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Developing a Vehicle Cost Calculator to Promote Electric Vehicle Adoption Among TNC Drivers

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Developing a Vehicle Cost Calculator to Promote Electric Vehicle Adoption Among TNC Drivers

June 2023

A Research Report from the National Center for Sustainable Transportation

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16. Abstract
This research developed EV Explorer 2.0, an online vehicle cost calculator (VCC) to meet the requirements of transportation network company (TNC) drivers considering acquiring an electric vehicle (EV). The tool was built to also support the needs of other users considering an EV, including other types of gig economy drivers as well as the general population of non-professional drivers. EV Explorer 2.0 includes several important features and functionalities to support the TNC driver use case that are not found in any other available tool: (1) It allows users to estimate TCO for used vehicles as well as new (others only estimate TCO for new vehicles); (2) Outputs include ridehail-driving income estimates, accounting for EV trip bonuses offered by Uber, net driving costs; (3) Estimates of total cost of driving (TCD) include charging network membership fees and charging session fees (in addition to electricity prices). It also includes key features found in other leading tools, such as presenting and tailoring EV purchase/lease incentive estimates (based on a database we developed), and innovative features to benefit all users, such as animations conveying the social and environmental impacts of vehicle choice. Design features were informed and validated in user testing with TNC drivers who had expressed interest in EV adoption.

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NCST

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EXECUTIVE SUMMARY

Vehicle electrification is an important strategy in moving toward a more sustainable transportation future, reducing dependence on fossil fuels and reducing greenhouse gas emissions (Hawkins et al., 2012; Hawkins et al., 2013; Jaramillo et al., 2009; Knobloch et al., 2020; Onat et al., 2015). The advent of transportation network companies (TNCs) creates an opportunity to reduce emissions from internal combustion engine vehicles (ICEVs), by regulating ridehailing operations (e.g., California Senate Bill 1014 "clean miles standard") and converting vehicles used for ridehailing services to electric vehicles (EVs).

At the same time, this transition faces many unique challenges. TNC drivers are independent contractors who supply their own vehicles and most often self-identify as low-income (Taiebat et al., 2022). Previous studies have demonstrated that high-income consumers are most likely to buy EVs (Erdem et al., 2010; Saarenpää et al., 2013), in large part due to their almost universally higher upfront costs. Even accounting for assistance from incentives such as rebates and federal, state and local tax credits, the upfront cost of EVs remains higher than comparable gas vehicles.

Though studies on EVs demonstrate that the total costs of ownership (TCO), which includes maintenance and fueling, are typically lower than comparable gas cars in the long run, it can be hard for consumers to recognize potential savings over time. Average car-buyers do not typically consider fuel and maintenance costs before purchasing a vehicle and tend to be grossly inaccurate when estimating fuel costs (Allcott, 2011; Turrentine & Kurani, 2007). However, research shows that when the information can be properly calculated, consumers choose higher fuel economy vehicles (Gabaix & Laibson, 2006) and that their willingness to pay for EVs is driven primarily by fuel cost savings (Hidrue et al., 2011).

Unlike average car-buyers, TNC drivers use their vehicles intensively and as such may be more motivated to adopt EVs. For TNC drivers, the operational cost savings of EVs relative to gas cars can ultimately yield much more favorable TCO and higher earnings. Researchers who study TNC drivers such as Taiebat et al. (2022) have argued that interventions to inform TNC drivers of the potential TCO savings with EVs will promote a faster transition to TNC electrification. This report outlines the development of one such information intervention: EV Explorer 2.0, a vehicle cost calculator (VCC) to help TNC drivers consider whether an EV would meet their needs and increase their earning potential.

EV Explorer 2.0 builds on the original EV Explorer (gis.its.ucdavis.edu/evexplorer/#!/) by factoring in vehicle acquisition costs, incentives, depreciation, and maintenance costs in order to provide the full picture of TCO. The TCO model used was built on Chakraborty et al.'s (2021) framework, adapting it to better suit the case of the TNC driver (and the gig driver more generally) so that EV Explorer 2.0 can provide accurate cost estimates for drivers that fully account for the potential savings with an EV compared to a gas car. Specifically, we aimed to account for impacts of higher mileage, likely dependence on DC fast public chargers, and used car and lease acquisition models. This called for two major adaptations of the model: to incorporate further inputs and new calculations for more precise operational cost estimates and to incorporate alternative vehicle acquisition models, such as used vehicle purchase and vehicle lease, whereas existing VCCs focus on new car purchase.

EV Explorer 2.0 is the first VCC where older vehicle models can be selected, supporting use cases where users are interested in purchasing used vehicles. It is the second VCC tailored to TNC drivers and the first to attempt to meet the needs of this special population as well as the general population of car buyers. EV Explorer 2.0 is the first VCC to estimate gig driving income in addition to, and juxtaposed with, operational costs. For example, it shows that a gig driver can earn over $10,000 more annually with a Chevy Bolt compared to a Toyota Camry when taking into account operational savings (fuel and maintenance) and the $1 trip bonus Uber is currently offering (assuming about 50,000 annual miles of ridehailing driving, California fuel prices, and home charging). It is also unique among VCCs in highlighting social and environmental impacts through the use of empathetic gauges– animations of wildlife conveying the benefits of EVs in terms of GHG emissions, local air pollution and gasoline use/waste.

The EV Explorer 2.0 user interface was designed to minimize demand on users but maximize the potential for customization. There are few inputs required before a user reaches the initial output, but a customization panel located along the bottom of the screen allows extensive customization via inputs for all factors that would significantly impact costs, particularly anything that differs substantially for EVs vs ICEVs. A single page, non-scrolling design keeps all the interactive inputs and outputs no more than one click away.

Another main goal of the interface was to tell a clear and compelling story. EV Explorer 2.0 visualizes different types of cost estimates, breaking down TCO into its constituent elements which are more comprehensible on their own and match drivers' mental models, thus hoping to make the full picture of TCO also more comprehensible. Specifically, cost outputs are split into Vehicle Costs, Driving Income and Costs, Total Costs, and Cumulative Costs.

The major datasets and models generated in this research are available for others to use[1]. Future development goals for EV Explorer 2.0 include updating our incentive database, further honing some of the calculations for the used vehicle purchase scenario, and acquiring a data source for vehicle MSRP so that the tool can have default purchase and lease cost inputs. We hope that TNCs, other gig driving companies, and advocacy groups will promote EV Explorer 2.0 to gig drivers, and that VCC developers in government and industry can use the research reported herein to develop or improve their own VCCs. Ultimately, we hope this research will support and empower gig drivers by informing them about the potential TCO savings and social

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and environmental benefits of EVs and support gig driving companies to continue developing goals and programs to transition to zero-emissions services.

Introduction

Vehicle electrification is an important strategy in moving toward a more sustainable transportation future, reducing dependence on fossil fuels and reducing greenhouse gas emissions (Hawkins et al., 2012; Hawkins et al., 2013; Jaramillo et al., 2009; Knobloch et al., 2020; Onat et al., 2015). There are two types of electric vehicles (EVs): Battery electric vehicles (BEVs) are powered exclusively by electricity from rechargeable batteries. Plug-in hybrid electric vehicles (PHEVs) can run on gas and/or electricity; they have a rechargeable battery in addition to an internal combustion engine.

