purchase/lease BEV

Household income (participants selected among income ranges rather than specifying exact amount) correlated negatively with change in perceived personal savings associated with driving a BEV. That is, participants with lower incomes were more likely to have an increased perception of the significance of personal savings associated with BEVs after using the EV Explorer ($r = -.296$, $p = .006$).

3.5   Use of Website Features and Relationship to Outcomes

Most participants reported that they independently noticed each of the features available on the tool (Table 5). However, only commute frequency and "choose a new car" were both independently noticed *and used* by a majority of participants. Notably, 29% did not independently notice the "choose a new car" feature, but they went back and used it after learning about it from the survey. Similarly, 33% did not initially notice but went back and used the feature allowing them to modify energy prices.

Table 5. Salience and participant utilization of each main EV Explorer feature

|		Noticed; used	Did not notice; went back and used	Noticed; did not use	Did not notice; did not use
Commute settings	Commute frequency	71%	8%	19%	1%
	Charging at destination	35%	17%	34%	14%
Car manager	Choose a new car	52%	29%	15%	5%
	Vehicle mileage/ range/time to charge	42%	13%	35%	10%
Energy prices		32%	33%	25%	10%

With the "choose a new car" feature, participants most frequently selected a vehicle they or someone in their household currently drives (52%), followed by a vehicle they are considering getting in the future (44%), a "dream" vehicle (30%), a vehicle they shopped for before deciding on current vehicle (14%), and a vehicle they or someone in their household used to drive (8%). Most commonly selected vehicle types were gas (69%), followed by HEV (37%), BEV (32%), and PHEV (28%). Figure 7 shows a breakdown of vehicle types per category of selected vehicle.
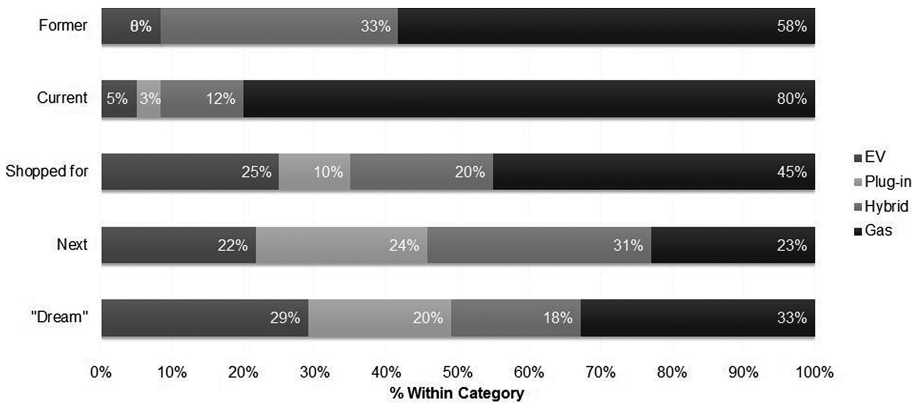
Fig. 7. Types of vehicles participants explored using the car manager feature

Taking advantage of the features allowing modification of commute frequency, information about charging at destination, and energy costs influenced outcomes. In particular, modifying commute frequency was significantly associated with a positive shift in attitude toward charging PHEVs [Mann Whitney $U = 451$, $p = .025$; Did not use feature: $M(SD) = -.33(.21)$; Used feature: $M(SD) = .21(.10)$]. Modifying information about charging at destination was associated with increased intention to purchase or lease a BEV [Mann Whitney $U = 1129$, $p = .020$; Did not use feature: $M(SD) = .21(.11)$; Used feature: $M(SD) = .50(.13)$]. Modifying fuel or electricity prices was associated with a positive shift in attitude toward charging PHEVs [Mann Whitney $U = 603.5$, $p = .003$; Did not use feature: $M(SD) = -.29(.15)$; Used

