Facilitating Electric Vehicle Adoption with Vehicle Cost Calculators

April 2020

A Research Report from the National Center for Sustainable Transportation

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16. Abstract

Consumer education regarding the costs of electric vehicles (EVs), particularly in comparison with similar gasoline vehicles, is important for adoption. However, the complexity of comparing gasoline and electricity prices, and balancing long-term return-on-investment from fuel and maintenance savings with purchase premiums for EVs, makes it difficult for consumers to assess potential economic advantages. Online vehicle cost calculators (VCCs) may help consumers navigate this complexity by providing tailored estimates of different types of vehicles costs for users and enabling comparisons across multiple vehicles. However, VCCs range widely and there has been virtually no behavioral research to identify functionalities and features that determine their usefulness in engaging and educating consumers and promoting EV adoption. This research draws on a behavioral theory, systematic review of available VCCs, and user research with three VCCs to articulate design recommendations for effective VCCs.

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NCST

Facilitating Electric Vehicle Adoption with Vehicle Cost Calculators

A National Center for Sustainable Transportation Research Report

April 2020

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TABLE OF CONTENTS

List of Figures

Facilitating Electric Vehicle Adoption with Vehicle Cost Calculators

EXECUTIVE SUMMARY

One of the potential consumer benefits of electric vehicles (EVs) is lower energy costs compared to internal combustion engine vehicles (ICEVs), particularly in terms of fueling and maintenance costs. However, the complexity of comparing gasoline and electricity prices, and balancing long-term return-on-investment from operating savings with purchase premiums for EVs, makes it difficult for consumers to assess. Online vehicle cost calculators (VCCs) may help consumers navigate this complexity by providing tailored estimates of different types of vehicles costs for users and enabling comparisons across multiple vehicles.

VCCs range widely and there has been virtually no behavioral research to identify functionalities and features that determine their usefulness in promoting EV adoption. This research draws on a systematic review of available VCCs and findings from user research to articulate design specifications for effective VCCs. We strategically selected three VCCs (EV Explorer, BeFrugal and PlugStar) to represent the range of available features and functionalities, which we tested in three types of user research: an online survey of EV Explorer users, in-person usability testing with EV considerers/shoppers, owners, and advocates, and a focus group with EV salespersons.

Recommendations

Based on the findings from the systematic VCC review and user research detailed above, we outline the following best practices and recommendations for VCC user interface design. A variety of stakeholders, including government agencies, energy utilities, and EV advocacy groups, can use these recommendations to create and promote VCCs that encourage EV adoption by providing consumers with accurate and relevant information that highlights the economic, social, and environmental benefits of EVs.

Outputs

- Focus on comparing operational savings of an EV v. a similar ICEV, e.g., in an initial output
- Compare acquisition costs in a separate output, highlighting impact of incentives
- Compare cumulative TCO, highlighting breakeven time for EV v. ICEV
- Present realistic (and editable) maintenance cost estimates for EVs
- Exclude costs that are not significant differentiators of EVs v. ICEVs from default outputs
- Define depreciation costs in layman's terms and do not include in TCO by default (optional)
- Integrate salient, emotionally-evocative information re: EV social & environmental benefits
- Include and define life-cycle emissions estimates (not just tailpipe and/or well-to-wheels)

- If including maps in output, use them to visualize EV range and public charging locations

User Experience

- Required inputs should be relatively minimal and high leverage in terms of tailoring output
- User inputs should have flexible response formats to minimize cognitive demand
- Maximize optional inputs to maximize ability to tailor results
- Optional inputs should be separate from required inputs to lessen perceived demand
- Optional inputs should be salient when the output is displayed so the user is aware of them
- Optional inputs that are irrelevant based on other user inputs should not be displayed
- Default optional input values should be as tailored as possible, accurate & explicitly labelled
- Annotate input defaults with sources and tips to help users decide whether/how to modify

Inputs

Vehicle Selection and Specification

- Require some vehicle selection inputs (e.g., one make-model-year, body style, price range)
- Provide comprehensive selection of vehicle models and years (inclusive of all drivetrains)
- Provide link alongside vehicle selection inputs to tool dedicated to EV shopping
- Enable comparison of at least 4 vehicles (more is better, but default at 2 for initial output)
- Allow users to modify efficiency-related specs for chosen vehicles

Driving

- Require some driving inputs, designed to estimate total mileage accurately or generously
- Communicate the implications of daily driving (between charges) for PHEV fuel costs
- Use flexible formats so users can easily estimate mileage in a way that makes sense to them
    - For mileage inputs, let the user specify the denominator (e.g., miles per day/year)
    - For mileage inputs, allow multiple daily profiles (e.g., weekdays and weekend days)
    - For trip inputs, allow more than one trip, route specification and waypoints
    - Supplement trip inputs with “other driving” and/or annual mileage input

Fueling

- Include optional inputs for fuel prices with defaults as specific to user location as possible
- Only display optional inputs for prices of fuel types used by the vehicles being compared
- Label default prices so the data source is clear (e.g., PG&E off-peak rate)
- Use off-peak rate as editable default for home charging price (with link to more rate info.)
- Allow users to easily indicate exclusively home charging or exclusively public charging
- Provide optional charging inputs to factor in time-of-use and multiple public chargers
- Partner with charger companies to estimate level and cost for user-selected stations

Financing

- Include optional inputs for new and used vehicle acquisition costs
- Include different sets of inputs based on acquisition type (cash, loan, lease, and rent)
- In default estimates of vehicle price, specify or note implications of different trim levels
- Estimate used car resale value based on Kelley Blue Book or Consumer Reports
- Include optional inputs for all relevant financing terms and state-specific taxes and fees
- Provide up-to-date federal, state and local incentive estimates
- Include household income tax information inputs to determine incentive eligibility
- Allow direct modification of vehicle price and incentives in addition to the above inputs

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 and can dramatically reduce climate-altering greenhouse gas emissions, given a sufficient mix of clean energy sources providing the electricity (Hawkins, Gausen, & Strømman, 2012; Hawkins et al., 2013; Jaramillo et al., 2009; Onat, Kucukvar, & Tatarim, 2015).

There are two types of plug-in electric vehicles (PEVs--referred to also as EVs in this report): (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.

Risks associated with EV adoption include relatively higher purchase price and limitations in vehicle range and charging infrastructure (Egbue & Long, 2012; Khan & Kockelman, 2012; Tamor & Milačić. 2015). These risks are founded in real challenges, but are also partly a function of consumers' lack of knowledge and experience with EVs. For example, Jakobsson et al. (2016) found that even prospective EV buyers have very little knowledge regarding range performance, charging infrastructure, and the ability to plug in at home. Regarding the phenomenon of "range anxiety"—fear of being unable to reach one's destination—most drivers' regular commute travel range is lower than the modern electric vehicle's range (Khan & Kockelman, 2012; Tamor & Milačić. 2015).

Human-computer interaction (HCI) researchers have developed web-based tools to help mitigate these risks, particularly the issue of range anxiety. Lundström and colleagues (2012, 2014, 2015) 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 include BMW's EVolve App and Stanford researchers' Virtual EV Test Drive (Schewel, 2011). These apps are excellent educational tools for prospective EV buyers, though they require a time commitment of several days or weeks to use properly.

There has been less HCI research regarding web-based tools that attempt communicate the potential benefits of EVs to consumers. Social science research shows that consumers weigh perceived benefits more heavily than perceived risks when evaluating new technologies (Starr, 1969). 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 (Alhakami & Slovic, 1994). Thus, tools that communicate benefits could be a promising part of the solution to increasing EV adoption.

Benefits of EVs for consumers include lower fuel and maintenance costs compared to gas vehicles (Cuenca, Gaines, & Vyas, 2000; Propfe & Redelbach, 2012). Online vehicle cost calculators (VCCs) can help communicate these benefits. Many vehicle cost calculators (VCCs) exist, but there is virtually no research exploring user experience with VCCs to understand how they are being used and assess the usability of different features and styles.

The goal of this seed project was to outline best practices for CC user interface design, based on behavioral theory and user experience research. A variety of stakeholders, including government agencies, energy utilities, and EV advocacy groups, can use these recommendations to create VCCs that promote EV adoption by providing consumers with accurate and relevant information that highlights the economic, social, and environmental benefits of EVs. The next section reviews the literature on car buyers' perceptions of vehicle fuel costs, demonstrating the need for VCCs and further setting the stage for the present research.

Car Buyers and Fuel Costs?

Research suggests that consumers do not typically consider, let alone analyze, fuel costs when making a vehicle purchase (Allcott, 2011; Turrentine & Kurani, 2007). Turrentine and Kurani interviewed 57 households across a diversity of lifestyle sectors; none analyzed fuel costs in any systematic way in their vehicle purchase decision. Allcott described results from a nationally representative survey which found that 40% of respondents did not think about fuel costs at all when making their last vehicle purchase decision and 35% thought some about it but did not do any calculations.

Not only do consumers tend to not think about fuel costs, we are also not very good at it. In Turrentine and Kurani (2007), only 2 of the 57 interviewed households were able to reasonably estimate potential cost savings associated with a higher fuel economy vehicle. Research on consumer perceptions of energy costs and savings in the context of fuel economy comparisons (MPG illusion, Larrick & Soll, 2008), and energy efficiency measures more broadly (Attari et al., 2010) points to common perceptual biases that contribute to large errors in estimations. In particular, consumers tend to underestimate relative savings potential when comparing lower MPG vehicles and overestimate differences between higher MPG vehicles. Allcott (2010) pointed to another bias called consumer myopia and the phenomenon of "shrouded costs" (Gabaix & Laibson, 2006), suggesting consumers focus on purchase price and ignore add-on costs, such as energy costs.

Calculations can overcome the perceptual biases affecting our more "off-the-cuff" estimations. For example, Allcott (2010) found a positive correlation between doing fuel cost calculations and choosing a higher fuel economy vehicle. However, calculating potential fuel savings with an EV compared to a gas vehicle is a complex endeavor, requiring no trivial amount of cognitive effort (Egbue & Long, 2012). For example, comparing a BEV to an ICEV requires knowledge regarding current gas prices and electricity prices at each place the consumer may charge the EV (home, work and/or other public charging stations), fuel economy of the gas vehicle, and electricity consumption per mile of the EV, all of which vary (Kurani, Caperello, & TyreeHageman (2016).

Eppstein et al. (2011) recommended vehicle energy cost calculators (VECCs) as a solution to help consumers navigate this complexity. Specifically, they noted that "simple tools (such as web calculators or automated kiosks in dealerships) could query consumers about their typical daily VMT, percent of city driving, place of residence, and expected duration of ownership of their next vehicle. Based on this information, users could be provided with a range of expected lifetime vehicle fuel costs, using high and low governmental gas price projections, while accounting for regional differences in electricity and gasoline prices." (p. 3800).

However, even if consumers recognize the energy costs savings associated with EVs, they may not understand whether these savings will offset the higher vehicle purchase price of an EV compared to a gas vehicle. Thus, Wu, Inderbitzin, and Bening (2015) recommended policies that facilitate consumer engagement in evaluations of total costs of ownership (TCO) which would account for the balance of acquisition and operating costs. They also specifically recommended vehicle cost calculators (VCCs) which may include multiple cost categories in addition to energy costs. Wu et al. noted that current VCCs are inconsistent (e.g., in terms of the cost elements and vehicle types included), which "might make difficult for policy makers to promote and for consumers to recognize a best practice. Hence, the consolidation of the currently fragmented platforms to one standardized platform could enable targeted promotions by policy makers and therefore increase the TCO awareness. As … the TCO of EV will become more competitive compared to conventional vehicles in the future, the probability of changing the high cost perception of EV with such a promoted tool could also increase" (p. 74). This research aims to support the recommendations of Wu et al. by articulating best practices for designing VCCs.

Methodology

This research involved two general data collection strategies: an in-depth review of currently available VCCs and usability research. The goals of the VCC review were to:

1. Operationalize the features of VCCs that could have implications for user experience and EV adoption intentions
2. Identify several VCCs to test in the user research that would represent the range of identified key features in existing tools
3. Inform recommendations for VCC design specifications

The usability research aimed to reach multiple relevant stakeholder groups (VCC users, EV shoppers and owners, and EV salespersons). Goals included gaining an understanding of use cases for VCCs and user experience of several specific VCCs (representing the range of available tools) and informing recommendations for VCC design specifications.

VCC Review

Available VCCs were identified via internet searches and consultation with experts. Search terms included: "car cost calculator", "electric vehicle calculator", "energy cost calculator". Tools were included if they provided user-customizable cost calculations for both gas (internal combustion engine or hybrid) and electric (plug-in hybrid or battery electric) vehicles, and cost outputs for energy costs. Manufacturer-specific and retail tools that focus only on purchase and lease costs were excluded. Table 1 lists the VCCs reviewed.

Table 1. Names and web addresses for VCC reviewed

VCC Name	Web address
AFLEET	afleet-web.es.anl.gov/afleet/
BeFrugal	befrugal.com/tools/electric-car-calculator/
Consumers Energy PEV Calc.	consumersenergy.com/apps/pev/index.aspx?ekfrm=3751
DOE VCC	afdc.energy.gov/calc/#result_a
UC Davis EV Explorer	gis.its.ucdavis.edu/evexplorer/#!/locations/start
PG&E EV Savings Calculator	pge.com/en/pevcalculator/PEV/index.page
Fueleconomy.gov Fuel Savings Calc.	fueleconomy.gov/feg/savemoney.jsp
“” My Plug-in Hybrid Calc.	fueleconomy.gov/feg/Find.do?action=phev1Prompt
“” Trip Calculator	fueleconomy.gov/trip/
Oncor Operating Savings Calculator	oncor.com/SitePages/EV-Savings.aspx
PlugStar	plugstar.com/cars/research; http://plugstar.com/cars/compare
SMUD	c03.apogee.net/mvc/home/hes/land/el?utilityname=smud&spc=evc
WattPlan	csi.wattplan.com/ev/

Extensive coding was conducted for each VCC to describe its objective features and functionalities. Coding was iterative; as new tools were reviewed, new coding categories and levels were specified, and other tools revisited to compare across each relevant dimension. Coding was also inductive; meta-categories were created to organize the information into high-level feature sets (e.g., energy price inputs), which guided the design of the user research. Notes on more subjective aspects of the tools were also recorded to support qualitative analysis and comparison of tool usability, e.g., in terms of ease of use and interpretation and engaging style. Table 2 presents a simplified summary of the coding.

Table 2. VCC Review Simplified Coding

	Inputs								Outputs							
	Vehicle Select. and Specs		Driving		Fueling		Financing		Financial Costs					Social and Environmental Costs		
Tool	Optional	Required	Optional	Required	Optional	Required	Optional	Required	Energy Costs	Total Costs	Cum./Payback	Incentives	Savings	Fuel Use	CO2	Air Pollution
Argonne Lab AFLEET	X	X	X		X		X				X			X	X	X
BeFrugal	X	X	X		X		X		X	X	X			X	X	
Consumers Energy Plug-in EV Calc.	X		X		X				X							
DOE Vehicle Cost Calculator	X	X	X				X		X	X	X			X	X	
PG&E EV Savings Calculator	X		X		X		X		X	X		X	X	X	X	
UC Davis EV Explorer	X	X	X	X	X				X							
Fueleconomy.gov Fuel Savings Calc.		X	X		X		X		X	X	X		X			
“” My Plug-in Hybrid Calculator	X		X	X	X				X					X		
“” Trip Calculator	X	X	X	X	X				X							
Oncor Operating Savings Calculator	X		X		X				X				X			
PlugStar “Compare”, “Research a Car”	X	X	X	X			X		X	X		X	X			
SMUD	X	X	X		X				X				X		X	
WattPlan		X	X		X		X		X	X	X	X	X		X	

Usability Research

Usability research was conducted with three stakeholder groups: VCC users, EV consumers representing the range of adoption stages (e.g., considering an EV, actively shopping for an EV, and current EV owners/drivers), and EV salespersons. These stakeholder groups were selected to offer a range of potential VCC use cases and user experience perspectives.

VCC User Survey

An online survey was designed to gain better insights into who VCC users are, what they want to accomplish, and their experience and preferences with respect to three VCCs (EVExplorer, PlugStar, and BeFrugal) chosen based on the VCC review. A contact list from EV Explorer, where users can enter their email address to volunteer to participate in EV research, was used to identify VCC users. A survey invitation was sent to all 105 contacts on this list.

Seven of the survey invitation emails bounced back and 22 recipients completed the survey, resulting in a response rate of 22%. The sample was predominately comprised of males (86%). Median age was 52. Median household income was $100,000-149,999, with 38% of respondents making over $150,000 per year. At the start of the survey, participants were asked if they had used others VCCs besides EV Explorer and most (67%) reported that they had.

The survey directed participants to explore each of the three VCCs for at least 5 minutes prior to answering a set of questions about their use and preferences for different features, including closed- and open-ended questions. In order to ensure participants understood what the question was referring to, each question about a VCC feature was paired with a corresponding image of that feature on the website. For example, Figure 1 shows an example of an image from PlugStar that was paired with the question "using the features highlighted in the orange box... are you satisfied with the ability to tailor vehicle cost estimates based on your driving patterns?" Questions for similar features were worded identically across the three tools to enable comparison. A short usability scale (Figure 2) was also included, referencing the cost comparison output each tested VCC.