Regulations are emerging that require transportation network companies (TNCs) to reduce emissions from ridehailing operations (e.g., California Senate Bill 1014 "clean miles standard"). A primary means of achieving these reductions is increasing the proportion of ridehailing trips made by electric vehicles (EVs). This is challenging because TNC drivers are independent contractors who are responsible for supplying their own vehicle and EV prices are higher than comparable internal combustion engine vehicles (ICEVs) and hybrids that operate on gasoline. Prior research has shown that higher-income consumers are more likely to buy EVs (Erdem et al., 2010, Saarenpää et al., 2013). (Hjorthol, 2013), whereas ridehailing drivers predominantly self-identify as low income (Taiebat et al., 2022).

EVs are incentivized by rebates and tax credits at the federal, state, and local levels, although not typically at a level that brings them to price parity with comparable gas vehicles. EVs are also cheaper to maintain and generally cheaper to fuel than gas vehicles (especially given current gas prices), which can make total costs of ownership (TCO) lower than for comparable gas cars in the long run. TNC drivers who use their vehicles intensively may reap greater benefits from the operational cost savings of EVs relative to gas cars, thus EVs can ultimately yield much more favorable TCO and higher earnings, and this will increasingly be the case as batteries become more affordable and EVs reach cost parity with ICEVs (Chakraborty et al., 2021; Hamza et al., 2021; Pavlenko et al., 2019).

Using data from all drivers on the Lyft platform in the US in 2019, Taiebat et al. (2022) recently estimated that a fully charged BEV with a 250-mile range (BEV250) could meet the daily driving requirements for more than 86% of Lyft drivers on at least 95% of days, and that both new and used BEVs would result in net savings for many drivers. They estimated that a purchase subsidy (or incentive total) of $5,700 for a new BEV250 would result in a lower TCO relative to a comparable gas car for that ~86% of range-suitable drivers on the Lyft platform. Higher-mileage drivers could achieve a lower TCO with a new BEV250 without any subsidy, and all drivers could achieve a lower TCO with a used BEV250, which had the lowest TCO of all vehicle types per their models.

Taiebat et al. (2022) recommended interventions to inform TNC drivers of the potential TCO savings with EVs to promote a faster transition to TNC electrification. This research developed one such information intervention: a vehicle cost calculator (VCC) to help TNC drivers (and gig drivers more broadly) consider whether an EV would meet their needs and increase their earning potential. Initial design specifications were informed by the authors' prior research.

Iterative design was informed by usability testing of VCCs with TNC drivers. This report proceeds with a literature review establishing the need for a VCC for TNC drivers and background information about our relevant prior research. It then turns to the present research, with a description of the user interface design and goals, website development process, TCO calculations, usability testing, and conclusions.

Literature Review: The Need for a VCC Tailored to TNC Drivers

Common consumer perceptions and habits make it difficult to recognize the operational cost savings, and thus lower net TCO, that can be achieved with EVs. Average car-buyers do not typically consider fuel and maintenance costs before purchasing a vehicle (Allcott, 2011; Turrentine & Kurani, 2007). The concepts of “consumer myopia” and “shrouded costs” suggest consumers focus on vehicle purchase price and ignore add-on costs (Allcott, 2010; Gabaix & Laibson, 2006).

Consumers are also typically very inaccurate when estimating fuel costs, and particularly potential savings from a more fuel-efficient vehicle (Allcott, 2011). Research has demonstrated common perceptual biases that result in large errors in cost savings estimates associated with energy-efficient technologies in general and fuel economy in particular (the “MPG illusion”; Attari et al., 2010; Larrick & Soll, 2008). Consumers tend to underestimate relative savings potential when comparing lower MPG vehicles and overestimate differences between higher MPG vehicles.

Calculating costs can correct for these biases that affect our “off-the-cuff” estimations. Research has found that consumers who calculate and compare fuel costs choose higher fuel economy vehicles (Gabaix & Laibson, 2006) and that willingness to pay for EVs is driven primarily by fuel cost savings (Hidrue et al., 2011). A survey of EV drivers on the Uber platform found that 72% calculated all vehicle costs before acquiring an EV (Sanguinetti & Kurani, 2021). Thus, TNC drivers, more than average car-buyers, may adopt EVs when it is economically rational to do so. For example, Bansal et al. (2020) found that TNC drivers who do rideshare driving daily are more inclined to use fuel-efficient vehicles. This is consistent with findings that EV adopters in the general population drive more miles than non-adopters (Plötz et al., 2014).

However, calculating potential operational (particularly fuel) cost savings for an EV compared to an ICEV is complex, for consumers (Egbue & Long, 2012) as well as experts (Hagman et al., 2016). It requires knowledge regarding gas prices and electricity prices--perhaps at multiple charging locations, as well as ICEV fuel economy and per-mile electricity consumption of the EV, which all vary (Kurani et al., 2016). Web-based vehicle *energy* cost calculators have been recommended as a solution to help consumers navigate this complexity (Eppstein et al., 2011), providing expected fuel costs based on a user’s driving patterns and local gas and electricity prices. However, even if consumers understand energy cost savings potential, they may not understand whether these savings, combined with available incentives, would offset a higher EV purchase price. Thus, Wu et al. (2015) recommended policies that facilitate consumer engagement in TCO evaluations, including via vehicle cost calculators (VCCs) that include acquisition costs as well as operating costs.

There are at least a dozen online VCCs available to consumers (Sanguinetti et al., 2020), but until recently none focused on the TNC use case. For example, existing VCCs only provide TCO estimates for new vehicles, not for used vehicles (ours is the first to do this). This also applies to Uber's EV Cost Calculator Guide, the first and only other consumer-facing VCC designed for TNC drivers besides the one developed in this research. Full-time TNC drivers who typically earn less than the median US salary may not predominantly be buying and leasing new cars (especially at the higher price points of EVs) and, as Taiebat et al. (2022) found, used BEV250s have the lowest TCO for the ridehailing use case of any vehicle type. Since vehicle operational cost is closely linked with TNC drivers' earnings, there is also potential for a VCC designed for TNC drivers to highlight the potential impact of vehicle choice on earnings in addition to TCO and ours is also the first to leverage this opportunity. Wu et al. (2015) suggested that VCCs will become increasingly effective as EVs approach price parity with ICEVs. This research aims to prepare for that moment and support TNC electrification by developing a VCC tailored to TNC drivers.

Background

The proposed project builds on two past NCST projects (Chakraborty et al., 2021; Sanguinetti et al., 2020) and other work at the UC Davis Electric Vehicle Research Center. The development of a VCC for this project built on the foundation of EV Explorer (gis.its.ucdavis.edu/evexplorer/#!/), a vehicle *energy* cost calculator developed by the UC Davis Electric Vehicle Research Center that provides estimated fuel (gas and electricity) costs for up to four (new or used) vehicles (of any drivetrain) at a time. EV Explorer is written in JavaScript and makes use of several freely available public APIs, all of which were adopted for the VCC developed in this project, which we named EV Explorer 2.0.

EV Explorer 2.0 builds on the original EV Explorer by factoring in vehicle acquisition costs, incentives, depreciation, and maintenance costs in order to provide the full picture of TCO. The TCO model for the VCC is built on Chakraborty et al. (2021), in which the authors developed a TCO model incorporating a teardown analysis of the cost of manufacturing different types of electric vehicles (short-, mid-and long-range battery electric vehicles and plug-in hybrid electric vehicles in the passenger car and passenger truck segment) and a flexible operating cost calculation model accounting for driver heterogeneity. This project adapted that model based on insights from our past VCC research and to better suit the TNC use case. For example, it was modified to account for leasing and used vehicle purchase, and it focuses more on the operational cost components and the lease contract costs (for the lease business model) than the manufacturing cost of a vehicle.