feature: $M(SD) = .31(.11)$] and increased intention to buy or lease an HEV [Mann Whitney $U = 1053$, $p = .044$; Did not use feature: $M(SD) = .03(.10)$; Used feature: $M(SD) = .23(.09)$]. Figure 8 illustrates these significant findings.
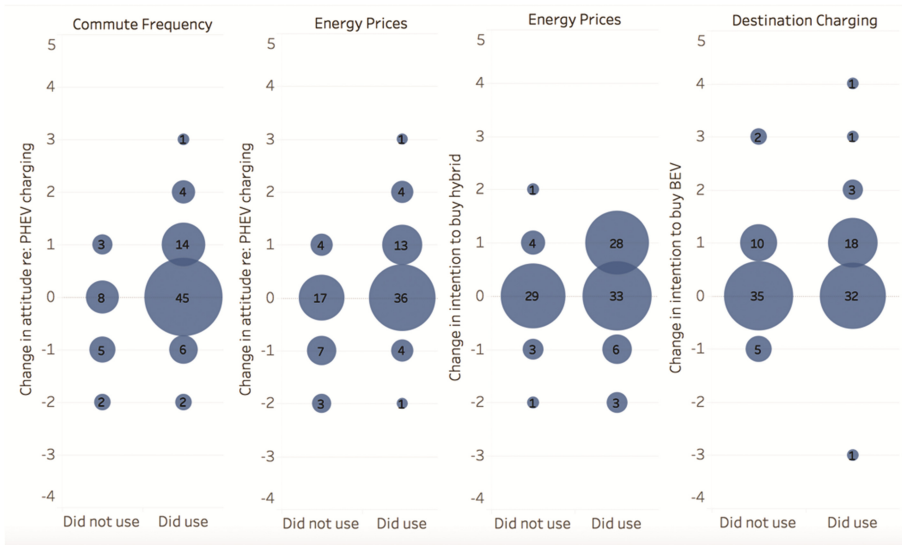
Fig. 8. Relationships between use of features and change scores in attitudes toward charging and intention to purchase/lease

3.6 Limitations and Future Research

There were some drawbacks to the methodology employed. Participant effects, which concern participants guessing the purpose of the study and being influenced by these expectations, are more likely with this kind of within-subjects experimental design. Furthermore, the duration of demonstrated effects on knowledge, attitudes, and intention, and their correlation with actual vehicle purchase decisions, are yet to be investigated. However, this study is the first to validate any impacts of online PEV energy cost calculators and uncover some of the features that make them effective.

Future research should replicate this study using a between-groups design with a much larger sample size. A larger sample size could also reveal more detailed relationships between intervening variables (i.e., demographics and use of features) and outcome variables (knowledge, attitudes, and intention with respect to electric vehicles). A particularly interesting opportunity for future research is to document the behavior of consumers at car dealerships that make this tool available for prospective electric vehicle buyers.

We have modified the design of EV Explorer based on the research findings. For example, we made "choose a new car" and energy price modification features more salient by allowing the user to click on relevant information in the initial bar chart output. In future design iterations of EV Explorer, we plan to incorporate additional commute

inputs and information about other vehicle attributes, such as purchase and lease prices and aesthetics (by including images of vehicles), for a more comprehensive tool.

4   Conclusion

EV Explorer and similar tools can help educate consumers about potential energy/cost savings and charging requirements of electric vehicles. These knowledge gains can promote more positive attitudes regarding charging and increased intention to adopt electric vehicles. In our evaluation, these outcomes were more pronounced for users who took advantage of the ability to personalize their energy cost estimates by inputting their commute frequency, details about charging infrastructure at commute destination, and gas and electricity prices, implying that these are important features to consider when designing electric vehicle energy cost calculators. By enabling quick and simple comparison of annual energy costs for conventional gas vehicles and electric vehicles, as well as information about charging requirements based on the user's own commuting context, electric vehicle energy cost calculators like EV Explorer can empower consumers with the knowledge prerequisite to electric vehicle adoption.

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