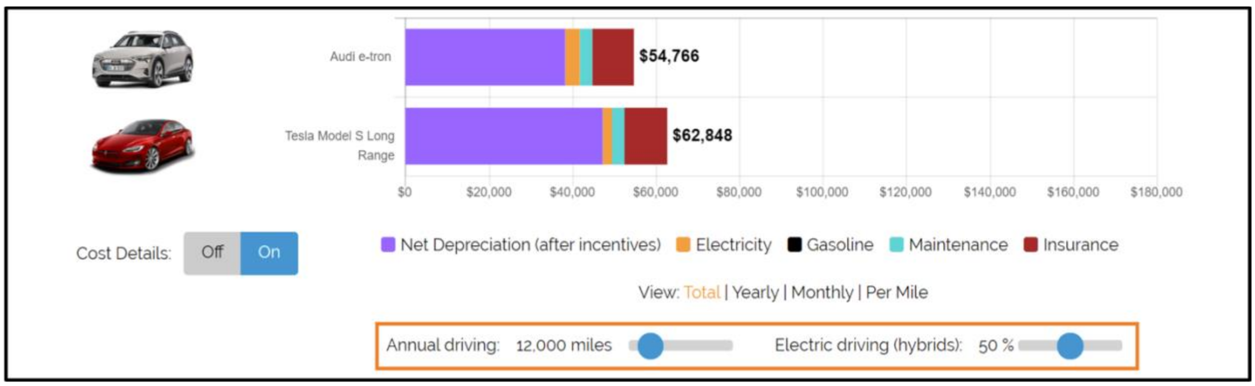


Figure 1. Survey prompt and image pairing

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The information is accurate and trustworthy.	○	○	○	○	○
The information is interesting and engaging.	○	○	○	○	○
The information is useful and relevant.	○	○	○	○	○
The information is persuasive and motivating.	○	○	○	○	○

Figure 2. Online Survey usability scale

Consumer Usability Interviews

In-person usability interviews were conducted with the same three selected VCCs, using several recruitment methods to capture multiple EV consumer perspectives. Researchers attended the Los Angeles International Auto Show and hosted a booth in the event's EV Lounge where they conducted usability interviews on-site with nine attendees who came into the EV Lounge, including some who participated in a tour of EVs at the auto show. Four participants were recruited via advertisement in the SacEV Newsletter, and two UC Davis employees who were considering an EV purchase were recruited through word-of-mouth. The latter interviews were conducted in a conference room in the UC Davis Plug-in Hybrid & Electric Vehicle Research Center. All interviewees received a $20 Starbucks gift card.

The protocol for these interviews involved moderated usability testing, in which researchers observed participants in-person while they interacted with the VCC websites and attempted to carry out tasks. Interviews at the auto show lasted 30-60 minutes and participants tested two VCCs, chosen randomly from the three being tested or based on interests the participant mentioned in casual conversation leading up to the testing (e.g., if they mentioned curiosity about incentives the researcher showed them PlugStar which was the only tested tool with incentive information). Interviews at the PH&EV Research Center lasted one hour and participants tested all three tools. The tools were presented in random order. All users were given 10-15 minutes to interact with each tool.

A mix of think-aloud and modified retrospective probing methods were used. Participants were encouraged to explore the VCCs as they would naturally, in a way that seemed interesting to them, and to talk about their reactions and thought processes as they went along (i.e., think aloud). At various points during and after testing, the researcher asked questions to get at participants' overall assessments of the VCCs and particular features; this modified retrospective probing method allowed the researcher to solicit detailed feedback on each tool's process and output rather than waiting until the end of testing when the participant may have forgotten some of their experiences. If the participant was frustrated or unable to find a feature, the researcher guided them in the interest of time and to keep the experience positive.

EV Salesperson Focus Group

In partnership with Plug In America, the researcher conducted a focus group with EV salespersons at a dealership in Roseville, CA; sales staff experienced in EV sales from multiple dealerships in the greater Sacramento area were invited to participate. The focus group assessed salespersons experiences and opinions regarding the PlugStar dealer app (unrelated to this study) and the cost calculator in PlugStar's consumer-facing website, which is one of the three VCCs that was selected for usability research. The researcher provided an overview of the VCC, focusing on the cost calculator, and then gave discussion prompts to answer the following questions:

- Are they aware of this website and feature?
- Do they use it or refer customers to it?
- How do they use it, or how would they like to use it?
- Does it seem to address questions that customers have when shopping for an EV?
- Where does it fall short?
- How do they explain cost differences between electric and gas vehicles to customers?
- What are the barriers for salespersons to use the tool and refer customers to it?
- Could/how could these issues be addressed to create a version of the tool they would be more inclined to use/refer customers to?

Results

Findings from the VCC review and usability research are integrated and organized into the four sections that follow: use cases, outputs, general user experience design considerations, and inputs. Inputs are organized into five sub-categories: car selection and specification, driving, fueling, financing, and other. Design recommendations based on insights from the VCC review and usability research are presented in a subsequent section.

Use Cases

User research revealed a variety of use cases for VCCs, for consumers with a range of knowledge of and experience with EVs. Use cases ranged in terms of specificity of goals, from more general exploratory research to the pursuit of precise answers to specific questions. Table 3 presents survey-takers' responses when asked why they first visited EV Explorer and similar tools. Findings across the user research were distilled into three general use cases:

1. **Exploratory:** May or may not have an EV, seeking to learn more about costs, range, and/or charging
2. **Computational:** May or may not have an EV, seeking to quantify costs; may wish to compare across vehicles (same or different drivetrain) or different routes
3. **Confirmatory:** Has an EV or wants an EV, seeking to validate adoption decision

Table 3. Survey Respondent Reasons for Using VCCs

Decide if an EV made sense for me
to compare costs
to put savings on gas into perspective
Too estimate potential savings on vehicle operations when deciding whether I could afford an EV.
I read an online article about it
to compare the cost of gas vs. electric car
To see which EVs would be most efficient.
Want to compare costs & ability to handle household (me & spouse's) commutes.
To see which PHEV would be cheaper for me and my wife to use (we have 2)
Checking out the data on EVs... And chargers.
Just to play with it.
To evaluate and research a vehicle that I was considering purchasing.
Seemed relevant
I don't need a website for ev purchase or lease
Gas / MPG Calculator for Research. Unnecessary window shopping for vehicles. Looking for overall cost of operation to help with Bills as well.
I don't remember the last time I visited EV explorer
curiosity to see if it was remotely accurate to my personal experiences.
Quantification of how much EV is saving me.
I can't remember, and it appears to be non-functional on an iPhone so I can't remind myself! I might have been doing research for a presentation about EV adoption.
To get an idea of the savings I get driving an all-electric vehicle, to inform others about driving electric.
purchasing decisions
I wanted compare costs of electric and gas vehicles as I'd probably buy a new car soon
Wanted to calculate cost of commute with ev
compare costs
to know more about recommended routes & fuel efficiency
to discover best routes & know them for better efficiency in driving
Don't remember
I was comparing costs of driving my hybrid versus an EV.

A minority seemed to be interested in just learning more about EVs, either generally (typically non-EV drivers) or in terms of a specific aspect like charging. Some wanted to know if an EV would work for them, including concerns broader than costs (such as range sufficiency). Most had goals involving cost comparisons, e.g., to support an upcoming purchase decision, including gas vehicle drivers trying to understand the cost implications of EVs compared to gas vehicles or trying to decide between multiple prospective EVs. Sometimes the focus was on energy or operational costs exclusively, and other times users wanted help understanding total costs, including acquisition/ownership costs. Interviewees confirmed the importance of information on acquisition costs and incentives, the latter being particularly important for those very close to the purchase decision, and highlighted a need for tools that better account for used vehicle acquisition and maintenance costs (one interviewee was interested in purchasing a used EV but unsure what to expect in terms of battery replacement).

Current EV drivers' use cases included seeking to quantify or compare their EV costs for their own curiosity, finance management, or to share the information with others. EV shoppers who were very close to the purchase decision resembled the EV drivers' confirmation use case (rather than a more exploratory or strictly computational use case) in that they saw the use of VCCs as helping them accomplish "due diligence" in confirming the benefits of the EV they had already decided to acquire. An illustrative case was a female interviewee who was considering a Chevy Bolt or Tesla Model Y and was clearly more attracted to the Tesla; upon seeing a $3 advantage in maintenance costs for the Tesla she enthusiastically exclaimed, "Score 1 for Tesla!"

Other use cases that could apply to gas or EV drivers involved comparing the efficiency of different routes or different vehicles for a specific trip; for example, one participant noted, "[I] would like to be able to calculate road trips (e.g., cost to drive to Seattle with gas vs. electric)." Though it did not emerge as a desired use case in the usability research, emerging standards promoting electrification of transportation network companies like Uber and Lyft suggest that another increasingly important use case for VCCs is to support ride-hailing drivers in identifying EVs that would meet their needs.

Outputs

VCC Review

The VCCs reviewed include different types of financial cost information displayed in different styles. Some tools include only energy costs (EV Explorer, SMUD's calculator, Oncor's Operating Costs Calculator, and Fueleconomy.gov's Trip Calculator), but most attempt to account for a broader picture of costs, including additional operating costs and acquisition costs as well. However, there is also variability in terms of which costs are included in a given tool's "total costs" and how costs are categorized. PlugStar provides a breakdown of total costs in terms of five categories: "net depreciation [or lease] (after incentives), electricity, gasoline, maintenance, and insurance"; the default output shows only total costs, but a box can be checked to display the breakdown within the same chart (Figure 3). BeFrugal's output provides a total for gas, electricity and maintenance costs (in addition to the three categories individually) and a total cost that includes acquisition costs based on vehicle financing and incentives but not accounting for resale value/depreciation; insurance costs are also not included and the inputs for financing do not build in an easy way to account for taxes and fees though it is possible for a user to adjust purchase price up to account for these factors (Figure 4). DOE's VCC folds fuel, maintenance, and several other costs into an "operational costs" category (Figure 5). WattPlan has an extensive set of cost outputs (Figure 6) and is unique in that it provides costs for solar PV installation as well as expected energy bills based on solar installation and EV charging.

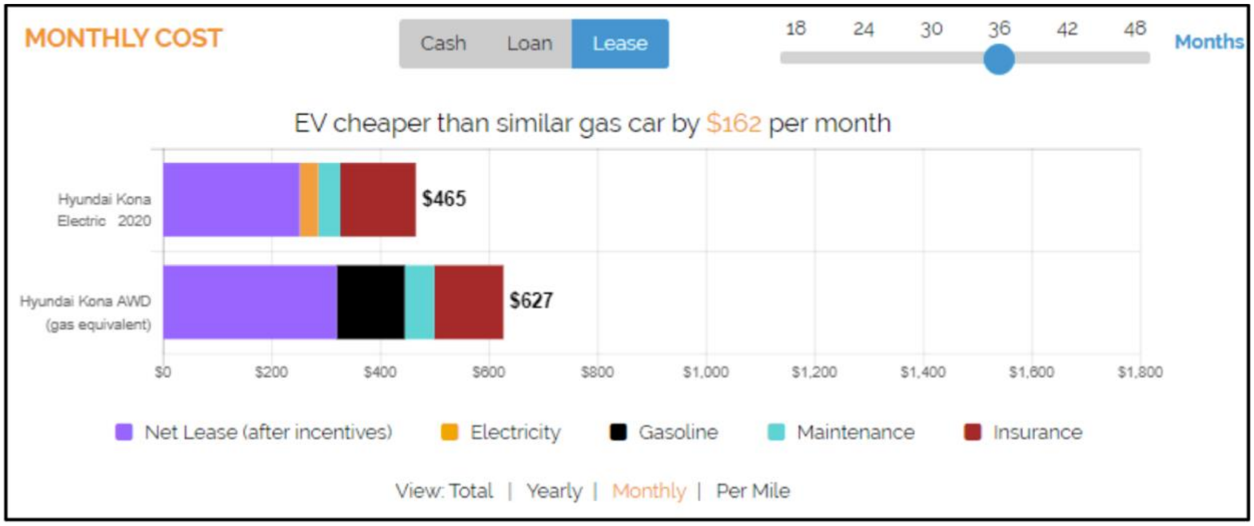


Figure 3. PlugStar output total cost and breakdown

Results:

Yearly Costs:

Annual Fuel & Maintenance Costs	Audi e-tron	Audi A6 55 TFSI 3.0T
Gas/Diesel Cost	$0.00	$2,843.41
Electricity Cost	$2,526.86	$0.00
Maintenance	$887.76	$1,475.00
Annual Payments	$24,943.80	$22,676.16
Total Annual Cost (First 3 Years)	**$28,358.42**	**$26,994.57**
Total Annual Cost (After 3 Years)	**$3,414.62**	**$4,318.41**
Cost Equivalent MPG[3]	**28**	**25**

Figure 4. BeFrugal output total costs and breakdown

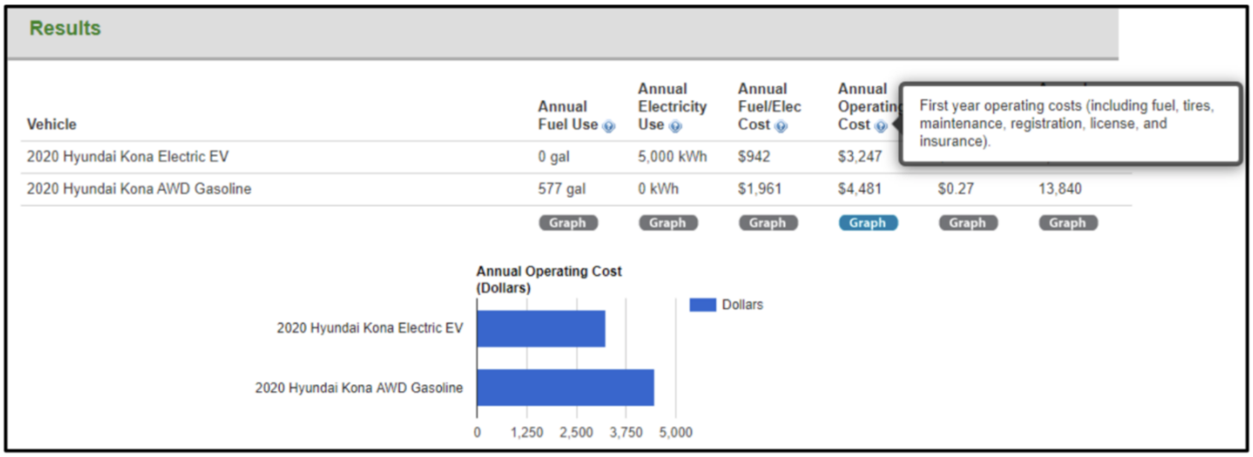


Figure 5. DOE's VCC output with interactive cost categories

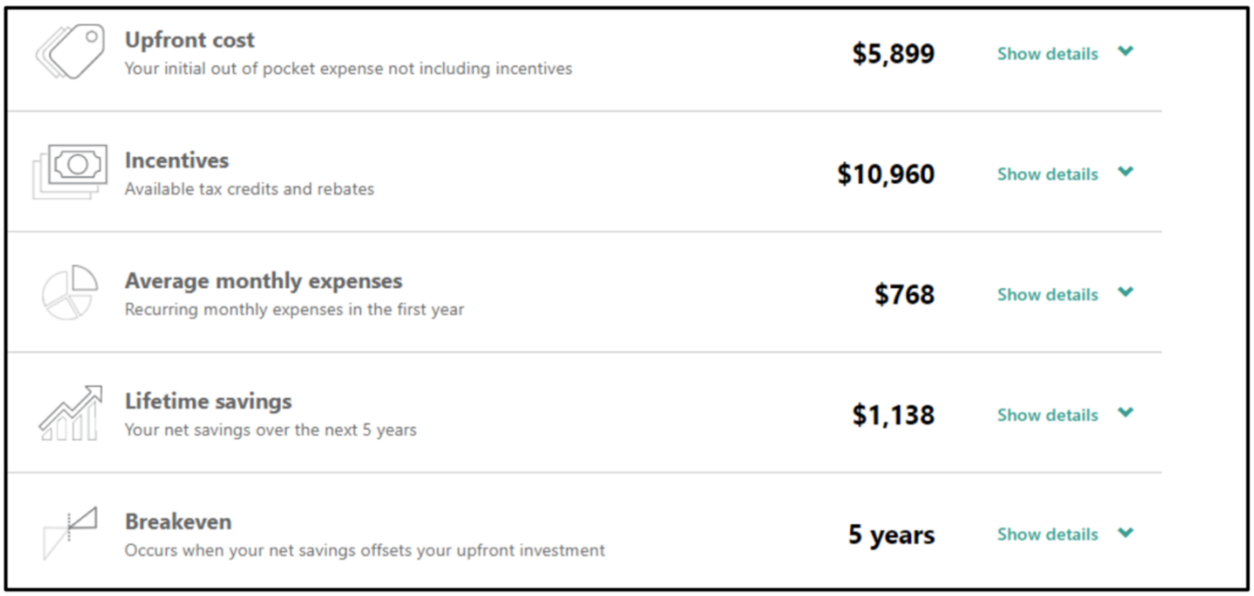


Figure 6. WattPlan output with extensive costs categories

Many tools also include social and environmental costs (i.e., fuel used, carbon emissions and other air pollutants). AFLEET, BeFrugal, DOE's Vehicle Cost Calculator, and Fueleconomy.gov's My Plug-in Hybrid Calculator, and PG&Es EV Savings Calculator provide information about fuel consumption, the latter also estimating number of trips to the gas station for a PHEV. AFLEET, BeFrugal, DOE's VCC, PG&E's EV Savings Calculator, PlugStar's Compare Tool, and WattPlan provide information about CO2 emissions. Oncor has a separate calculator for just carbon emissions (Figure 7) that mirrors their Operating Savings Calculator, which just shows fuel consumption and costs. BeFrugal is unique in breaking CO2 down into tailpipe and upstream emissions (Figure 8). WattPlan, BeFrugal, and PG&E also provide equivalencies for CO2, e.g., BeFrugal provides the number of trees required to offset the same amount of carbon and WattPlan provides trees planted and tons of waste recycled for carbon spared with an EV

(Figure 9). AFLEET is unique in including other air pollutants in addition to GHG emissions and petroleum use (Figure 10).