This research team has also conducted the only published research testing the effectiveness of VCCs in promoting EV adoption (Sanguinetti et al., 2016). We conducted an experiment with the original EV Explorer to assess user 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 validated the tool as an educational and persuasive strategy to promote EV adoption.

In a subsequent NCST-funded project, Sanguinetti et al. (2020) articulated best practices for VCC user experience design based on a systematic analysis of VCCs and extensive usability research with VCC users and likely users (i.e., EV shoppers and owners). This was foundational research as others had pointed out how inconsistencies across VCCs (e.g., in terms of TCO calculation methods; Wu et al., 2015) made it difficult to recognize best practices. Appendix A provides the list of best practices and analysis of other VCCs as context for the new VCC developed in this research. Our VCC design also drew on an understanding of the needs of ridehailing drivers with EVs based on research conducted in collaboration with Uber Technologies, Inc. Specifically, the project PI conducted a focus group with EV drivers on the Uber platform and an online survey for which Uber recruited all their EV drivers in the US and Canada (Sanguinetti & Kurani, 2021).

User Interface Design

The following sections describe the EV Explorer 2.0 user interface design. Appendix B provides detailed documentation of the website features and functionalities. Overall goals for the design were to:

- minimize demand on users, but
- maximize the potential for customization;
- tell a clear and compelling story about potential TCO savings with an EV compared to a gas vehicle, including for the specific case of ridehailing drivers, while also prioritizing accuracy and transparency; and
- highlight the social and environmental benefits of EVs.

Other overarching goals were to attain a professional appearance and provide a pleasant user experience. Specific objectives and strategies related to these goals are discussed in the following sections.

The initial design relied heavily on the best practices articulated in our prior research (Sanguinetti et al., 2020). Other sources of inspiration are mentioned where applicable. We also weave discussion of insights from usability testing into the description as rationale for design choices, while the usability testing methodology and some broader analyses are presented in a subsequent section.

Minimize Demand

The landing page is a simple introduction to the tool that quickly orients the user (Figure 1). We considered adding facts about the non-cost related benefits of EVs (e.g., fun to drive) that could potentially increase users' knowledge, interest, and intention to adopt. However, VCC users seek these tools out because they are already interested in EVs (confirmed in our prior research: Sanguinetti et al., 2016, 2020); VCCs might be considered a "pull" marketing strategy as opposed to a "push". However, programs that promote the use of VCCs among TNC drivers who would not seek them out independently should leverage the opportunity to increase users' awareness of non-cost related EV benefits. One strategy along these lines that we did use, based on feedback from usability testing, was to change our vehicle graphic on the landing page from a small hatchback (similar to a Chevy Bolt) to a more appealing Tesla-esque sedan.

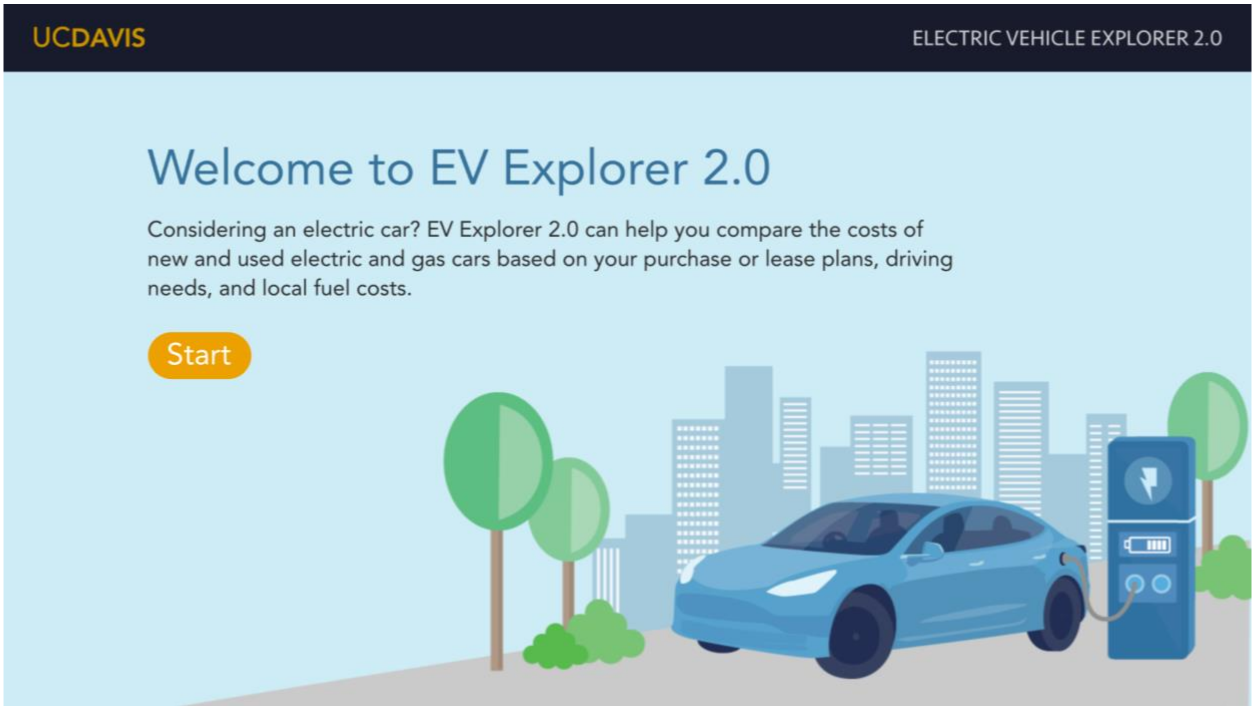

Figure 1. EV Explorer 2.0 Landing Page

Beyond the simple landing page that allows the user to move quickly into the main purpose of the VCC tool (i.e., cost estimates and comparisons), there is a short series of modal screens that collect user inputs (Figure 2 and Figure 3). The required inputs in the modal (i.e., those a user must fill out to proceed) are designed to be minimal and high leverage in terms of their ability to personalize outputs. It is also at this point that paths diverge for the gig-driving versus non-gig-driving user, since this information is critical to tailor the output in a meaningful way. The reader may note here that we broadened our mission to tailor the tool for not only ridehailing drivers, but gig drivers in general–including those who provide ridehailing and/or delivery-based services.

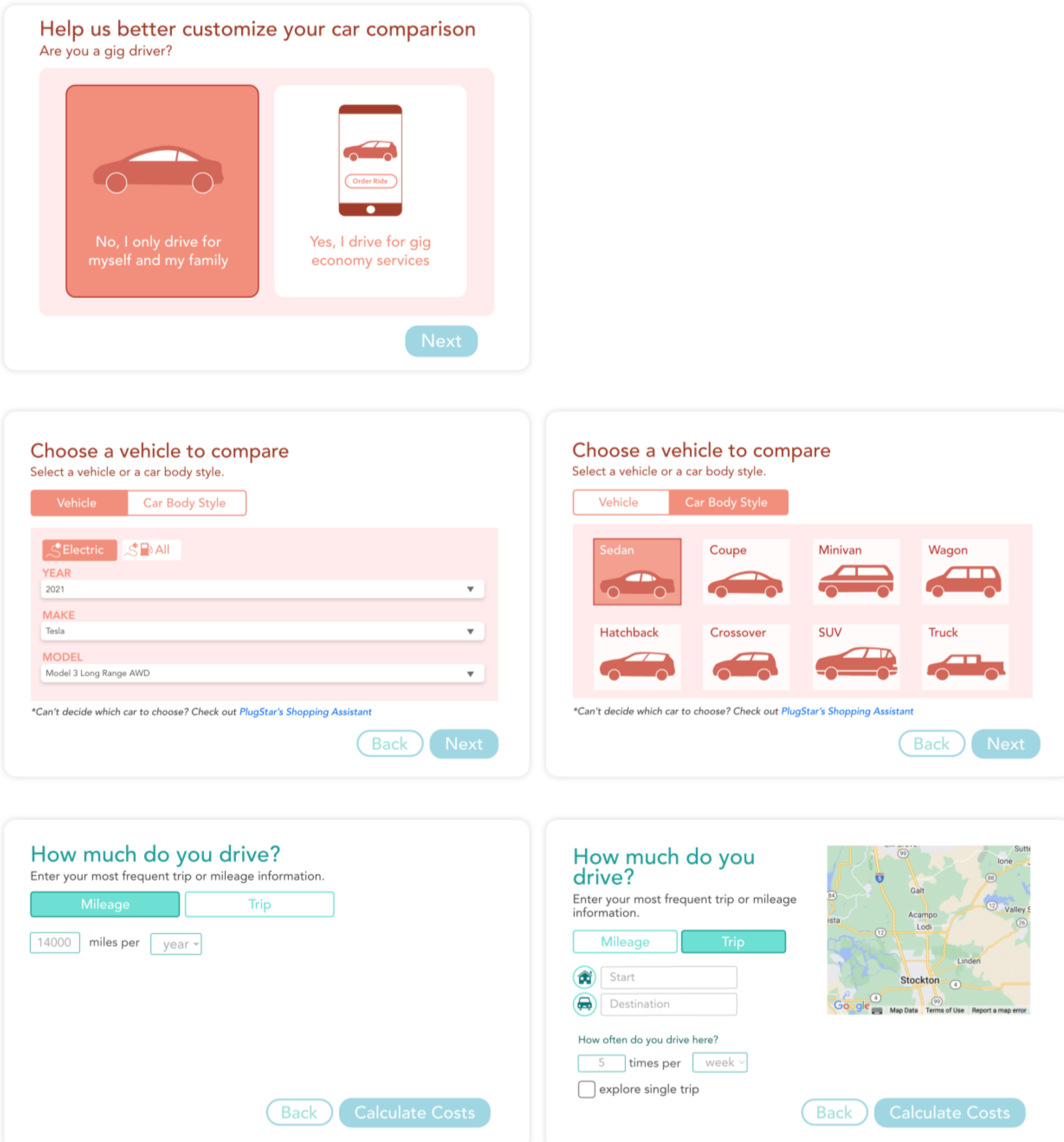

Figure 2. Modal Screens with Required User Inputs, Non-gig Driver Pathway

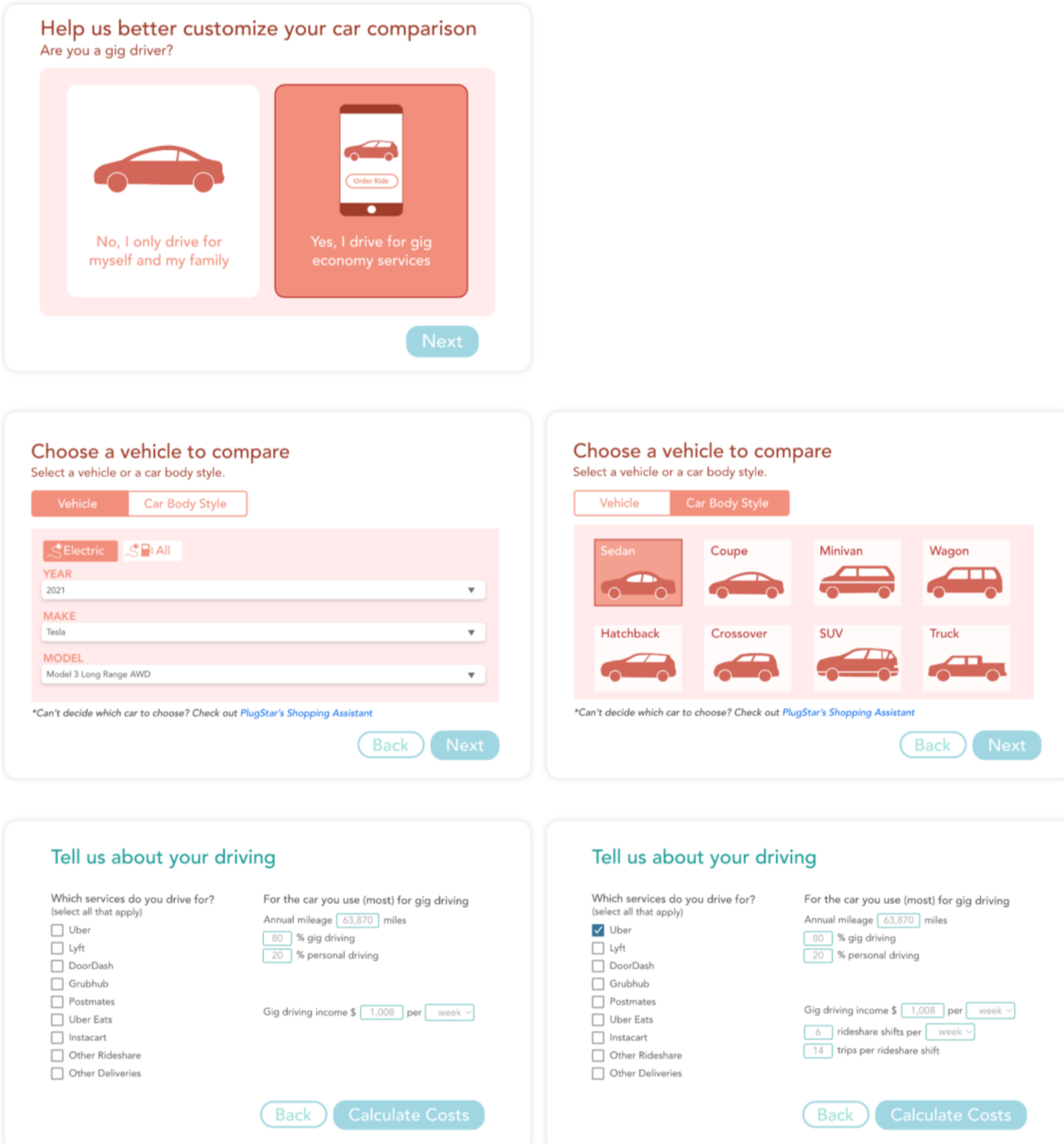

Figure 3. Modal Screens with Required User Inputs, Gig Driver Pathway

For both the gig-driving and non-gig-driving pathway, the user must choose a vehicle model or body style. Our past research showed users prefer to choose a vehicle upfront rather than after an initial cost output. The flexibility of allowing users to choose a specific model or a body style category lowers demand because it provides options suited to two different mental models: one where the user is interested in a specific vehicle (whether electric or gas) and one where the user may be unaware of specific EV models and interested in exploring the options available for a preferred body style. A notification appears beneath this modal screen for the gig driver pathway if the user chooses a two-door vehicle model or body style or a vehicle older than 2007 that states the vehicle or style may not be eligible to provide rides on Uber or Lyft platforms.