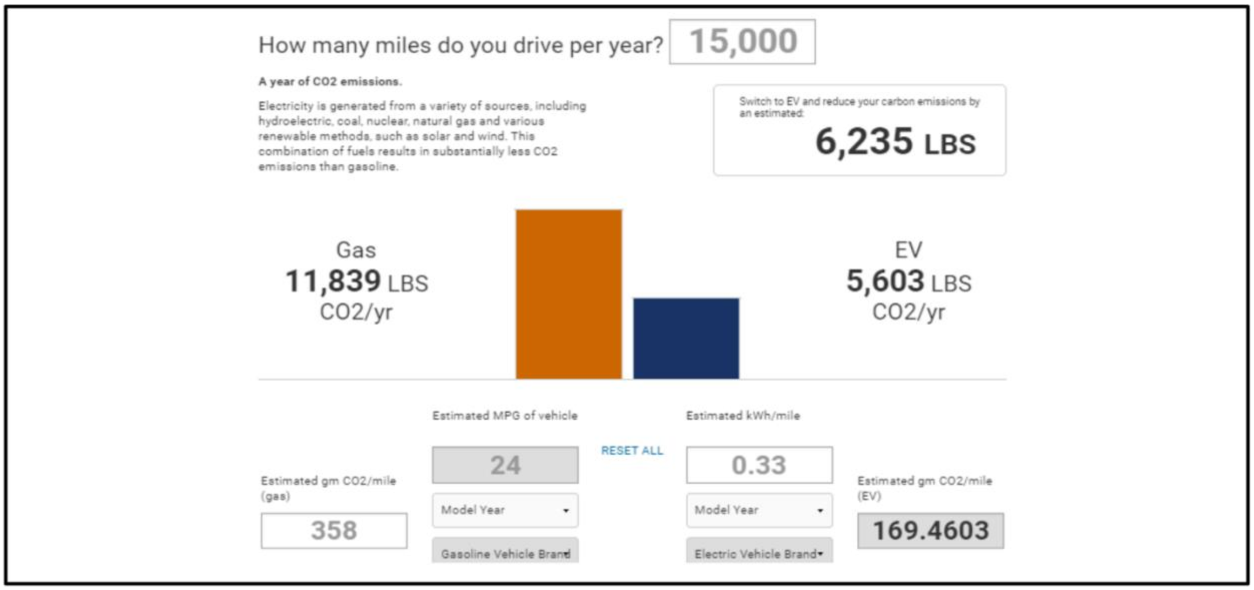


Figure 7. Oncor Air Quality Calculator comparison of CO2 for EV versus gas vehicle

Annual Environmental Costs	Audi e-tron	Audi A6 55 TFSI 3.0T
Gas/Diesel used per year (gal)	0	1175
Electricity used per year (kWh)	12090	0
Tailpipe CO_2 (in tons)[4]	0.0	10.3
Upstream CO_2 (in tons)[5]	2.1	2.6
Total CO_2 Emissions (in tons)	**2.1**	**12.9**
Equivalent in trees[6]	54	335

*Note that Audi e-tron has a battery range less than your road trip mileage. This means that you will need to recharge your battery to complete your road trip(s).

Figure 8. BeFrugal breakdown of total CO2 into tailpipe and upstream and equivalent in trees

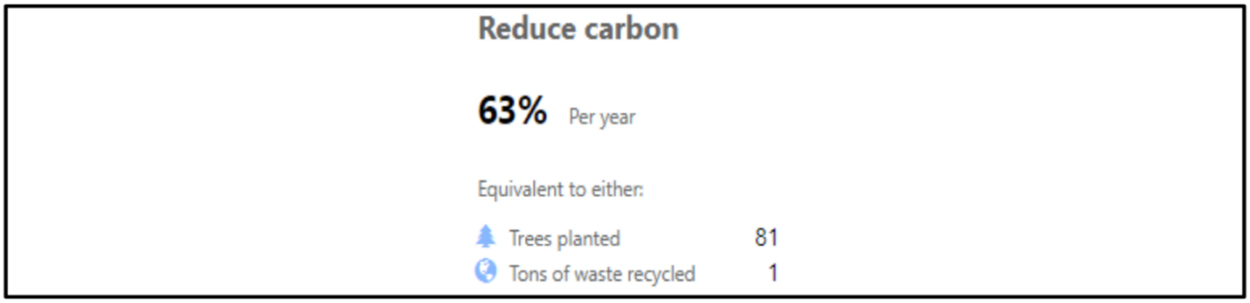


Figure 9. WattPlan summary of carbon emissions savings with EV compared to gas vehicle

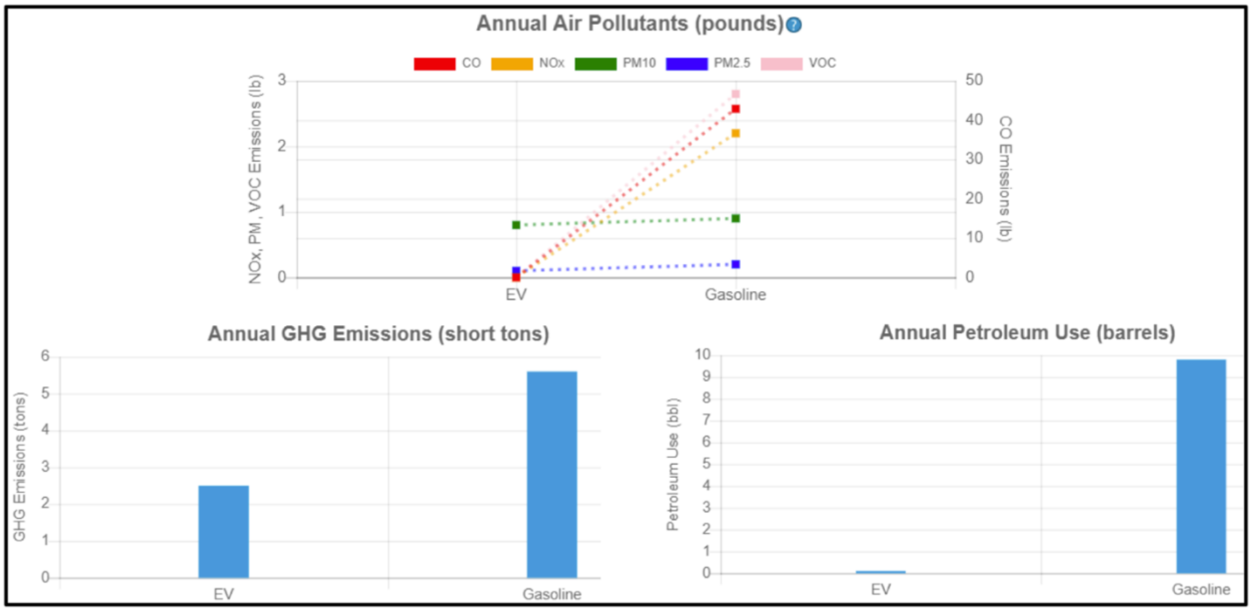


Figure 10. AFLEET comparison of air pollutants, GHG emissions and petroleum use for EV versus gas vehicle

In addition to displaying the separate costs for multiple vehicles, some VCCs specifically call out the potential financial savings achievable with an EV compared to a gas car (e.g., PlugStar's Research a Car Tool, WattPlan, SMUD, Oncor, PG&E, and Fueleconomy.gov's Fuel Savings Calculator; see Figure 11). WattPlan, SMUD, Oncor, and PG&E also specify carbon emissions savings for the EV versus gas car comparison rather than just displaying the separate emissions of each vehicle. With other tools (e.g., EV Explorer, BeFrugal, DOE's Vehicle Cost Calculator, and PlugStar Compare Tool), the user would need to independently calculate the difference between values for the compared vehicles. Another way of framing costs for the user is to show cumulative costs over time, which can reveal years to breakeven if considering a car with higher acquisition costs but lower operating costs than a comparison vehicle (as is the case for EVs and comparable gas vehicle models). BeFrugal, DOE's Vehicle Cost Calculator, WattPlan, Fueleconomy.gov's Fuel Savings Calculator include this approach. BeFrugal and WattPlan also call out the time to break even so the user does not have to interpret the graph (Figure 12-13).

Figure 11. Savings highlighted in Fueleconomy.gov's Fuel Savings Calculator

Figure 12. BeFrugal's cumulative costs and breakeven output

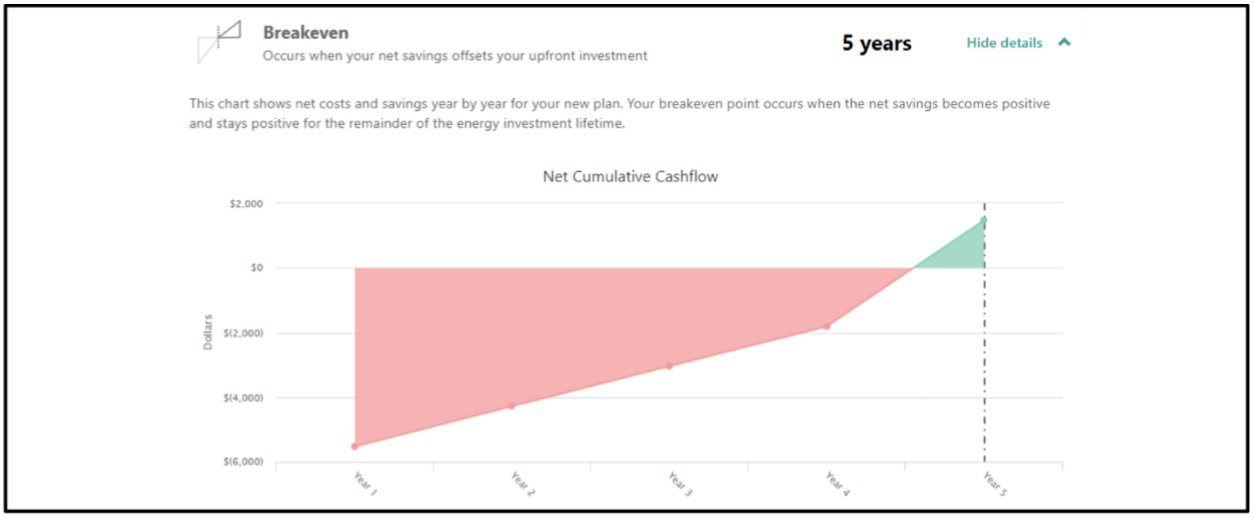
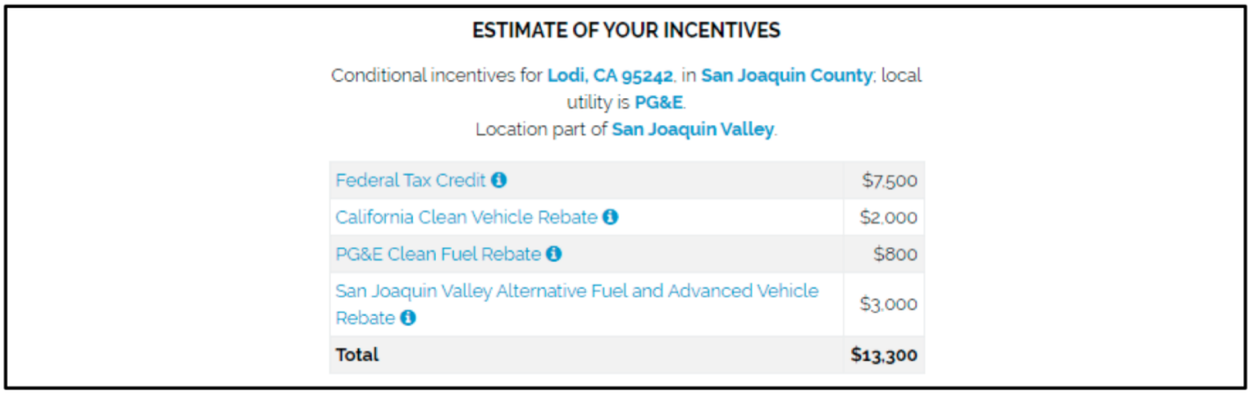


Figure 13. WattPlan's cumulative costs and breakeven output

Cost outputs are displayed over various time periods (or over distance, e.g., per mile costs) and in various data visualization styles. Cost (and savings) breakdowns over specific time periods and costs per mile are typically displayed in bar charts and/or tables with text (Figure 3-5). PlugStar and Fueleconomy.gov's Fuel Savings and My Plug-in Hybrid Calculators offer flexibility within a given output by providing a toggle or menu allowing the user to change the interval over which costs are calculated (e.g., per-mile, weekly, monthly, annually, over the expected ownership period); e.g., Figure 3. Cumulative costs are typically displayed with line graphs (Argonne's AFLEET is an exception, it uses a bar chart). WattPlan is unique in that it highlights the net difference between whereas others display cumulative costs for each car. Social and environmental costs are typically presented only as annual costs (with the exception of PlugStar's Compare Tool which gives grams per mile and SMUD which provides monthly CO_2 savings) and there is less consistency in the display style, e.g., text table in BeFrugal (Figure 8), bar chart in Oncor (Figure 7), line graph and bar chart in AFLEET (Figure 10), icons with text and text table in WattPlan (Figure 9).

EV incentives are an important consideration for VCC outputs related to acquisition costs and/or total costs, so they are often explicitly included in optional inputs. For example, BeFrugal has an optional input field for incentives with a (relatively untailored) default value but the user must refer to other sources to know which incentives apply to their household and prospective vehicle. However, information about incentives can also be considered an output in some tools. On the other hand, PlugStar, WattPlan, and PG&E's EV Savings Calculator provide the user with tailored incentive information based on other inputs (e.g., selected car, user zip code) which in turn factors into their cost calculations (Figure 14-16).



ESTIMATE OF YOUR INCENTIVES

Conditional incentives for Lodi, CA 95242, in San Joaquin County; local utility is PG&E.
Location part of San Joaquin Valley.

Federal Tax Credit	$7,500
California Clean Vehicle Rebate	$2,000
PG&E Clean Fuel Rebate	$800
San Joaquin Valley Alternative Fuel and Advanced Vehicle Rebate	$3,000
Total	**$13,300**

Figure 14. PlugStar incentives output

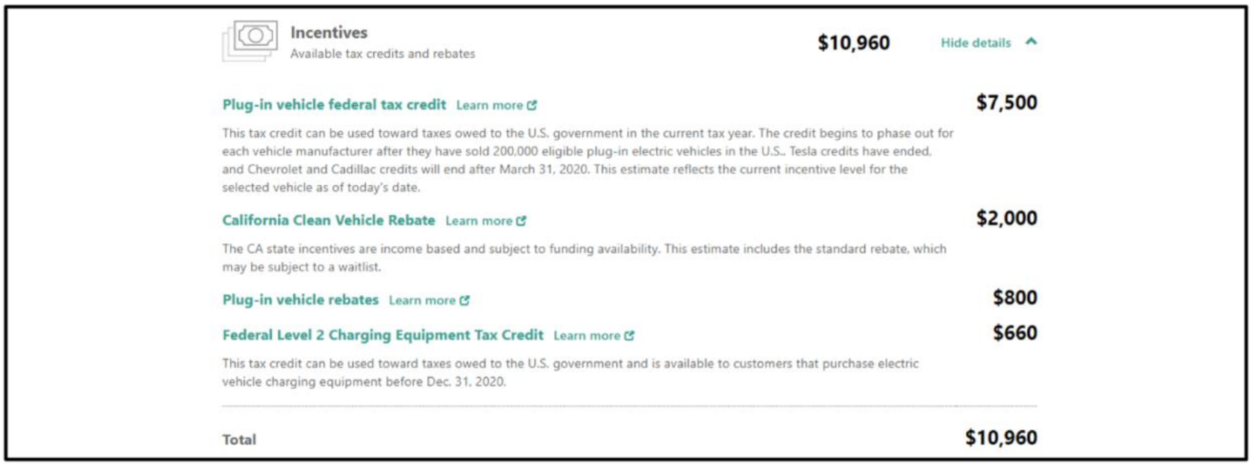


Figure 15. WattPlan incentives output

Figure 16. PG&E incentives output

Another category of outputs in some VCCs pertains to range sufficiency of selected EV models. This is typically a tangential output not highly integrated with cost outputs. For example, WattPlan provides a map at the end of their output highlighting the one-way and roundtrip distances of the selected EV relative to user location (modifiable) as well as nearby charging stations (Figure 17). BeFrugal provides a fine-print caveat if a selected EV does not have sufficient range to accomplish the driving pattern inputs (see footnote on bottom of Figure 8). EV Explorer will not present cost outputs for EVs that cannot make the specified round trip journey on a single charge, and indicates each displayed EV's range relative to roundtrip mileage on a meter at the bottom of the output (Figure 18). PlugStar and PG&E's EV Savings Calculator have another dedicated tool within their respective websites that helps the user find EV models suited to their needs (Figure 19) including required range (PlugStar's tool is called Shopping Assistant).

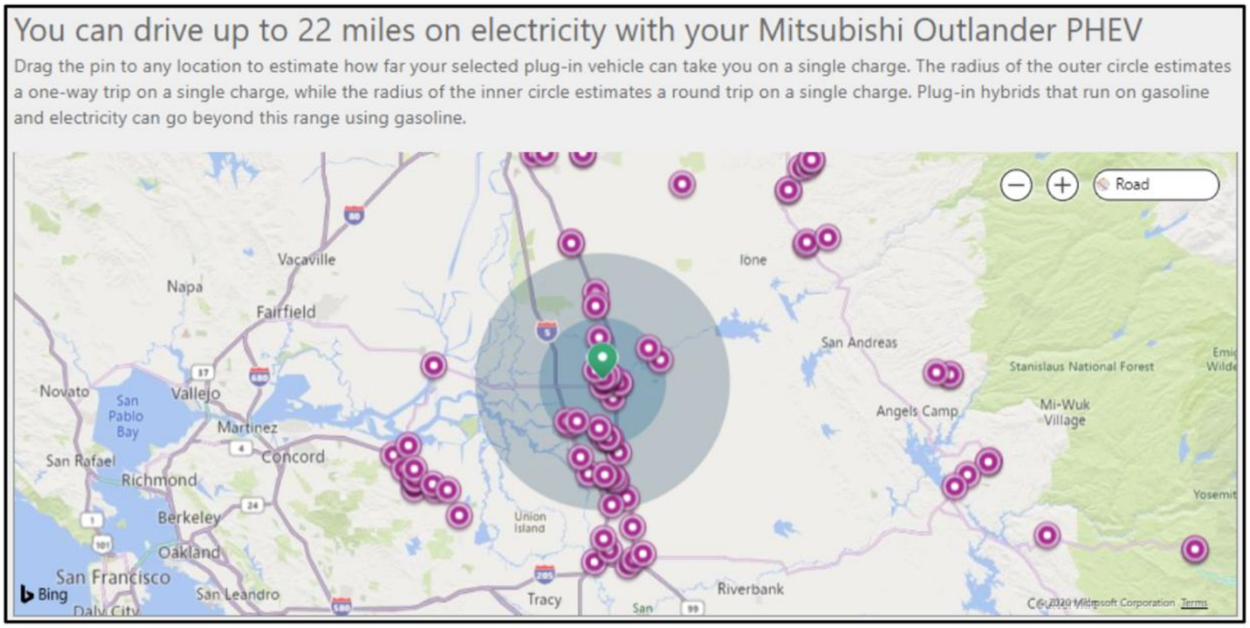


Figure 17. WattPlan local range and charging stations output

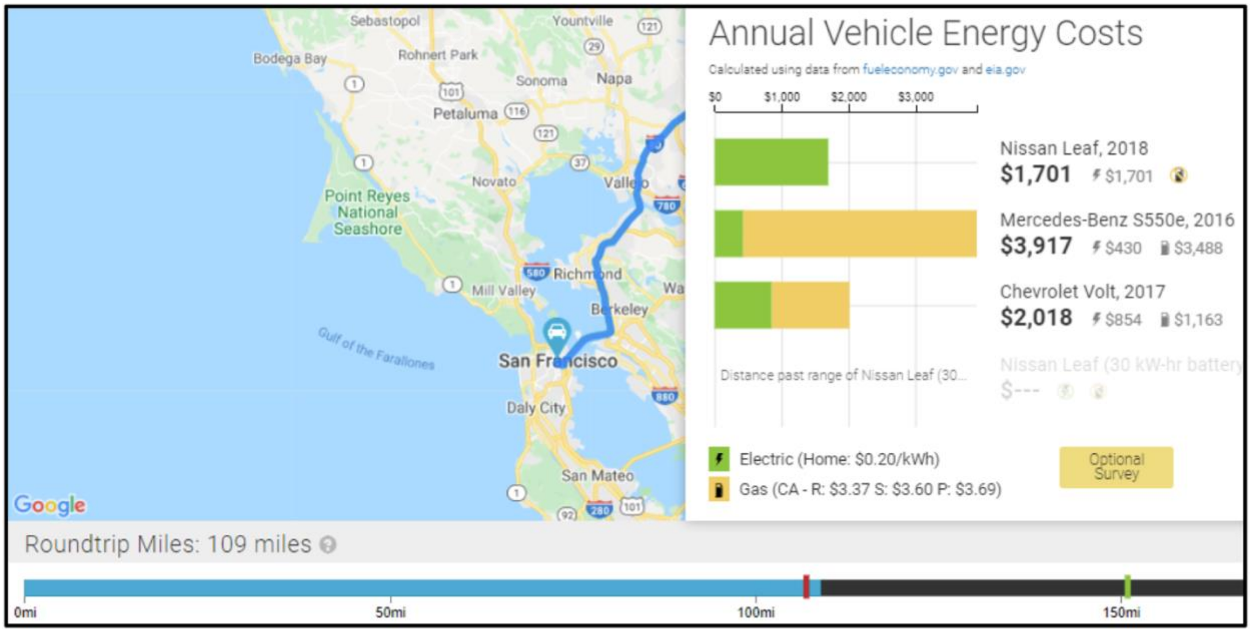


Figure 18. EV Explorer's insufficient range indicators

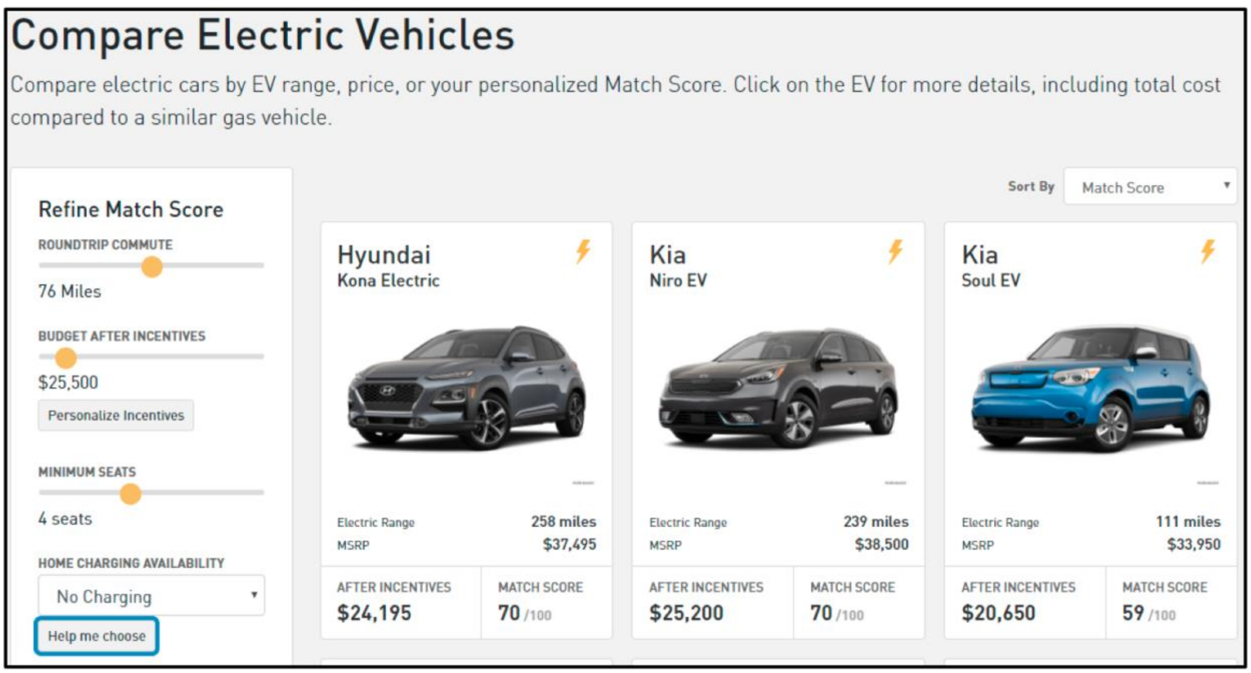


Figure 19. PG&E's EV Savings Calculator complementary tool to find suitable EV models

User Research

Survey participants' assessments of the overall usability of each tested tool's outputs are summarized in Figure 20. BeFrugal was rated highest in terms of accuracy and relevance, likely because it allows for the highest degree of customization. PlugStar was rated highest in engagement, likely due to its far superior aesthetics and interactive output. Interviewees were clearly most impressed with the aesthetics of PlugStar. Interviewees did not seem as positive about BeFrugal's accuracy and usefulness, which might be because they were less prepared to take advantage of the many editable inputs due to relatively less motivation to use VCCs and/or less experience with them.

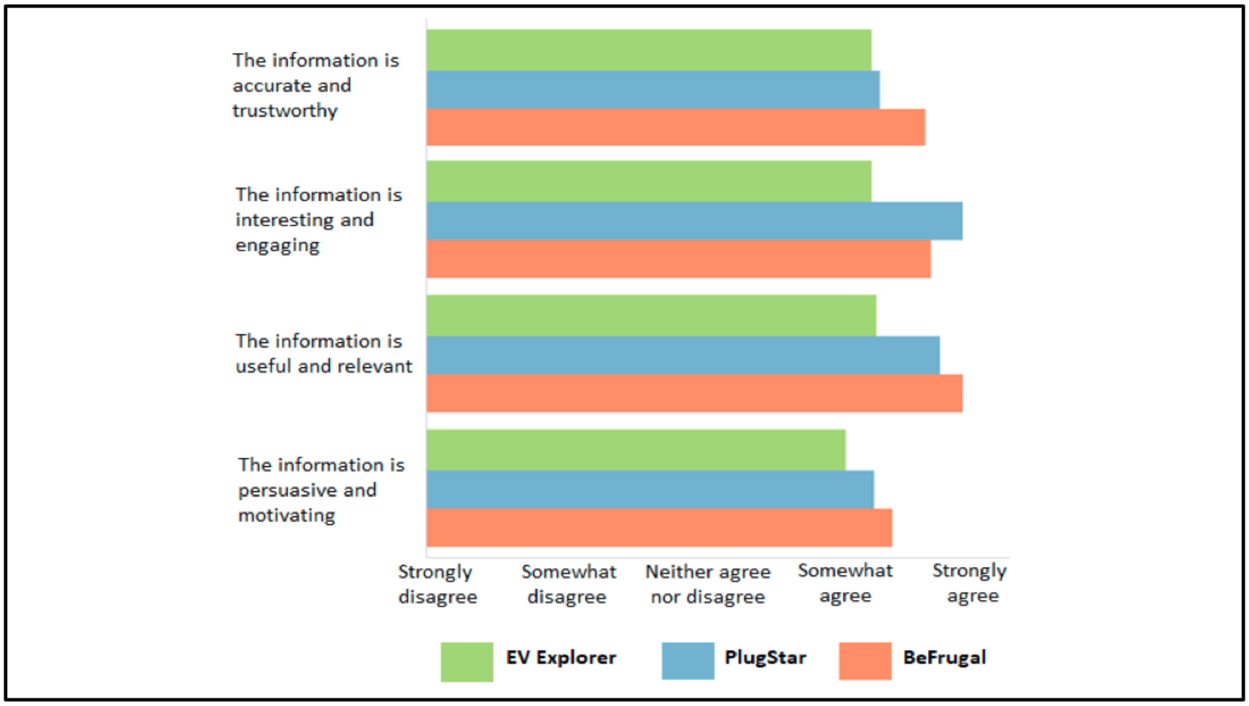


Figure 20. Output usability scores from VCC user survey

While participants liked simplicity of EV Explorer, they expressed a desire for more information in the output, beyond energy costs. One survey respondent noted, "This is just operation cost information. If I needed payment info / insurance info, I could now use the other sites presented in this survey." Another wanted to "show savings based on cheaper vehicle registration for BEVS" and multiple mentioned desire for maintenances costs. An interviewee remarked, "If I'm going to be hunting for information on a calculator like this, I want more info than that."

Others expected more to happen on the map, and when they realized it did not, remarked that the map took up too much space relative to the cost calculations output. Notably, usability testing was conducted on a large monitor and the output takes up more space relative to the map on smaller screens. Others mentioned a desire to use the map more. Some hoped to be able to interact with the map to modify the route or compare the efficiency of multiple routes (as possible in Fueleconomy.gov's Trip Calculator). Another desired use of the map was to display charging stations (as in PlugStar, PG&E EV Savings Calculator and WattPlan), e.g., "I would want it to tie into PlugShare and EVgo and ChargePoint data to show me where charging was an option." Moreover, one survey respondent expressed a desire for this feature to be integrated with the cost outputs: “Pre-populate charger costs based on choosing a charger location.” (No identified VCCs currently do this.)

Participants initial reaction to the PlugStar cost comparison output was generally more positive compared to the other tested tools, although as they tried to interpret it there were a couple common usability issues. Many participants had difficulty understanding the net depreciation cost category. A couple participants were curious about differences in insurance costs for comparable cars, but they did not scroll down to read the relevant assumptions about insurance costs. Some salespersons (who only provided feedback on PlugStar’s VCC) suggested that depreciation and insurance costs be excluded from the tool because they are not good distinguishers of EVs versus gas cars. One remarked, “all cars are depreciating assets; nobody invests in a car,” suggesting that car buyers do not usually think in terms of depreciation, although they noted that EVs do depreciate faster. Insurance is not something they focus on and also they noted that it would not be much different for comparable cars. In their conversations with customers, they focus on the benefits of incentives and operational cost savings (fuel and maintenance). These tend to be separate discussions: (a) customer’s net cost for buying or leasing, and (b) fuel and maintenance savings (along with associated non-monetary benefits).

One survey respondent thought environmental costs should be featured more in PlugStar, with another noting, “Emissions are not as important as total life cycle CO_2. If manufacturing, etc. is taken into account, it isn't indicated” (Figure 21). Other consumers throughout the usability testing expressed a desire to better understand the life cycle carbon emissions (particularly those association with manufacturing) for EVs versus gas cars, indicating some concern that focusing only on emissions associated with operating costs paints an overly optimistic picture. Some participants also expressed a desire for more meaningful metrics, beyond grams, pounds or tons of carbon and equivalent trees, or contextual information to understand the emissions.

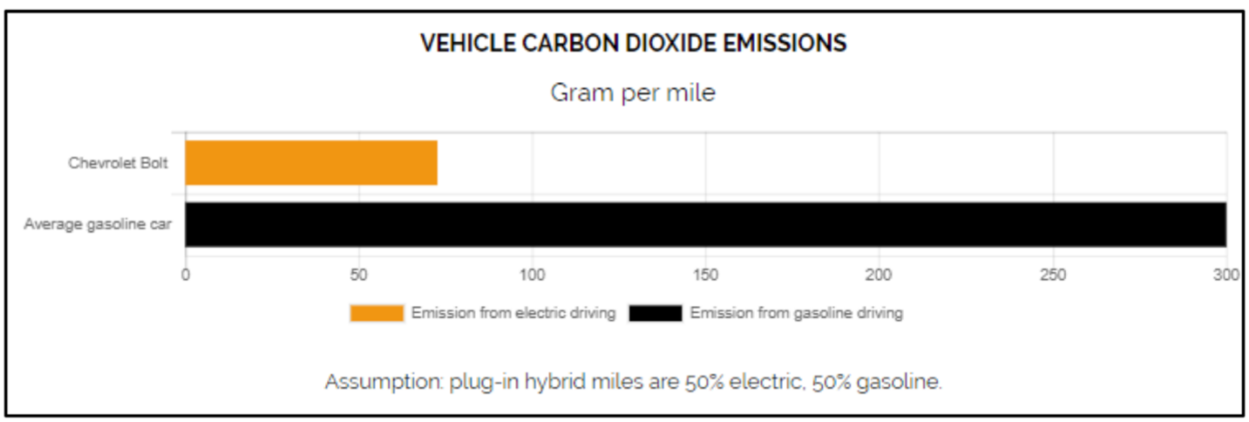


Figure 21. PlugStar Compare tool emissions output

A common criticism of both PlugStar and BeFrugal was inaccuracy of maintenance costs; in particular, EV maintenance costs seemed too high, e.g., “Maintenance cost is way off. What costs $563 on an EV?!” (BeFrugal), “Maintenance costs for EV are almost zero. Longer timeframe makes the comparison clearer but even at three years" (PlugStar). Those who had an EV already were particularly in-tune to this issue. Other participant feedback regarding outputs pertains to the capacities for customization through user inputs, which are covered in the user inputs section.

General User Experience Design Considerations

VCC Review

Available VCCs vary in terms of a variety of user experience design parameters, including linearity of the process. Some tools are highly structured such that the user is guided through considering all possible inputs before an output can be produced. In some cases, the user must begin the entire process again if they wish to explore other inputs (e.g., change a car being compared). Such tools can be considered linear, as opposed to more non-linear tools that may present an output earlier on in the process and allow the user to modify it further via optional inputs. Most VCCs use a combination of linear and non-linear processes, beginning with linear steps to produce an initial output and then allowing the user to modify original inputs and/or offering additional inputs. PG&E's EV Savings Calculator and PlugStar's Calculator are examples of more non-linear tools. WattPlan and BeFrugal are examples of more linear tools.

Regardless of the degree of linearity, VCCs vary in terms of the number of required and optional inputs and the number of different forms containing those inputs. Required inputs are those that the user must enter in order to generate an output. PG&E's EV Savings Calculator has the fewest required inputs (0); most tools have 2-6. Optional inputs often have default values that the user can modify if they wish, and they may be present before or after an initial output is generated. The more inputs a VCC has, the more opportunities a user has to tailor cost outputs. WattPlan and BeFrugal have the most optional inputs (24-26 for BeFrugal).

All required and optional inputs may be presented in a single form or organized into multiple forms, often by category (e.g., choosing a car, reporting driving habits, specifying fuel prices), and in either case they may be layered such that certain inputs appear conditionally based on other inputs. More linear tools may guide the user through a series of (required and/or optional) input forms which can only be accessed in a particular order (e.g., FuelEconomy.gov's My Plug-in Hybrid Calculator; Figure 22) and/or organize the inputs listwise and present the output beneath them (e.g., DOE's Vehicle Cost Calculator) after the user presses a button, typically labeled something like "Calculate" or "Get Results". Others allow for easier iterative exploration by displaying optional inputs on the same page as outputs and automatically updating results when inputs are changed. Some tools have another dimension of output interactivity which is being able to alter the type of output, e.g., switching to view the output for different cost categories or over different time intervals.