The modal also collects some input on how much the user drives, a variable with a big impact on TCO and a particularly important factor when comparing ICEVs and EVs. Gig drivers are also asked to report the companies for which they drive, their income, and (if they drive for Uber) the amount of trips they make. The latter is used to estimate potential additional income from EV trip bonuses that only Uber currently provides ($1 per trip). For non-gig drivers, the driving inputs are flexible, allowing users to report mileage information (over a user-selected time interval: week, month, or year) or specify a most frequent trip. Again, the intent of flexibility here is to provide paths suited to different mental models; in this case, someone familiar with their mileage can easily use that input, whereas someone unsure of their mileage can enter their trip information to have it calculated (this works best for a commuter, as others may not have a single trip that dominates their driving patterns).

After selecting a vehicle model or body style and inputting a minimal amount of information about their driving in the modal, the user reaches the output screen (Figure 4). From this point forward, every output and input window is available via one click on the visible screen (i.e., no scrolling). This is meant to facilitate easy access and use of features and to minimize the potential for a user to get lost.

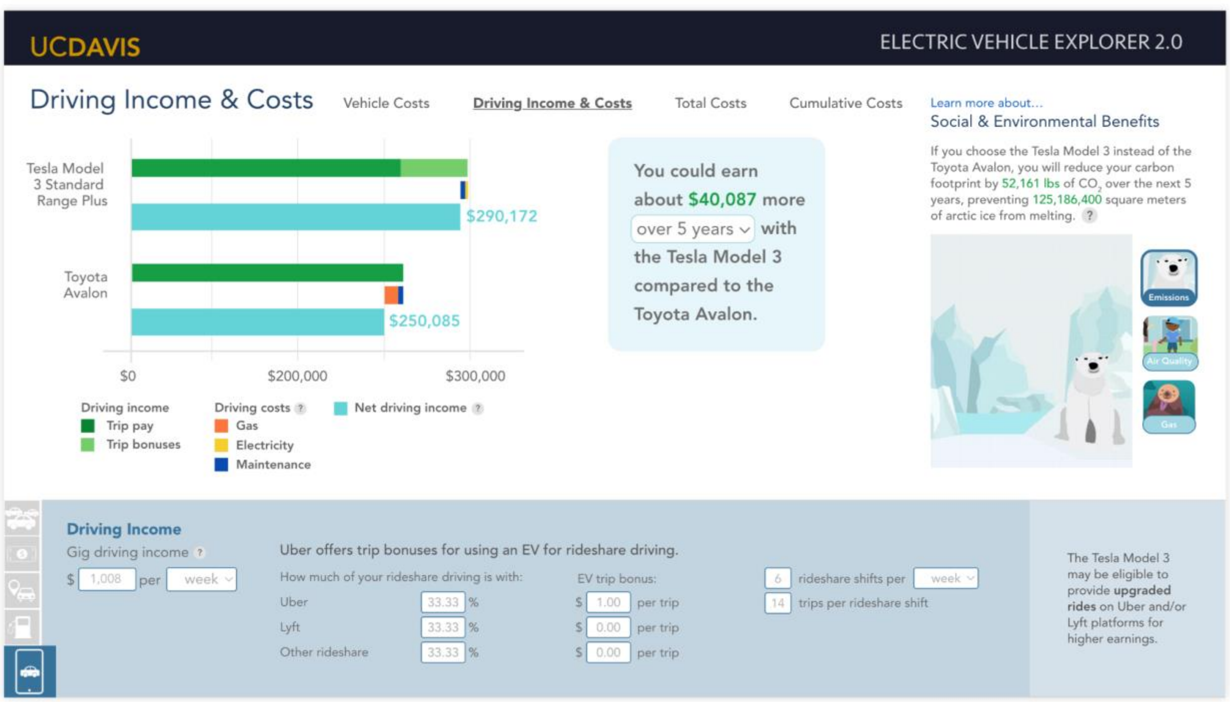

Figure 4. EV Explorer 2.0 Output Page

Further user interactions follow a non-linear process. Users can edit information in the customization panel along the bottom of the screen (described later in detail), including all their initial inputs, to change the cost outputs. (Tools with a more linear process require starting an initial input process all over to change the outputs.)

Tell a Clear and Compelling Story

The output provides cost estimates in a two-car comparison format. The two cars must be one EV (either BEV or PHEV) and one gas-powered car (ICE or hybrid). Our past usability research showed that users preferred to be able to compare more than two cars at once, but this functionality was sacrificed in the interest of simplicity and telling a clear story. The main goal of conveying the potential TCO savings with an EV compared to a gas car is accomplished in a two-car comparison, and users can change the cars in the comparison to obtain the information for as many cars as they wish.

The comparative cost estimates are divided into four categories, each with its own data visualization, navigable via tabs at the top of the screen. These are Vehicle Costs, Driving Income & Costs (just Driving Costs for non-gig drivers), Total Costs, and Cumulative Costs. Each has a narrative component to the right of the data visualization that interprets the chart, highlighting the cost difference between the EV and the gas car. This element is intended to help less numerate users more easily understand the information. Not all VCCs explicitly provide this information; some show just the costs of each vehicle and the user would need to do the difference calculation on their own. Sacrificing the ability to compare multiple cars at once was related to this priority, since the narrative gets more complex with more than two cars.

The first cost output displayed when the user reaches the output page after filling out the modal inputs is Driving Income & Costs for gig drivers (Figure 5) and Driving Costs for non-gig drivers (Figure 6). The strategy in this is to lead with the cost category that best highlights the benefits of EVs for each user group. Operating costs (termed driving costs in the tool to be more colloquial), including fuel (gas and electricity) and maintenance, are where EVs save users the most money compared to gas cars. For gig drivers, situating operating costs within the context of driving income may be particularly compelling as it highlights greater earning potential.