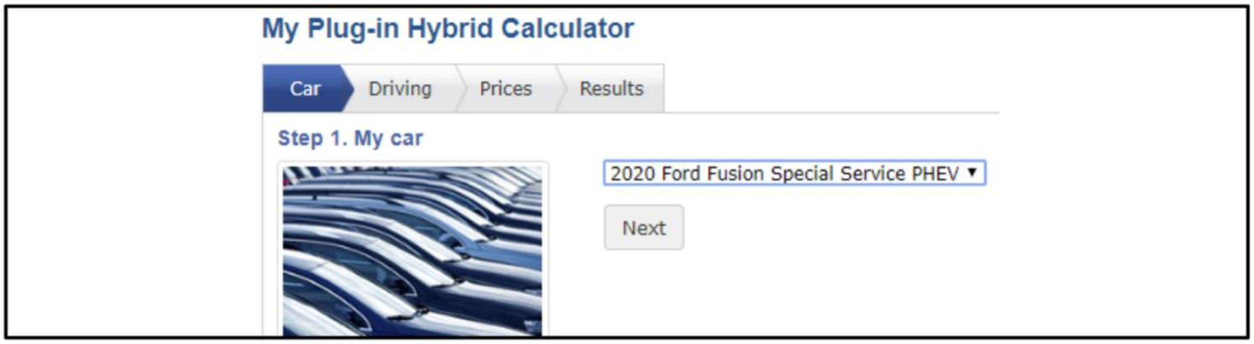


Figure 22. My Plug-in Hybrid Calculator input categories and initial linear process

User Research

In the usability interviews, participants generally engaged more with the optional inputs that were integrated in the linear process leading up the initial cost comparison output than with optional inputs that were only available after the initial output. For example, most interviewees deliberated for at least a moment about each of the optional inputs and their default values in BeFrugal. However, this engagement was not necessarily positive. Some participants felt the process in BeFrugal was too long, and they were frustrated when they were unsure if the default values in the optional inputs were accurate or they could not easily estimate a more accurate value. For some participants it was not always obvious what some of the inputs meant and that was particularly the case when inputs were not relevant (e.g., City and Highway MPG fields for electric vehicles with default values of 0; this was also the case for the % electric driving input in PlugStar when there were no PHEVs in the cost comparison).

On the other hand, with the less linear EV Explorer and PlugStar, users often did not notice optional inputs without prompting. For EV Explorer, participants typically noticed the optional inputs that appeared in the same form where they had entered required inputs, but often did not notice the input forms accessible only via the menu in the website header ("Car Manager" and fuel prices); Figure 23 illustrates via eye-tracking results how one participant looked back and forth between the output and inputs after the output was generated but did not look at the menu. For PlugStar, most participants noticed the optional inputs integrated in the output (financing type and term, annual mileage, and % electric driving), but they did not independently locate the additional optional financing inputs which are only accessible via the menu tabs above the output (i.e., "Build" and "Incentives"; notably, changing electricity rate under "Charging" does not update the cost output). Some interviewees also did not notice the cost details checkbox or change the time interval for the output.

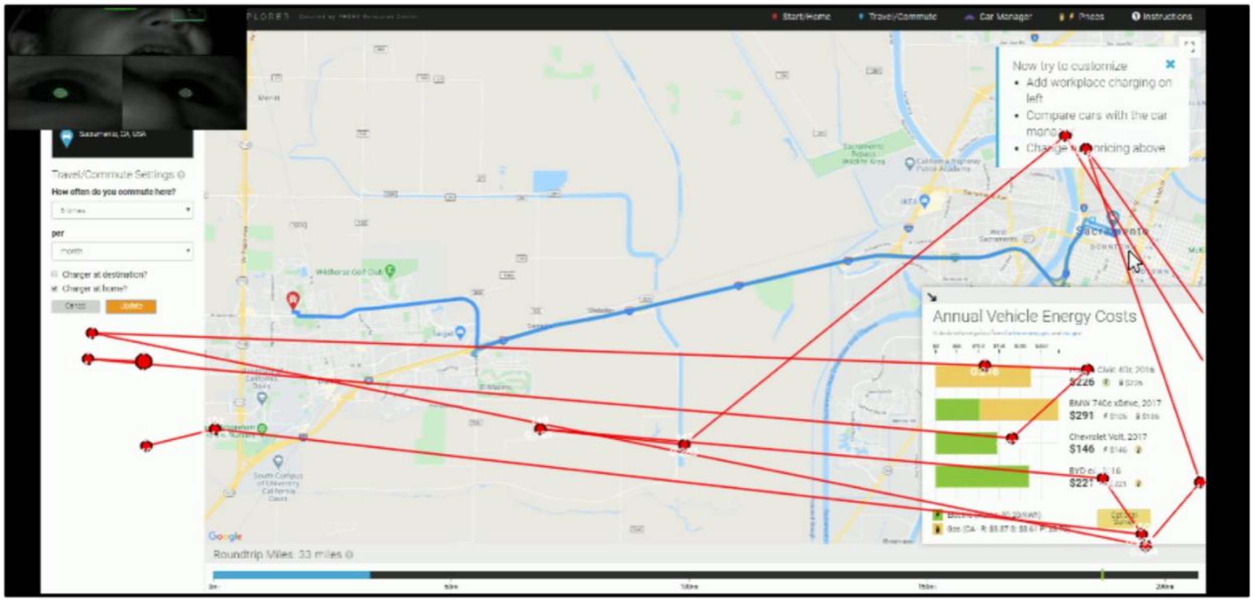


Figure 23. Eye-tracking results after EV Explorer output was generated

User Inputs

All the VCCs reviewed include opportunities for user input to customize cost calculations. Inputs may be required or optional. Required inputs are those that the user must fill in order to generate vehicle cost outputs. Optional inputs are sometimes available before an initial cost output and/or they are available after the initial output enabling further customization. Inputs were organized into four main categories: vehicle selection and specification, driving patterns, fueling patterns and prices, and financing. Table 4 summarizes survey participants' satisfaction with the user inputs afforded in each tested VCC.

Table 4. Satisfaction with VCC Inputs (*N* = 22)

		EVExplorer			PlugStar			BeFrugal		
		Yes	No	Not interested	Yes	No	Not interested	Yes	No	Not interested
Vehicle Selection	Are you able to find the vehicles you would like to compare?	76%	24%	0%	74%	26%	0%	48%	52%	0%
	Are you able to compare as many vehicles as you wish?	72%	28%	0%	91%	9%	0%	57%	43%	0%
	Are you satisfied with the ability to tailor vehicle cost estimates based on your vehicle efficiency and charging requirements?	68%	24%	8%	N/A	N/A	N/A	70%	17%	13%
Driving	Are you satisfied with the ability to tailor vehicle cost estimates based on your driving patterns?	60%	40%	0%	65%	30%	4%	78%	18%	4%
Fueling	Are you satisfied with the ability to tailor vehicle cost estimates based on your charging opportunities?	58%	38%	4%	N/A	N/A	N/A	N/A	N/A	N/A
	Are you satisfied with the ability to tailor vehicle cost estimates based on your gas and electricity prices?	64%	28%	8%	N/A	N/A	N/A	73%	18%	9%
Financing	Are you satisfied with the ability to tailor vehicle cost estimates based on your car payment details?	N/A	N/A	N/A	50%	27%	23%	45%	30%	25%

Vehicle Selection and Specification

All the reviewed VCCs include opportunities to choose a specific vehicle make and model for which costs are calculated. Some tools require the user to specify one or more vehicles (make and model) before a cost output is generated, whereas others provide an output for default vehicles which can then be changed. Tools also vary in terms of the number of vehicles for which costs can be calculated in a single output; from one at a time (no side-by-side comparison) to unlimited.

Tools range widely in terms of the range of models available to select (typically from dropdown menus). Sometimes the range is restricted to limited manufacturers (e.g., BeFrugal has very limited selection of gas vehicles), only new models (e.g., PlugStar and BeFrugal), or only particular drivetrain(s) (e.g., allowing selection of one ICEV and one BEV, or selection of an EV which is compared to a comparable gas vehicle that cannot be modified, e.g., PG&E's EV Savings Calculator). The DOE's Vehicle Cost Calculator is unique in that it provides space for a custom vehicle in addition to year, make and model menu options (Figure 24). Several other tools, including EV Explorer and BeFrugal, allow the user to change vehicle specifications related to efficiency (MPG, MPGe, city/hwy), range and time to full charge for EVs (Figure 25-27).

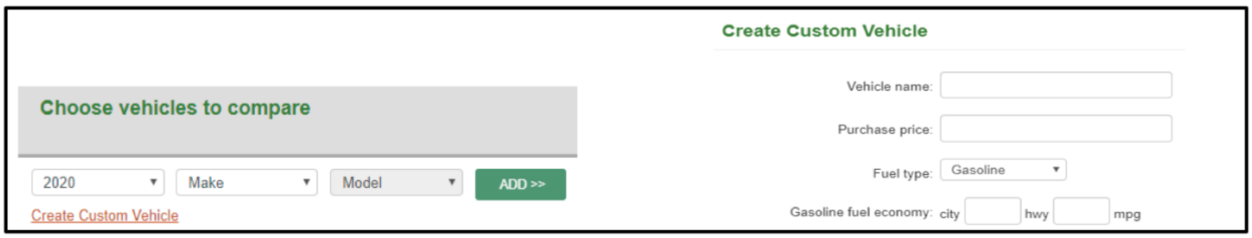


Figure 24. DOE's VCC vehicle selection and specification inputs

Figure 25. EV Explorer vehicle selection and specification inputs. When in the "Car Manager" menu, users can change the four default cars (left) or edit their efficiency and range (right).

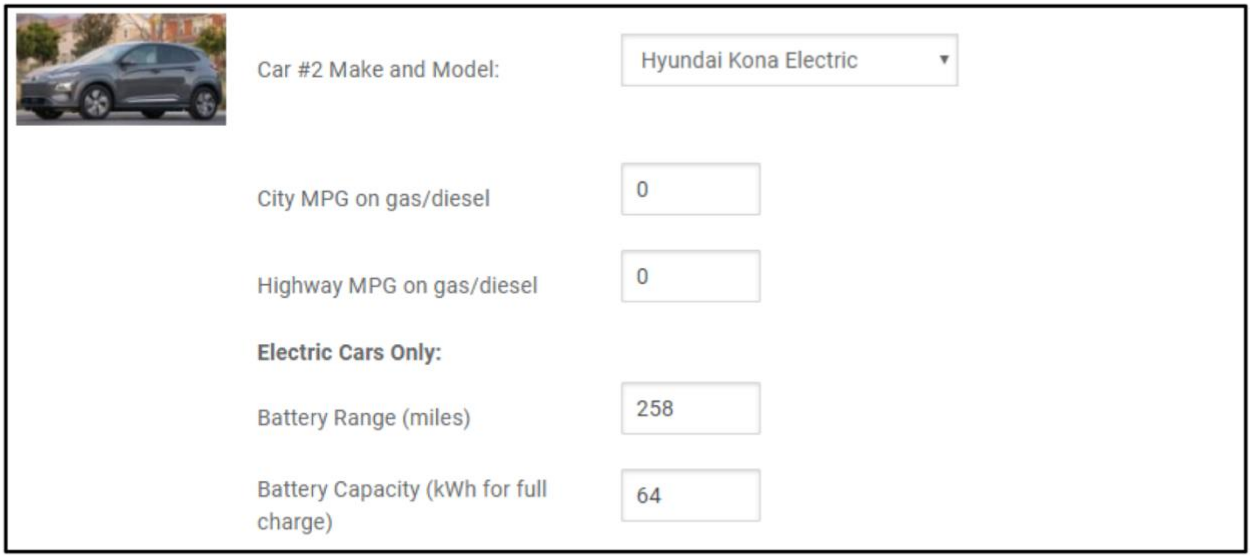


Figure 26. BeFrugal vehicle selection and specification inputs

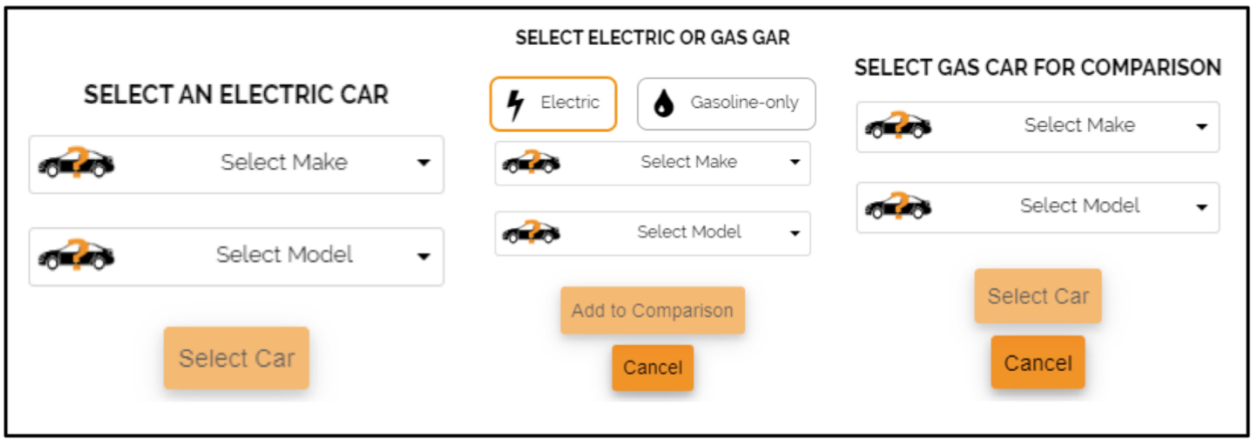


Figure 27. PlugStar vehicle selection inputs. Left: Users must enter an EV first upon selecting either "Compare" or "Research a Car" from the top menu. Middle: In the Compare path, they can add another EV or gas vehicle. Right: In the Research path, they can only change the gas car comparison to the chosen EV.

The consumer usability survey and interviews confirmed that vehicle selection is an important component for VCCs. Most had at least one specific vehicle in mind that they wished to investigate or compare. Consumers' level of engagement tanked if the vehicle model or year they wanted to investigate or compare was not available. EV Explorer satisfied the most participants in terms of offering the vehicle of interest. However, their interest in the initial output was greatest when tools required some vehicle specification input(s) upfront (including the vehicle they wished to select), rather than displaying cost calculations for default vehicles that could later be changed (EV Explorer).

Consumers also preferred to be able to compare as many vehicles side-by-side as they wished, without limit, although they most commonly chose to compare only two. PlugStar was rated most highly by survey-takers in this regard. However, in the interviews some users became frustrated with the restrictions on types of vehicles that could be added to the comparative output in PlugStar (e.g., if they decided they wanted to add another EV to the comparison when in the Research a Car path that compares a selected EV with a gas vehicle, but did notice the Compare Favorites feature which switches them to the Compare path where they can add multiple EVs; or if in the Compare path and they clicked to "show cost calculations" for one of the EVs it would send them to the Research a Car path in another window where the comparison vehicle switches to a comparable gas car).

There are some limitations to vehicle selection by make and model. Some interviewees were not well-versed in EV makes and models (e.g., confusing the Volt and the Bolt). One interviewee expressed interest in being able to select more general categories of vehicles because he knew he wanted an EV, but was not set on a specific model; he was specifically interested in semi-automated technologies. Salespersons reported that they would be more likely to refer customers to a VCC if it vehicle selection were restricted to the EV(s) they sell. In particular, they suggested that the EV(s) that a user could select should be theirs, but a comparison ICE vehicle could be from a different manufacturer.

The option to modify default values for vehicle efficiency and range in EV Explorer and BeFrugal was not widely used by participants, except in one or two cases with Be Frugal when the user was essentially creating a custom vehicle because the tool did not include a vehicle they wanted to select. Some participants mentioned that they were not sure if the default values were best or if they should change them. One survey participant mentioned they would like to set efficiency estimates for highway and city (MPG or MPGe) as in BeFrugal instead of an average as in EV Explorer. One interviewee who was a long-time EV owner and advocate suggested that if a user is exploring a used EV there could be some qualifying information near the range and time to charge optional inputs to educate the user about potential for battery degradation.

Driving

Most VCCs allow customization of cost calculations based on the user's driving patterns. Driving patterns inputs range from a single prompt for daily or annual mileage to a detailed breakdown of different daily driving profiles and infrequent trips. Like vehicle selection, some tools require driving pattern inputs whereas others offer an initial output based on default assumptions regarding mileage, then offer optional inputs to further tailor the output.

The most common inputs in this category are annual and daily mileage (in a variety of formats). Daily mileage has implications for operating costs for PHEVs (% gas versus electric driving) and enables tools to provide information on adequacy of a particular EV's range for the user's needs. Simpler formats for daily mileage often assume a consistent workday commute or are at least much easier to answer and more accurate if that is the case (e.g., a field for daily mileage or information for a single journey). The Department of Energy's My Plug-in Hybrid Calculator on fueleconomy.gov offers more flexibility by allowing the user to either enter driving patterns in a short form (daily and annual mileage) or a long form that accounts for different daily driving profiles (e.g., weekday and weekend), infrequent long distance trips, and percentage of stop-and-go traffic. EV Explorer, FuelEconomy.gov's Trip Calculator, and WattPlan ask for commute origin and destination (paired with frequency in EV Explorer); in all three tools these inputs are limited to a single journey (Trip Calculator allows for waypoints and modifying the route; the others do not).