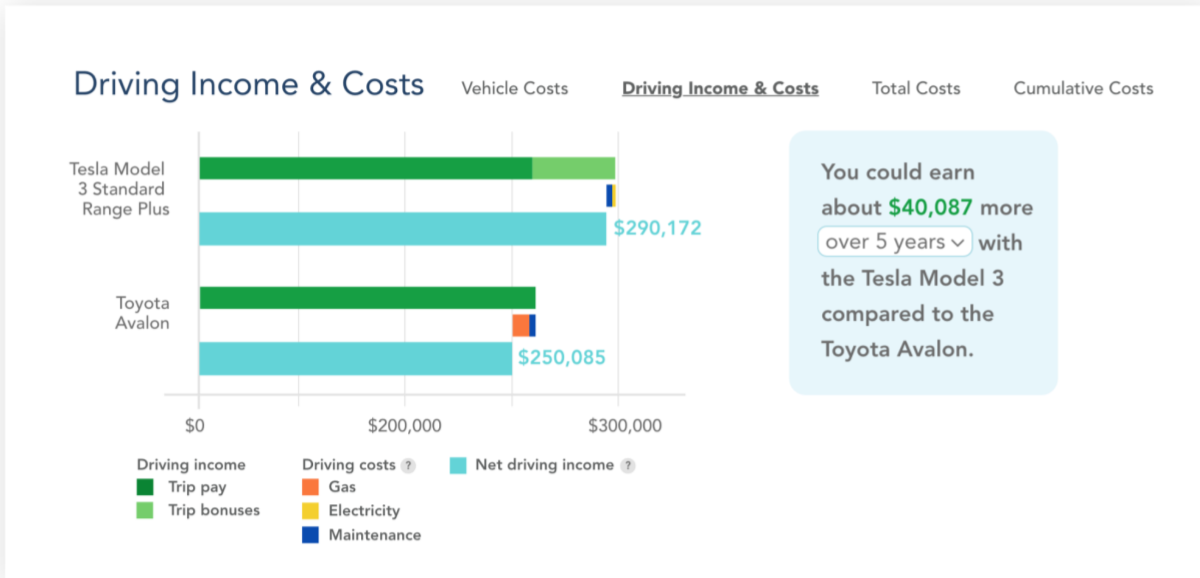

Figure 5. Driving Income and Costs Output for Gig Drivers

Figure 6. Driving Costs Output for Non-gig Drivers

The other intention behind this strategy of splitting up types of costs is to match users' mental models—how they think about these things. Research has shown that car buyers in the general population (not gig drivers) rarely consider fuel costs when choosing a vehicle (Turrentine & Kurani, 2007). Operational costs, if considered at all, might be more likely than part of weekly or monthly budgeting, separate from a large purchase decision (Allcott, 2011). For the gig driver, operational costs factor into their earning potential, and thus something they are highly likely to consider and compare to their income (Sanguinetti & Kurani, 2021). The Driving Income and Costs output matches this mental model (Figure 5).

The Vehicle Costs output (Figure 7) speaks to the mental model that focuses on the upfront costs of buying or leasing a vehicle, e.g., if a consumer has a price range (or maximum) in mind and they consider this independently from TCO. The availability of incentives for purchase or lease of new EVs is relevant in this mental model as it impacts the net total purchase or lease cost. The first data visualization displayed when the user clicks over to Vehicle Costs is a chart comparing the incentives available for each vehicle (always $0 for the gas vehicle in the comparison). The user can then navigate across two other tabs in this section: Purchase or Lease Cost (Figure 8) and Net Cost (Figure 9). The Purchase or Lease Cost chart shows the purchase or lease costs of each vehicle, based on which acquisition mode the user indicates, before incentives. The Net Cost chart introduces the incentives back in to show how they impact the total upfront cost of the EV and the comparison to the gas car. One user noted "It flows really easy and it actually gives you options to look at your financing and to get some different incentives in there. That's, I like that it really breaks down to specifics that you probably wouldn't even think of without looking at this page. It shows over $10,000 (incentives) estimated for the vehicle that I chose. That's amazing. So it's actually overall cheaper or less expensive to do the EV than the Toyota Rav4."