Consumer usability research identified insufficiencies in each of the tested VCC's driving inputs (Figure 28-29). BeFrugal's calculator was criticized for having too many inputs upfront that were not easy to answer quickly (although they are not required). Some found it too demanding to estimate daily and road trip mileage and route information (percent city versus highway); even though these inputs were not required, users considered them because of the layout of the tool as mentioned previously. BeFrugal does not allow direct modification of annual mileage.

On the other hand, annual mileage is the only driving input in PlugStar. Not all users noticed it and modified the default value and some had trouble scrolling to the precise number they wished to enter (as mentioned earlier). Annual mileage was easier to estimate for some participants, compared to daily driving, with some citing familiarity with annual mileage in the context of auto insurance. In particular, participants with variable driving patterns, e.g., retired persons (which may be overrepresented among EV adopters), found daily mileage annoying to estimate. The first four responses to the VCC user survey perfectly illustrate the diversity in how users are naturally inclined to report their mileage; when asked, open-ended, "Approximately how much do you drive?" responses were:

- "120-150 miles a week" (weekly),
- "90 mile commute daily and 30-50 on weekends" (daily),
- "12,000 EV miles per year" (annually)
- "800 miles per month" (monthly)

Participants liked the map feature on EV Explorer, but its method of only allowing one trip destination does not adequately reflect the driving patterns of many users; as one interviewee noted, "Right up front my commute location was demanded, and I don't drive to work." A survey participant highlighted that a single trip is also insufficient because it doesn't provide the full picture even for commuters, "While the commuting cost is a big one for me, including annual trips would give an even more accurate estimate of costs as BeFrugal does." Others suggested the ability to modify the route and add waypoints would be useful, e.g., "I'd like to add waypoints along the map and re-route manually."

Figure 28. BeFrugal driving pattern inputs

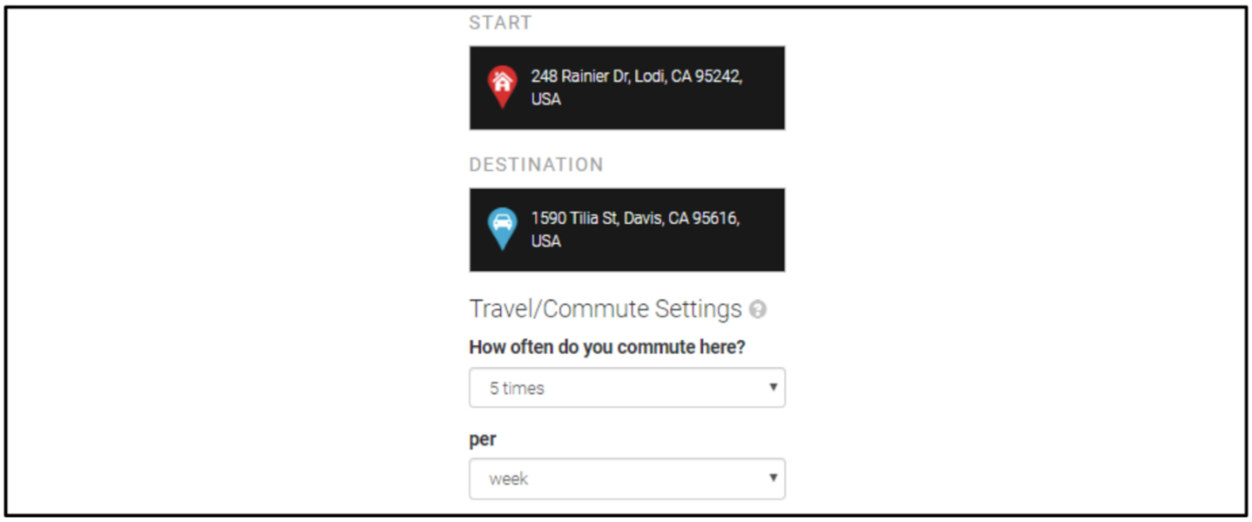


Figure 29. EV Explorer driving pattern inputs

Fueling

Most VCCs allow the user to modify fuel (gas and electricity) prices and charging opportunities. However, unlike vehicle selection and driving patterns inputs, these inputs are always optional, never required. Default gas and electricity price values are typically provided based on user location (which is either auto-generated or supplied by the user). For example, EV Explorer identifies user's location from their IP address and then BeFrugal defaults to the national average prices but provides links for users to check current local prices. Both EV Explorer and BeFrugal allow users to modify fuel prices (Figure 30-31). PlugStar uses state average gas prices and identifies more localized (off-peak) electricity prices based on user zip code (a required input) but does not allow users to modify these values (Figure 32).

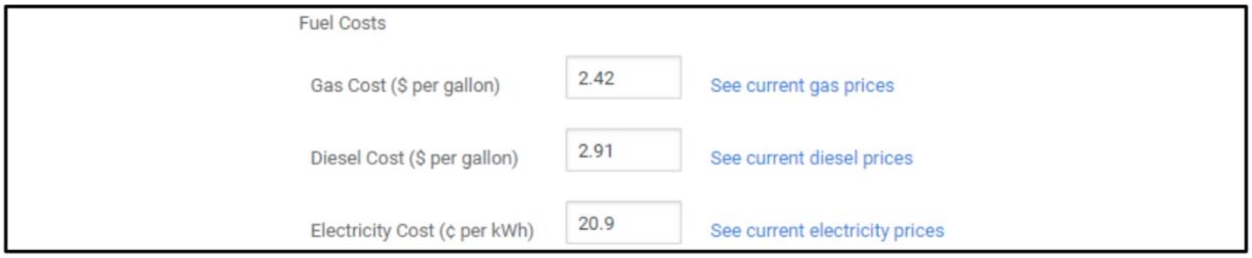


Figure 30. BeFrugal optional fuel price inputs

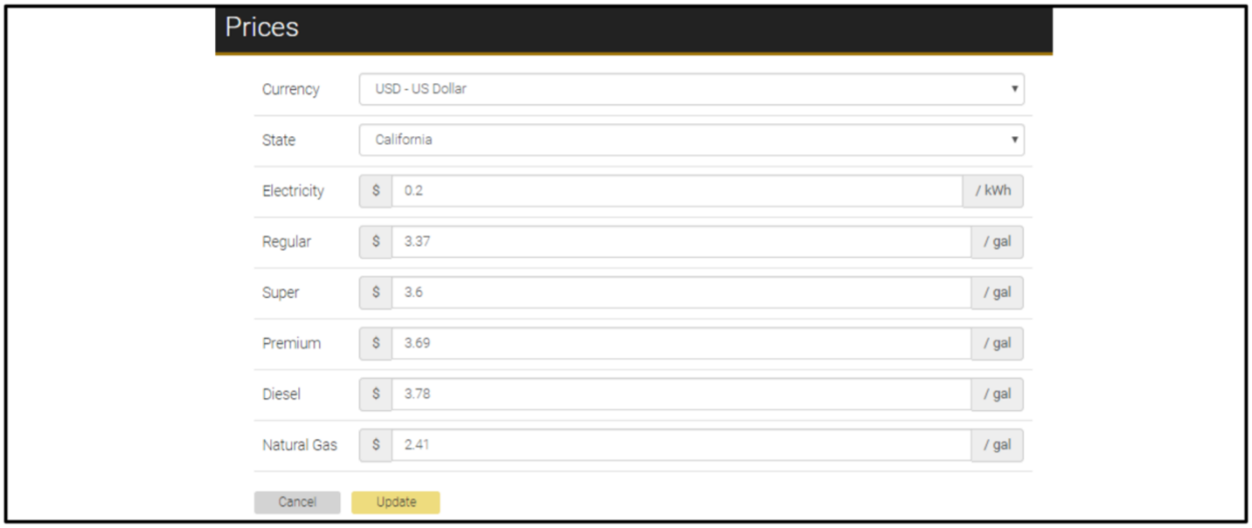
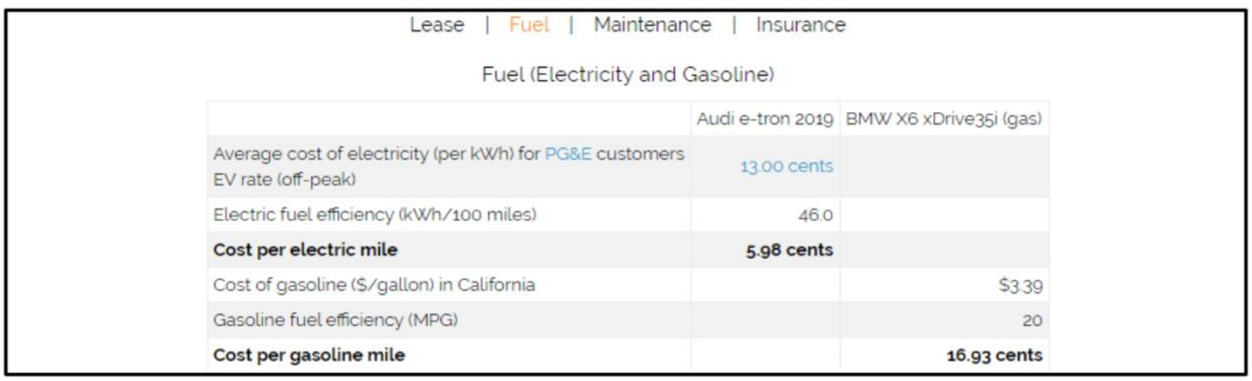


Figure 31. EV Explorer optional fuel price inputs



	Audi e-tron 2019	BMW X6 xDrive35i (gas)
Average cost of electricity (per kWh) for PG&E customers EV rate (off-peak)	13.00 cents	
Electric fuel efficiency (kWh/100 miles)	46.0	
Cost per electric mile	**5.98 cents**	
Cost of gasoline ($/gallon) in California		$3.39
Gasoline fuel efficiency (MPG)		20
Cost per gasoline mile		**16.93 cents**

Figure 32. PlugStar non-modifiable assumptions for fuel prices

About half the VCCs reviewed include the option to specify if there is a home charger and/or charging level. Many tools assume charging will be done exclusively at home and either assume off-peak charging only or use average electricity rates (ignoring time of use pricing). WattPlan is unique in that it includes inputs for home charger installation cost and time of charging (Figure 33); (it also has detailed inputs to define household solar PV, energy use, and energy storage systems). WattPlan also finds the user's optimal electricity rate plan based on inputs about charging time and typical electricity bill. PlugStar provides information about home charging electricity rates, charger installation rebates, and local public charging locations but these features are not integrated with their VCC.

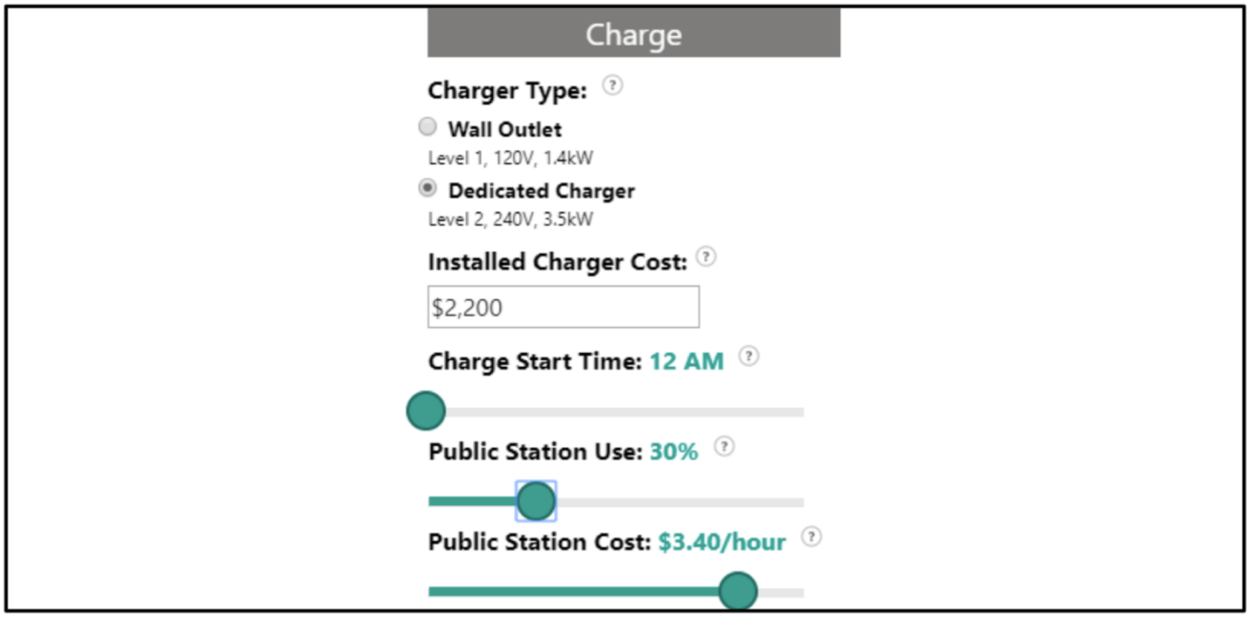


Figure 33. WattPlan fueling patterns and prices inputs

Only a few tools (WattPlan, EV Explorer, and PG&E's EV Savings Calculator) allow the user to specify details about charging away from home. WattPlan and EV Savings Calculator ask for overall percent of charging at public stations and associated cost, whereas EV Explorer asks for time parked at destination, charging level, and cost (Figure 34). A few other tools (AFLEET, DOE's VCC, and My Plug-in Hybrid Calculator) ask about charging frequency (Figure 35-37). When charging information is integrated with driving inputs, as in EV Explorer and My Plug-in Hybrid Calculator, assumptions can be generated on the back end of the VCC to determine gas versus electricity usage and costs for PHEVs. Rather than calculate this based on other user inputs, at least two tools ask directly for percent of driving in electric mode (Figure 38-39).

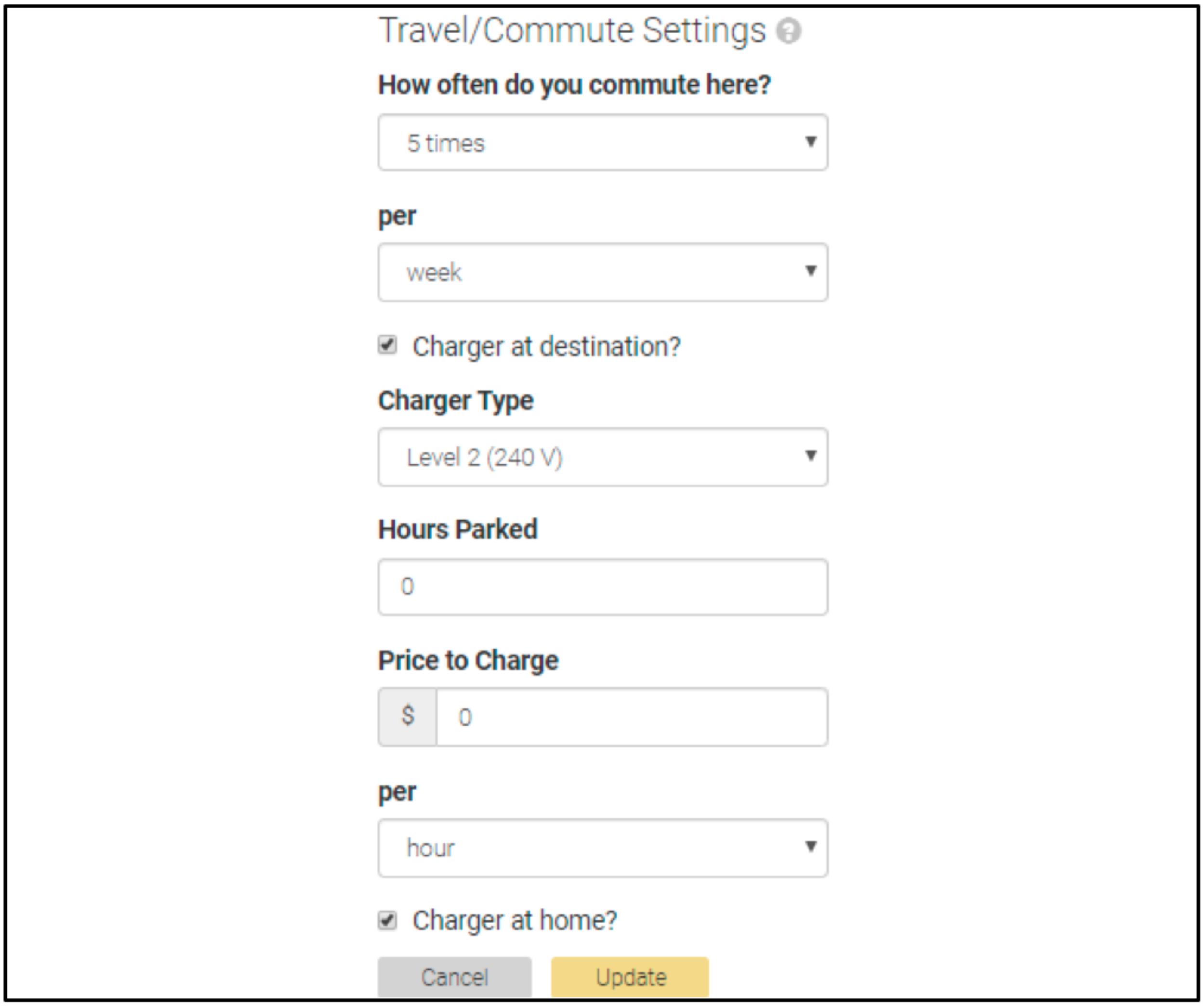


Figure 34. EV Explorer integrated driving and charging inputs

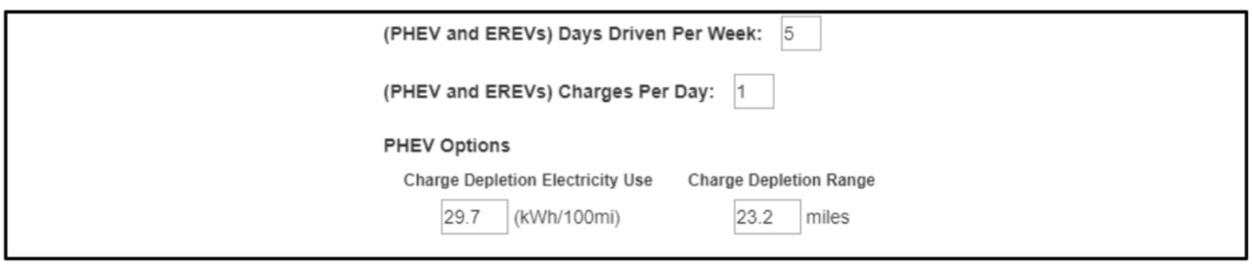


Figure 35. AFLEET PHEV charging frequency and efficiency specs inputs

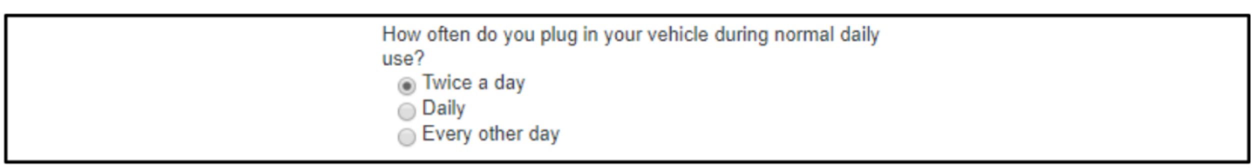


Figure 36. DOE VCC PHEV charging frequency input

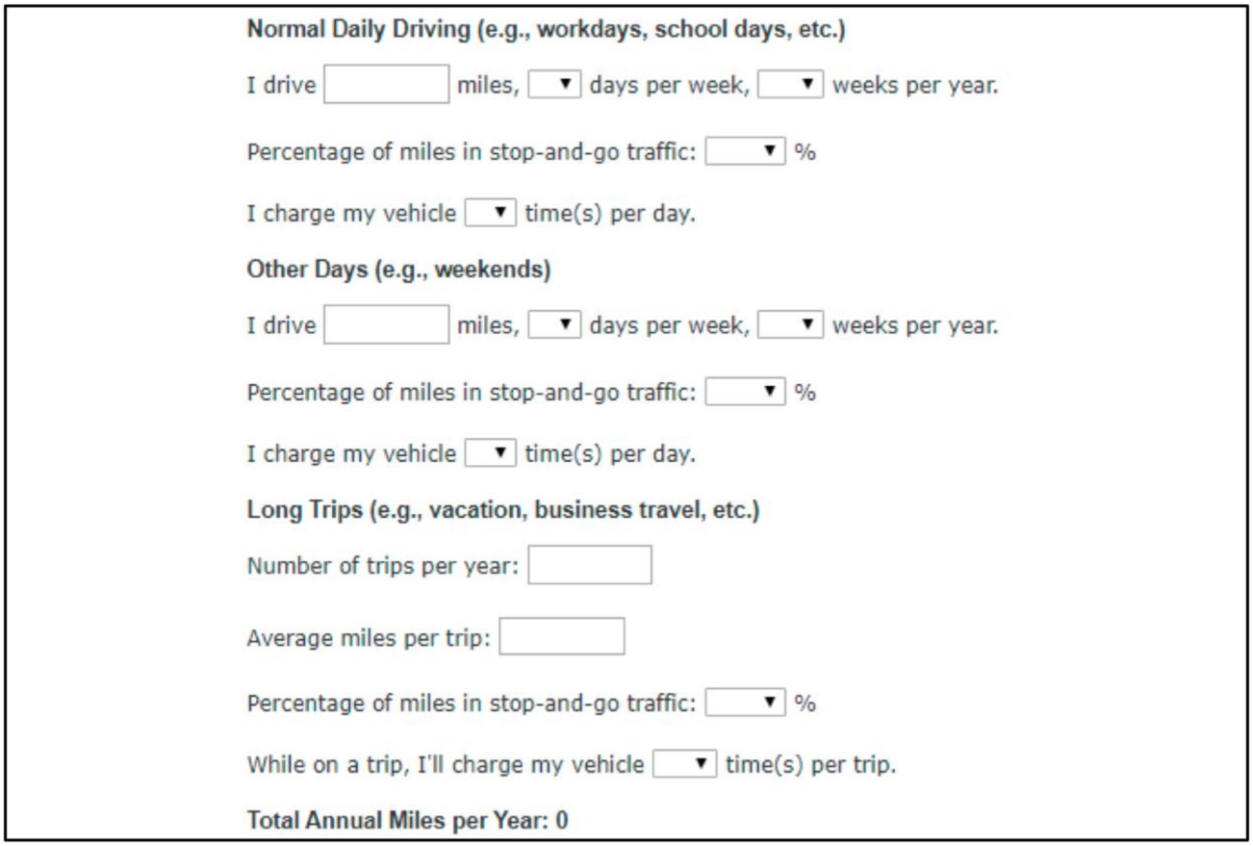


Figure 37. My Plug-In Hybrid Calculator's charging inputs integrated with driving inputs

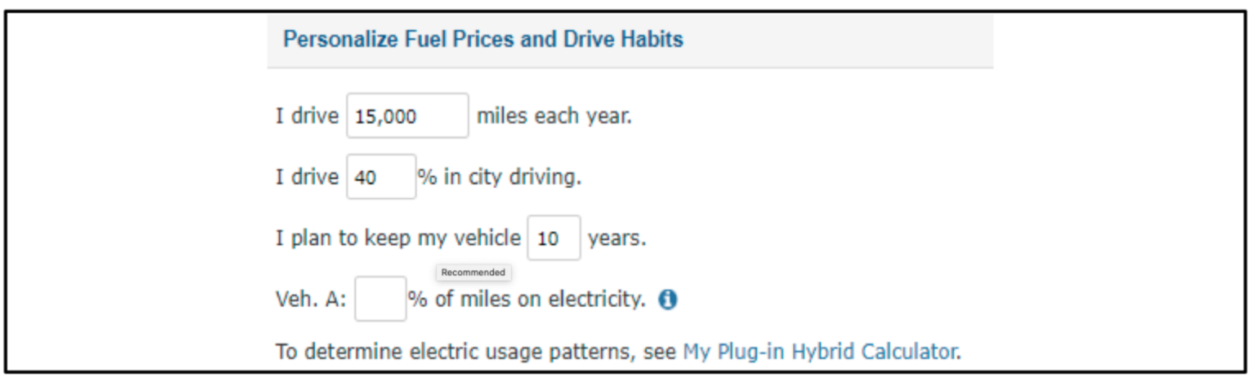


Figure 38. Fueleconomy.gov's Fuel Savings Calculator

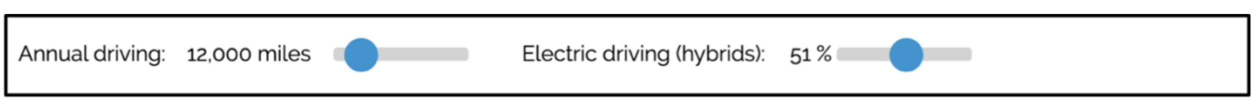


Figure 39. PlugStar driving and fueling inputs

In the user research, the national average fuel prices in BeFrugal (Figure 40) were a turn-off for some participants who noticed they were inaccurate and did not know where the values came from (there is no indication on the site that they are national averages). Some appreciated the provided links to find state average fuel prices, while others had a high standard for accurate defaults and did not want to leave the website to research fuel prices. Participants rarely noticed the optional fuel price inputs in EV Explorer (Figure 41), and when directed to them interviewees rarely modified the values. However, participants often remarked that they did not know their electricity rate, with one survey participant stating regarding EV Explorer: "I'd want some links to help me find the data." BeFrugal was rated slightly higher in survey participants' reported satisfaction with ability to tailor outputs based on fuel prices, even though only one fuel price could be specified (not different rates for home v. destination charging as in EV Explorer).

Although PlugStar does not allow further tailoring of fuel prices, it does identify more specific electricity prices than the other two tested tools (though it assumes only off-peak home charging) and it provides a link to local utility rate schedules (Figure 42). However, not all utilities are represented. For example, an interview from Roseville recognized that the default electricity rate was much higher than his local utility rate. When trying to figure this out, he did not notice the fuel cost assumptions listed beneath the output. A few participants mentioned the need to take time-of-use pricing into account (which is becoming more common and included in special EV rate plans provided by some utilities), for charging during on- versus off-peak hours; none of the three tested tools have the capacity to factor in time-of-use pricing like WattPlan.

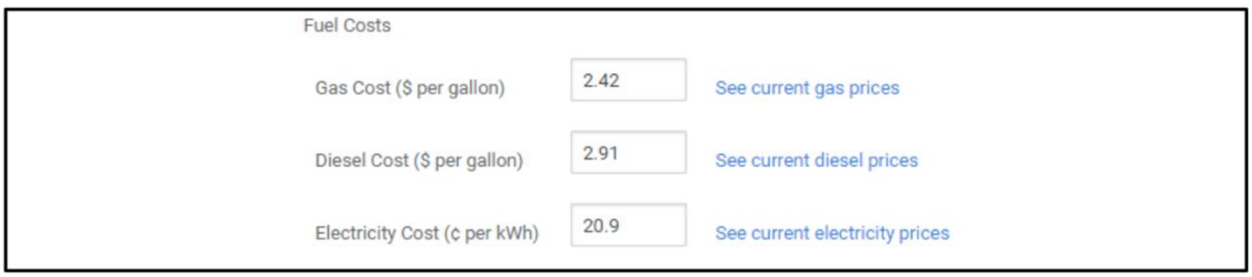


Figure 40. BeFrugal optional fuel price inputs

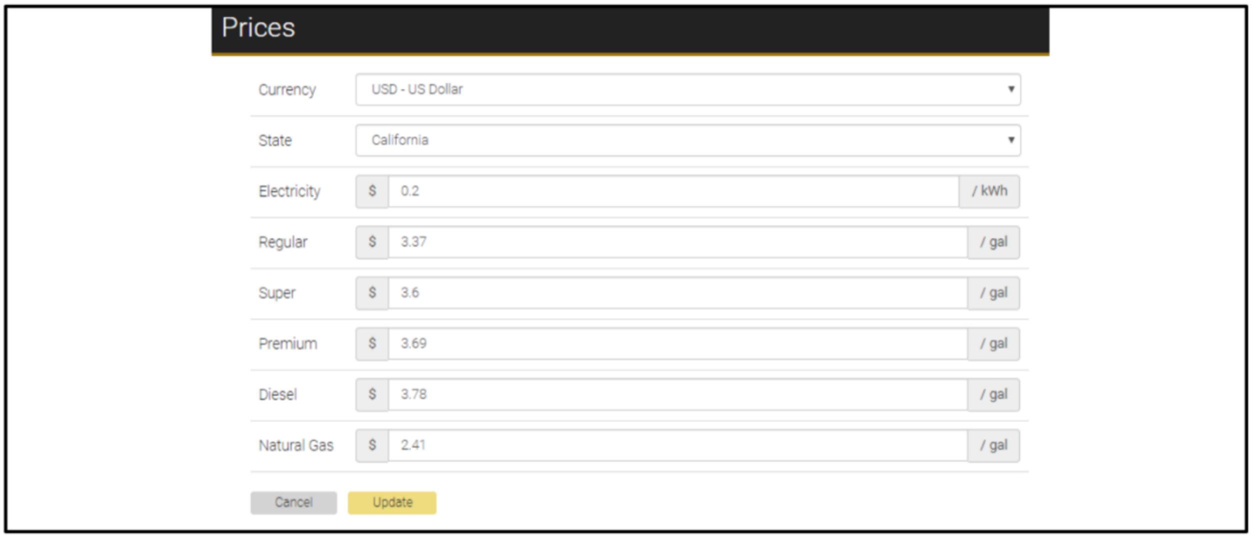
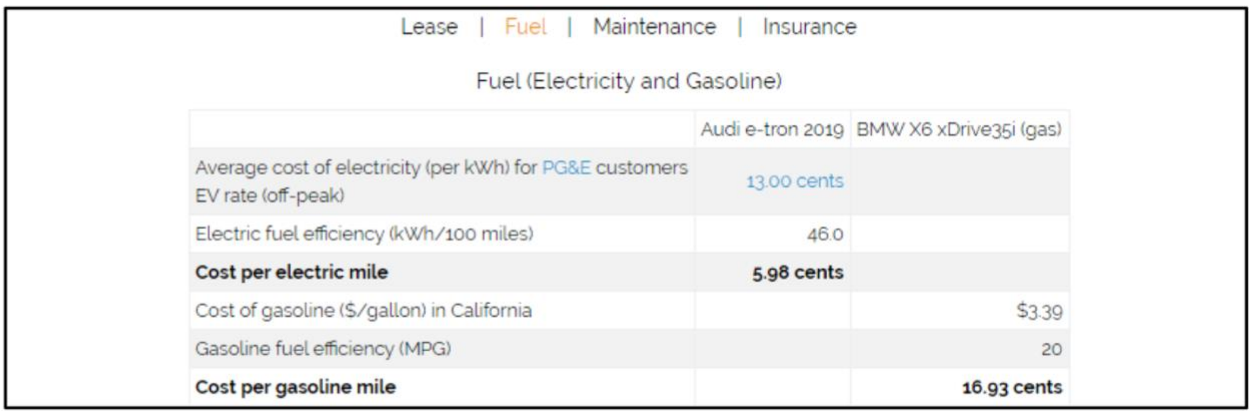


Figure 41. EV Explorer optional fuel price inputs


Lease | Fuel | Maintenance | Insurance

Fuel (Electricity and Gasoline)

	Audi e-tron 2019	BMW X6 xDrive35i (gas)
Average cost of electricity (per kWh) for PG&E customers EV rate (off-peak)	13.00 cents	
Electric fuel efficiency (kWh/100 miles)	46.0	
Cost per electric mile	**5.98 cents**	
Cost of gasoline ($/gallon) in California		$3.39
Gasoline fuel efficiency (MPG)		20
Cost per gasoline mile		**16.93 cents**

Figure 42. PlugStar non-modifiable assumptions for fuel prices

Regarding charging information (for EV Explorer), many participants did not know how much public charging would cost or the charger level. One survey participant suggested that those costs would auto-populate based on charger location. The percent electric driving input in PlugStar was not often used and several participants wondered what it meant; this input was present in some outputs that did not include a PHEV, which further confused some participants.

Financing

VCCs that present calculations for total costs of ownership include inputs to specify vehicle acquisition costs, including purchase price, financing terms, taxes and fees, and incentives. Tools that allow customization of acquisition costs typically include several sets of fields depending on user-selected vehicle financing type (cash, loan, lease). These can include purchase price (or additions or discounts from default MSRP), down payment, length of loan or lease, and interest rate, with default values that can be edited (i.e., always optional rather than required inputs). See Figure 43-44 for examples.