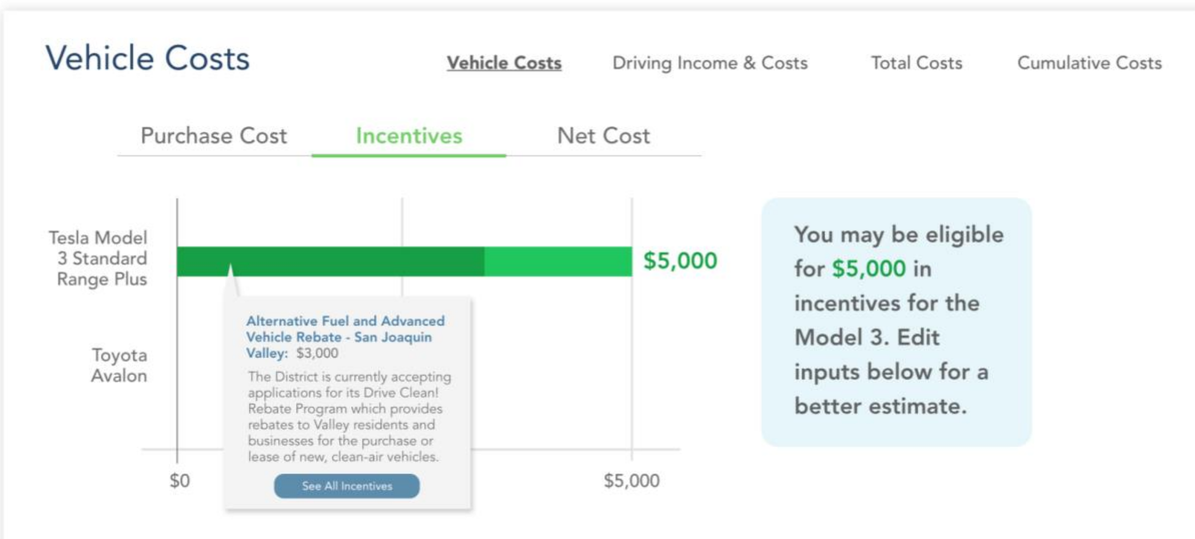

Figure 7. Vehicle Costs Output: Incentives View

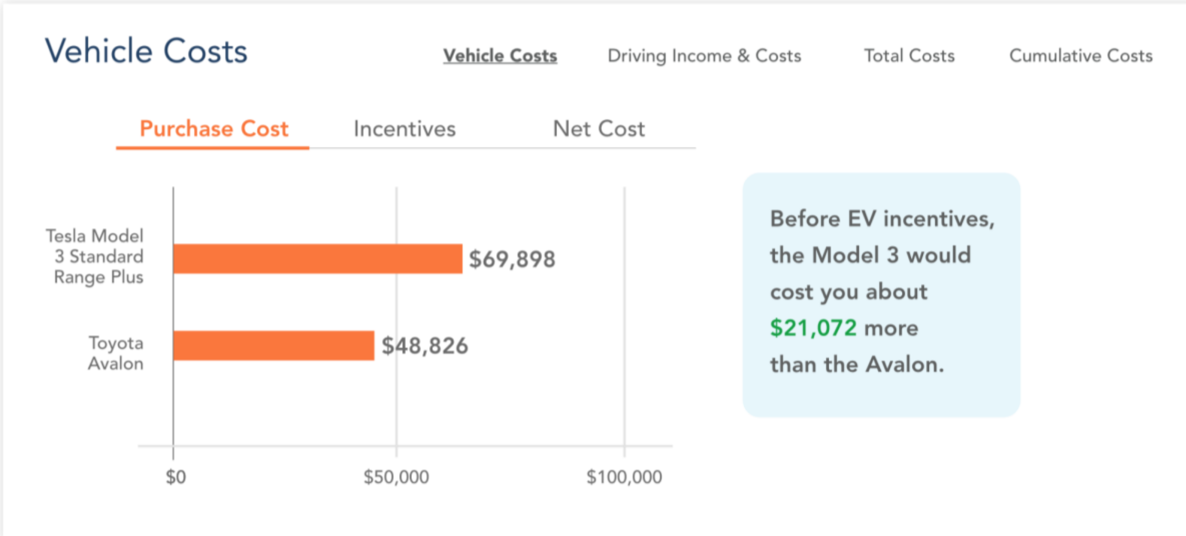

Figure 8. Vehicle Costs Output: Purchase or Lease Costs View

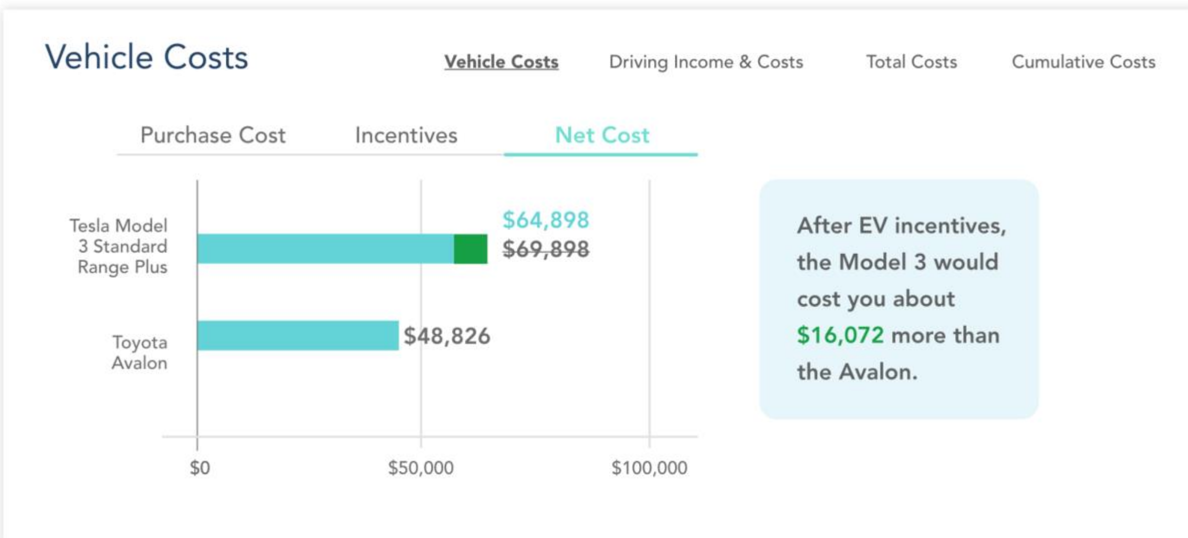

Figure 9. Vehicle Costs Output: Net Cost View

There were logistical and strategic reasons for breaking up Vehicle Costs into these three sections. We were limited in our ability to provide default vehicle prices (this is discussed further in the Data Sources section), so users typically have to add that information themselves before the tool can calculate initial and net purchase costs. However, we wanted to provide some valuable data initially in this output without further demand on the user to enter vehicle price before seeing anything in the chart. Additionally, singling out incentives first allows the spotlight to shine on EV benefits of which users may not be aware. If we had a source for MSRP data, we might consider changing this output to a waterfall chart type similar to the one we use for the Driving Income and Costs output (Figure 5).

The last two cost outputs, Total Costs and Cumulative Costs, reflect TCO. The Total Costs output (Figure 10) was inspired by Zappy Ride[2] tools that provide a concise summary of TCO in a stacked bar chart. Our usability testing in this and prior projects has shown that users find this output visually appealing. However, they have difficulty comprehending all the information at once. In particular, the contribution of vehicle ownership to TCO (purchase cost minus incentives and resale value at the end of a specified timeframe) is complex, as illustrated in Figure 11 which shows one of our usability testers interacting with the Zappy Ride TCO chart in the Uber EV Cost Calculator and Guide.

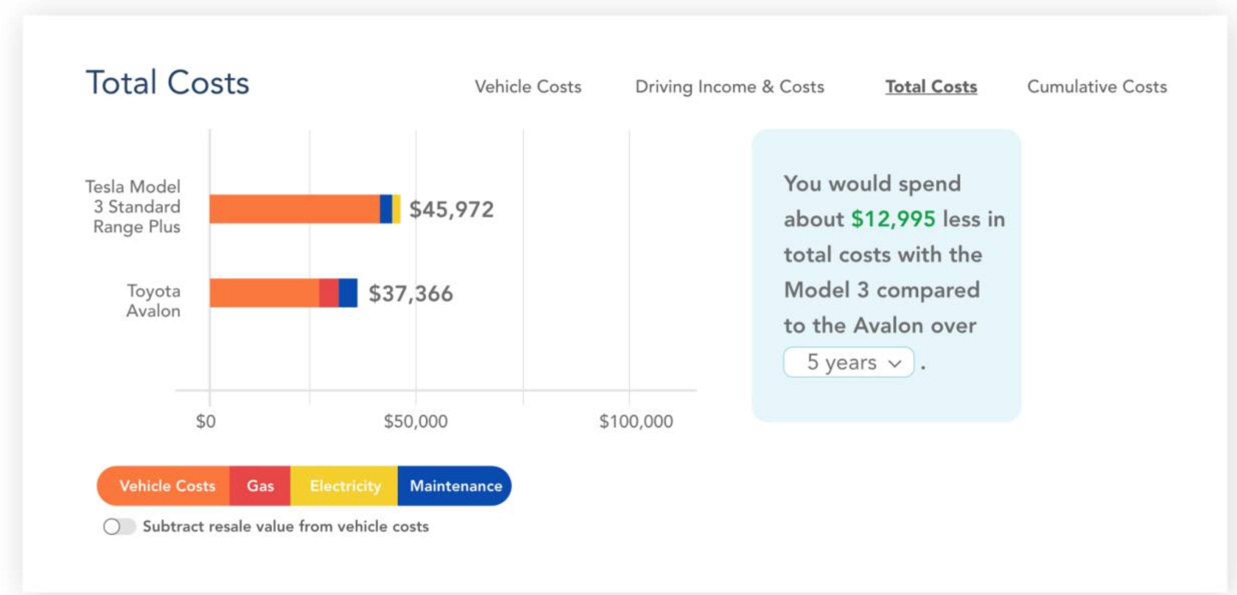

Figure 10. Total Costs Output

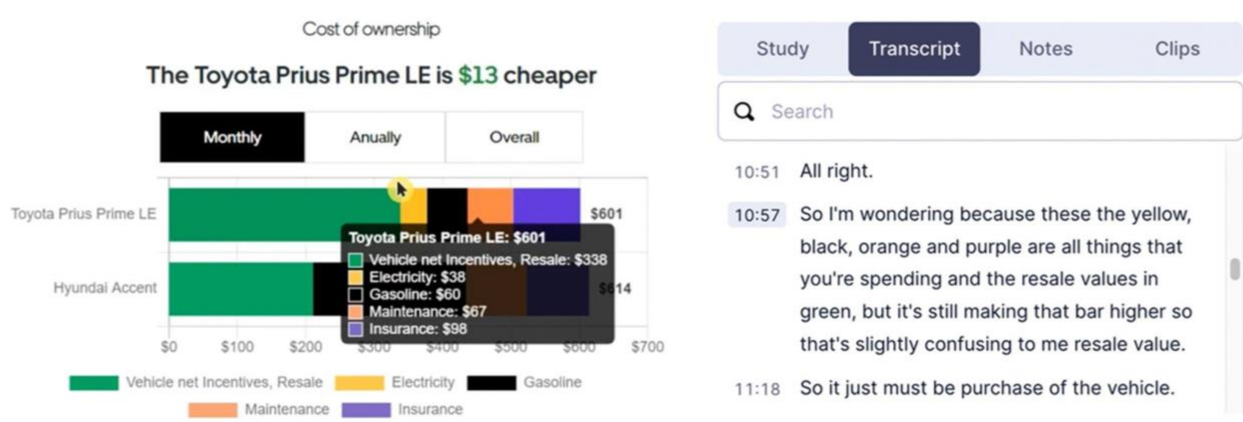

Figure 11. Usability Tester Interacting with TCO Chart in Uber EV Cost Calculator and Guide

[2] https://www.zappyride.com/

Our Total Cost output attempts to make this concept more comprehensible by using clear and simple language and presenting vehicle costs first without subtracting resale value; a toggle allows the user to subtract resale value from the vehicle cost factor. The idea is that a user might be more likely to understand this factor if they first orient to the familiar concept of vehicle costs and then consider resale value. Figure 12 shows the same usability tester featured in Figure 11, easily and quickly understanding resale value when using the toggle