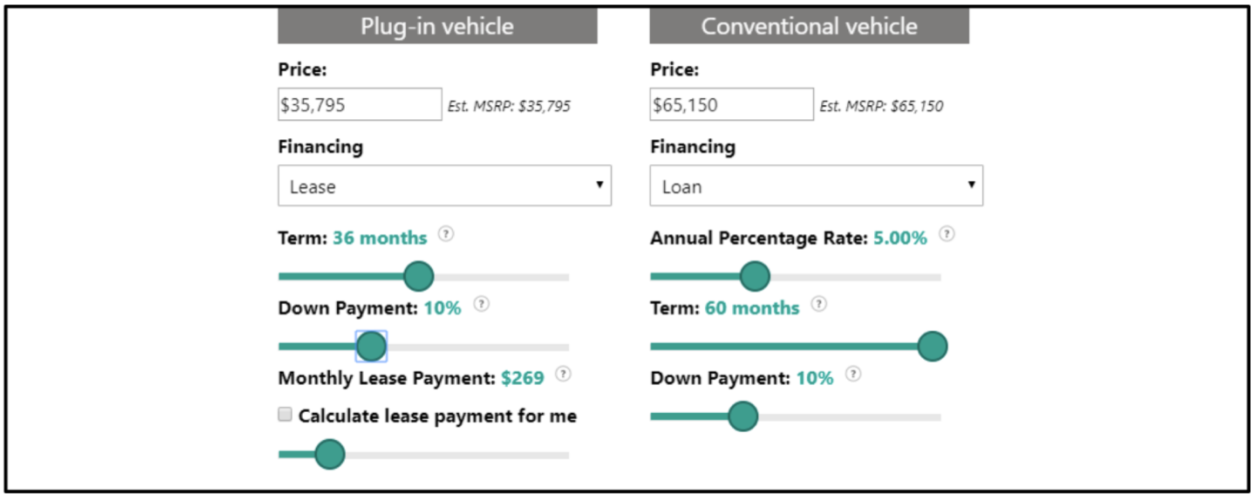


Figure 43. WattPlan vehicle financing optional inputs

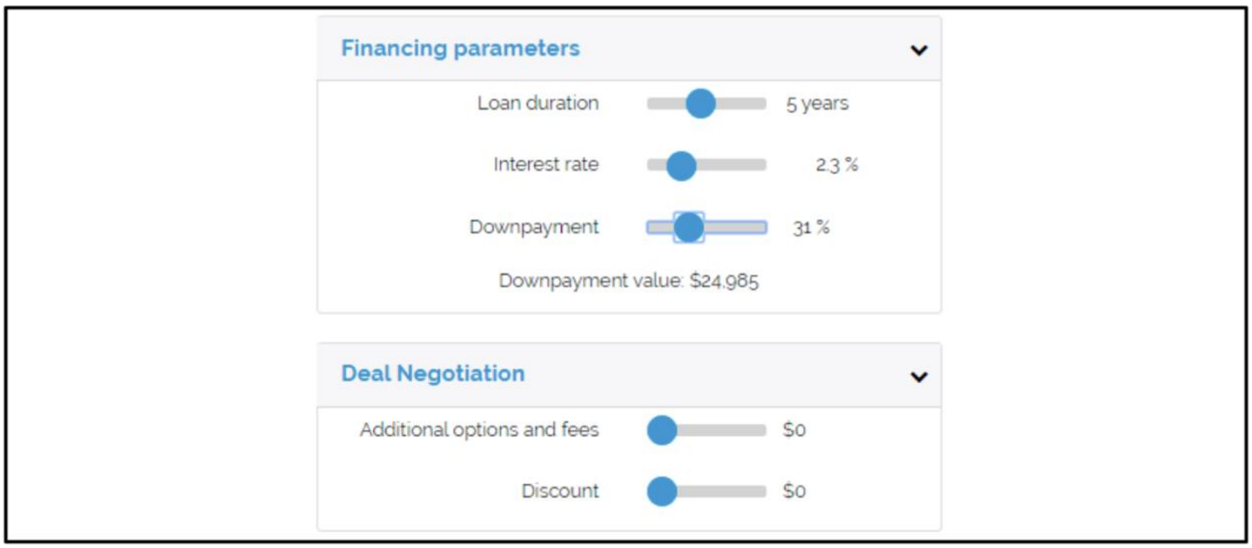


Figure 44. PlugStar vehicle financing optional inputs

VCCs vary widely in terms of how they enable users to identify incentives and account for them in their cost calculations. For example, BeFrugal has a modifiable input for a one-time incentive for EV purchase with a default value of $7,500 for EVs (Figure 45), whereas PlugStar, PG&E's EV Savings Calculator and WattPlan calculate federal, state and local incentives based on user location and factor them into their respective cost comparison outputs. WattPlan is unique in that it factors charger installation costs (optional input) and rebates into the comparative cost outputs, whereas PlugStar and PG&E provide charger installation incentive eligibility information but do not factor it into comparative cost outputs. WattPlan and PlugStar do not allow modification of incentive assumptions. PG&E allows some further tailoring of incentive values by allowing the user to enter income tax related information to determine income eligibility for available incentives (Figure 46). Only BeFrugal allows direct modification of incentive value. DOE's VCC has a single modifiable input for purchase price and prompts the user to consider incentives (Figure 47).

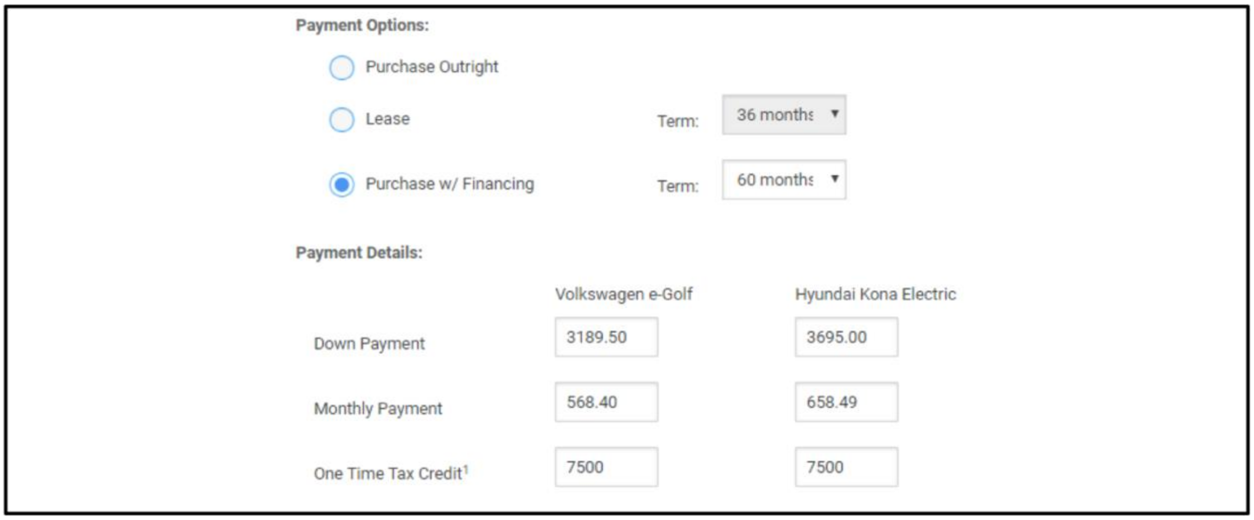


Figure 45. BeFrugal vehicle financing and incentives inputs

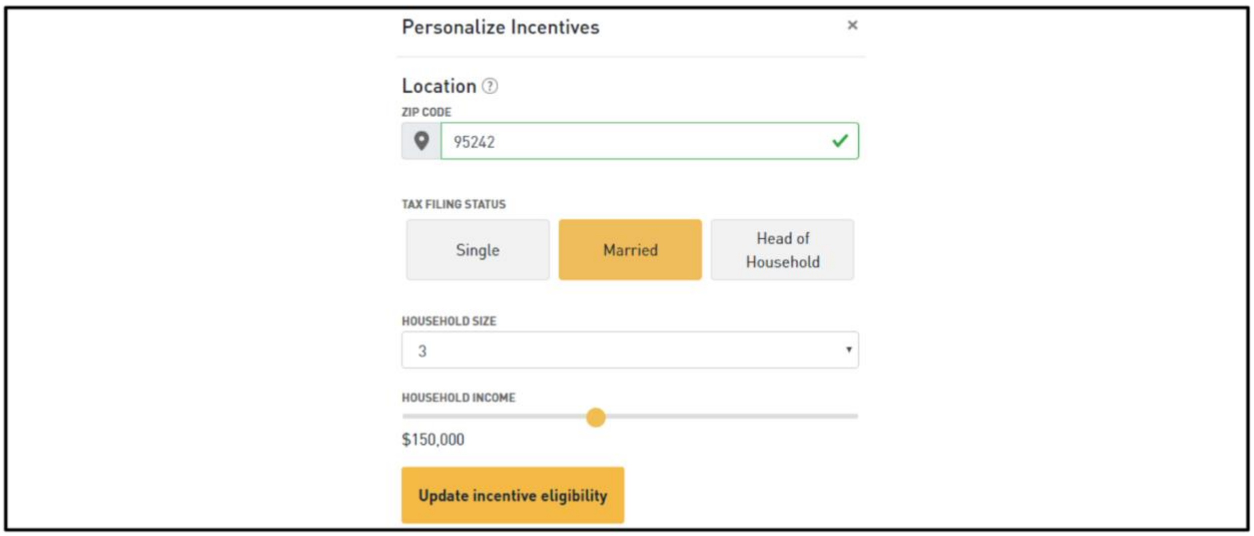


Figure 46. PG&E's incentives tailoring inputs

Figure 47. DOE VCC financing + incentives input

In the usability interviews, participants typically used the cash/loan/lease inputs in PlugStar with no issue, but two participants remarked that the lease length options needed to include terms longer than 48 months. As previously noted, the additional financing inputs in PlugStar (under the "Incentives" tab) were not intuitive to find (also, researchers initially directed participants to the cost tab in the interest of time); thus, only one interviewee was observed interacting with these inputs (after being led to them by the researcher based on comments he made). He wanted to change a car purchase price directly, which is not possible, rather than modify the additional fees and discounts toggles since he knew the final purchase price but articulating those details took some working backwards. On the other hand, several survey respondents criticized the absence of inputs for interest rate, taxes, and/or registration fees in BeFrugal, although purchase price or down payment amount was directly modifiable and could be adjusted up to account for these additional costs (again, researchers had directed participants to look at the cost tab, so they may not have explored as much as they would otherwise).

Interviewees at the auto show recognized that the default vehicle prices in BeFrugal and PlugStar did not reflect the marked-up prices they had been seeing for the EV model they wanted. Salespersons also expressed concerns about purchase price assumptions, with regard to PlugStar. They noted that advertised MSRP and lease prices may not reflect the actual price dealers are asking, which varies greatly by location due to different taxes and mark-ups based on demand. They reported some negative experiences with customers coming in with "unrealistic" expectations because of specific prices seen in advertisements or on websites. One interviewee said it should be made clear whether the default was the base trim level or be able to select a trim level; this is actually possible in the "Build" tab in PlugStar, but the participant did not notice it.

Finally, several interviewees and survey-takers were dissatisfied with financing inputs in BeFrugal and PlugStar because they could not describe used vehicles they were considering purchasing or their current vehicles that were already paid off in order to calculate the cost differences for keeping a current vehicle versus trading it in/selling and replacing with an EV. For example, regarding PlugStar one survey respondent suggested, "Used car pricing/depreciation should be an option." Another said of BeFrugal, "Does not allow me to include a car that has been paid off for years so I can compare against new car." As discussed in the outputs section, one interviewee exemplified both these use cases: he wanted to know at what point, if ever, it might be economical (or at least not a big difference in costs) to trade in/sell his current gas vehicle which was old and requiring more maintenance and purchase a used EV to replace it. The tested VCCs did not meet his needs.

In terms of incentives inputs, although participants greatly appreciated the personalized incentive information in PlugStar some indicated they wanted to be able to modify it. On the other hand, with BeFrugal, participants were able to specify incentives value but most needed more guidance to accurately factor in the available incentives.

Other Inputs

Other inputs that do not fit squarely in one of the four categories above include user location, which is typically requested as zip code or state and used to determine default fuel prices and identify relevant incentives. The only usability issue with these was when one interviewee wanted to check electricity price defaults in different cities on PlugStar, and had to spend considerable time figuring out the zip code he wanted to compare. As described in the outputs section, a major point of confusion in the user research was the portrayal of EV maintenance cost in BeFrugal and PlugStar (not a factor in EV Explorer). In BeFrugal but not PlugStar, users were able to modify the default annual maintenance cost as they wished (Figure 48), and some did (particularly for an EV they owned already). This maintenance cost input is located with the vehicle selection and specification inputs.

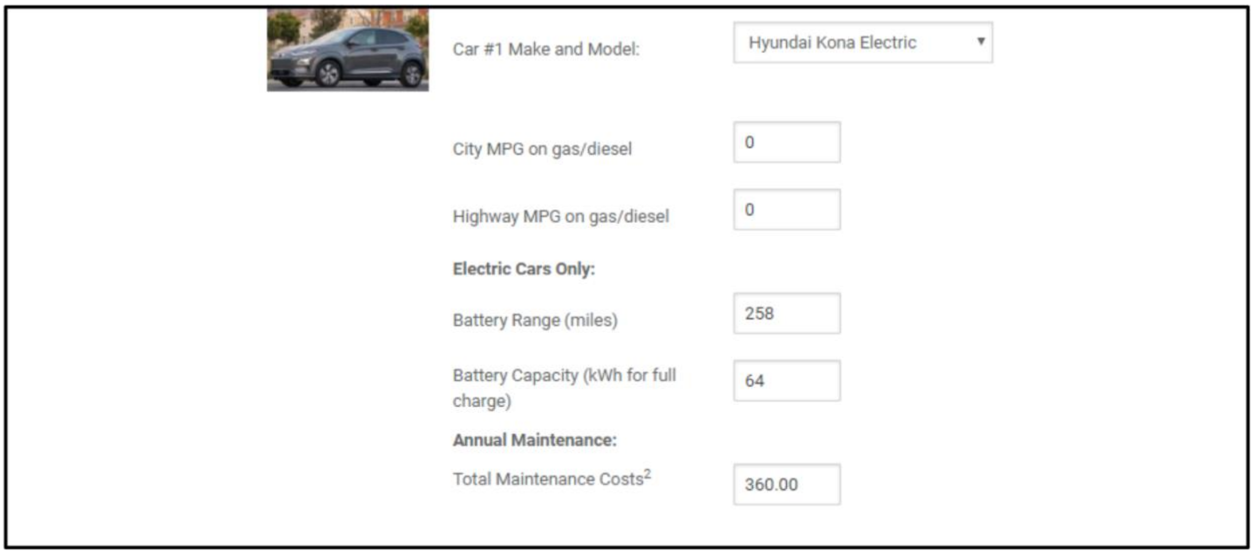


Figure 48. BeFrugal optional maintenance input

Recommendations

Based on the findings from the VCC review and user research detailed above, we outline the following best practices and recommendations for VCC user interface design.

Outputs

- Focus on comparing operational savings of an EV v. a similar ICEV, e.g., in an initial output
- Compare acquisition costs in a separate output, highlighting impact of incentives
- Compare cumulative TCO, highlighting breakeven time for EV v. ICEV
- Present more realistic maintenance cost estimates for EVs, particularly in the short term
- Exclude costs that are not significant differentiators of EVs v. ICEVs from default outputs
- Define depreciation costs in layman's terms and do not include in TCO by default (optional)

- Integrate salient, emotionally-evocative information re: EV social & environmental benefits
- Include and define life-cycle emissions estimates (not just tailpipe and/or well-to-wheels)
- If including maps in output, use them to visualize EV range and public charging locations

User Experience

- Required inputs should be relatively minimal and high leverage in terms of tailoring output
- User inputs should have flexible response formats to minimize cognitive demand
- Maximize optional inputs to maximize ability to tailor results
- Optional inputs should be separate from required inputs to lessen perceived demand
- Optional inputs should be salient when the output is displayed so the user is aware of them
- Optional inputs that are irrelevant based on other user inputs should not be displayed
- Default optional input values should be as tailored as possible, accurate & explicitly labelled
- Annotate input defaults with sources and tips to help users decide whether/how to modify

Inputs

Vehicle Selection and Specification

- Require some vehicle selection inputs (e.g., one make-model-year, body style, price range)
- Provide comprehensive selection of vehicle models and years (inclusive of all drivetrains)
- Provide link alongside vehicle selection inputs to tool dedicated to EV shopping
- Enable comparison of at least 4 vehicles (more is better, but default at 2 for initial output)
- Allow users to modify efficiency-related specs for chosen vehicles

Driving

- Require some driving inputs, designed to estimate total mileage accurately or generously
- Communicate the implications of daily driving (between charges) for PHEV fuel costs
- Use flexible formats so users can easily estimate mileage in a way that makes sense to them
    - For mileage inputs, let the user specify the denominator (e.g., miles per day/year)
    - For mileage inputs, allow multiple daily profiles (e.g., weekdays and weekend days)
    - For trip inputs, allow more than one trip, route specification and waypoints

    - Supplement trip inputs with “other driving” and/or annual mileage input

Fueling

- Include optional inputs for fuel prices with defaults as specific to user location as possible
- Only display optional inputs for prices of fuel types used by the vehicles being compared
- Label default prices so the data source is clear (e.g., PG&E off-peak rate)
- Use off-peak rate as editable default for home charging price (with link to more rate info.)
- Allow users to easily indicate exclusively home charging or exclusively public charging
- Provide optional charging inputs to factor in time-of-use and multiple public chargers
- Partner with charger companies to estimate level and cost for user-selected stations

Financing

- Include optional inputs for new and used vehicle acquisition costs
- Include different sets of inputs based on acquisition type (cash, loan, lease, and rent)
- In default estimates of vehicle price, specify or note implications of different trim levels
- Estimate used car resale value based on Kelley Blue Book or Consumer Reports
- Include optional inputs for all relevant financing terms and state-specific taxes and fees
- Provide up-to-date federal, state and local incentive estimates
- Include household income tax information inputs to determine incentive eligibility
- Allow direct modification of vehicle price and incentives in addition to the above inputs

Other

- Include zip code input for tailoring fuel price and incentives estimates
- Allow modification of maintenance costs estimates

Limitations

This research focused on the user interface, or front-end, of VCCs. As such, the recommendations do not account for back-end implications, i.e., how user inputs should be factored in to cost calculations in VCC outputs. Further research is needed to articulate best practices for back-end development, including integrations with multiple data sources and cost calculations. Our future research plans include more consultation with EV experts to help develop specifications for back-end programming solutions.

Methodological limitations of the user research include the small sample size of exclusively Californians. Other potential limitations relate to the contrived nature of the testing (at the auto show and researcher’s office). Participants may not have given the tools their fullest attention (particularly at the auto show) and they may not have had resources available to them that they would have if exploring the tools more naturalistically (e.g., more time to consider inputs and interpret outputs, and other family members to consult).

Conclusion

This research articulated best practices and recommendations for VCC user interface design. A variety of stakeholders, including government agencies, energy utilities, and EV advocacy groups, can use these recommendations to create and promote VCCs that encourage EV adoption by providing consumers with accurate and relevant information that highlights the economic, social, and environmental benefits of EVs.

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Data Management

Products of Research

Data from usability testing (surveys and interviews) were collected.

Data Format and Content

The usability testing data collected includes a spreadsheet with responses from a survey of VCC users. It also includes video and audio files generating with Gazepoint eye-tracking equipment in .prg, .mp3 and .avi file formats.

Data Access and Sharing

The survey data are available at https://doi.org/10.25338/B8SC9T

Reuse and Redistribution

Survey data can be cited, provided the authors/users cite this report and the dataset. The dataset should be cited as:

> Sanguinetti, Angela (2020), VCC User Survey Results, UC Davis, Dataset, https://doi.org/10.25338/B8SC9T.

Eye-tracking data will not be shared, but readers can inquire for more information about these results.