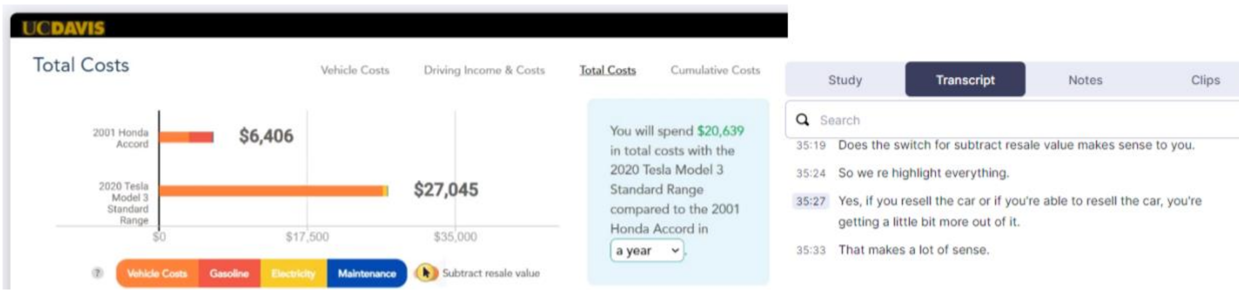

Figure 12. Usability Tester Interacting with TCO Chart in EV Explorer 2.0

The Cumulative Costs output (Figure 13) was inspired by WattPlan (wattplan.com). In the (common) case that an EV costs more to purchase or lease than a comparable gas vehicle (even after incentives), this output highlights the breakeven point, i.e., the time at which total costs for the gas vehicle surpass total costs for the EV. In other words, this shows a user how long they would need to drive a given EV for it to be worth the investment relative to a comparison car. The benefits of being able to see costs over time in a straightforward manner were noted by drivers during the usability tests. One user noted, "break even in 5.9 years, interesting, that is really meaningful information. I'm impressed with the algorithms on this, that they can show you that really quickly. The Tesla does seem like a significant savings, obviously not for six years, but then it clearly skyrockets."

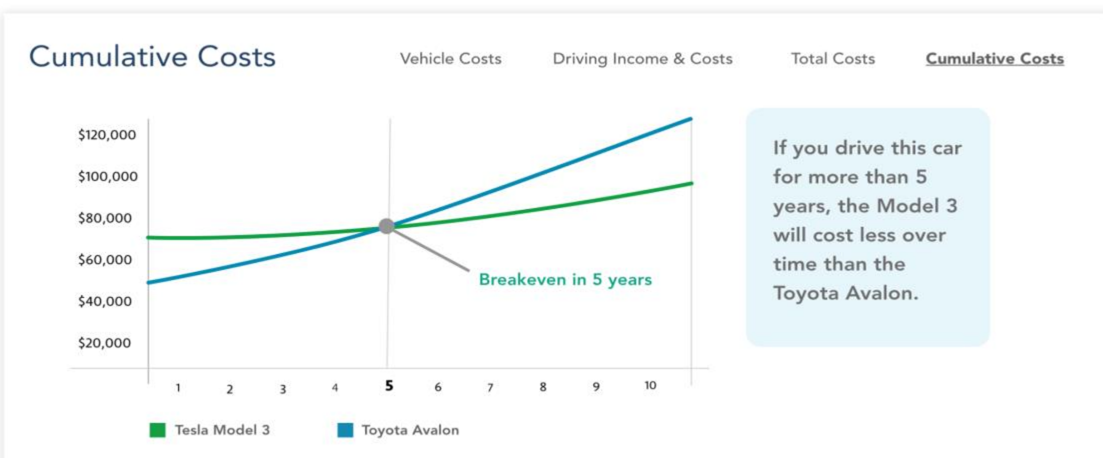

Figure 13. Cumulative Costs Output

Highlight Social and Environmental Impacts

EV Explorer 2.0 includes salient information about the environmental and social benefits of EVs relative to gas cars alongside the cost outputs (Figure 14). Specifically, it compares the two displayed vehicles in terms of three types of impacts: carbon emissions from vehicle production and operation, local air pollutants in tailpipe emissions, and gasoline use. Each of these outputs is accompanied by an animation to illustrate the concepts and make the data more emotionally evocative and compelling; this strategy is called an empathetic gauge (Petersen et al., 2016). Emissions information also includes a conversion to an equivalent amount of arctic ice melting (Notz & Stroeve, 2016). This contrasts sharply with other tools that only report these data in numeric form and scientific data visualizations, and even those that include conversions intended to make the information more meaningful, like number of trees required to sequester an equivalent amount of emissions with a small green tree icon at the bottom of a list of vehicle attributes.

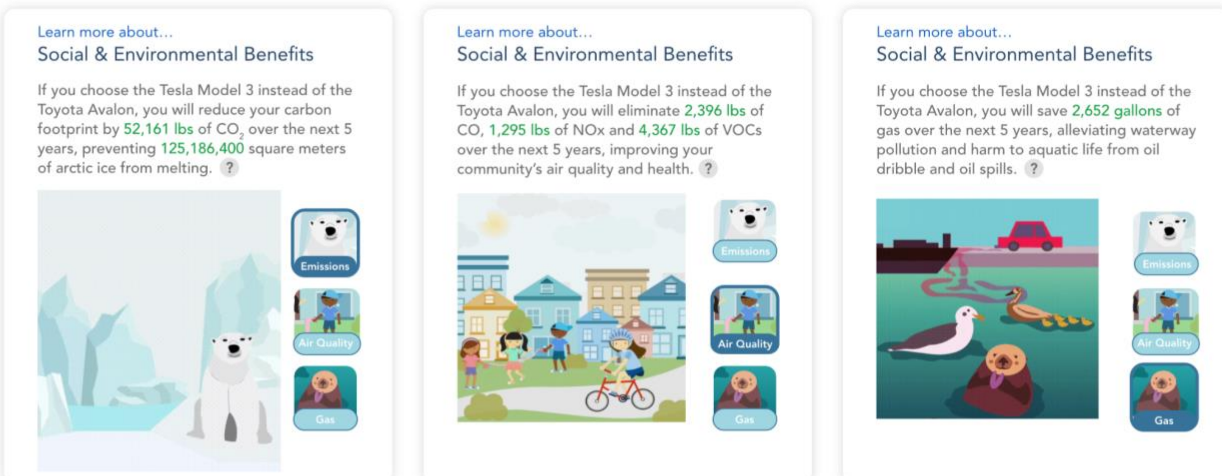

Figure 14. Social and Environmental Impacts Outputs

There were several reasons behind the strategy of including more information on environmental and social impacts than seen in other VCCs and giving it comparable salience relative to the cost outputs. First, we know from past research that environmental awareness and motivation have been key drivers of EV adoption to-date (Rezvani et al., 2015). Second, our past VCC usability research (Sanguinetti et al., 2020) indicated users appreciated emissions information, although some were unclear or skeptical about the scope of emissions (e.g., on-road versus lifecycle), particularly if the information was vague (EV Explorer 2.0 includes an information defining the emissions scope and providing the source for emissions data and the conversion to melting arctic ice). Finally, by juxtaposing the environmental and social benefits of EVs with vehicle costs, we hope to support users in framing any additional financial costs associated with an EV compared to a gas car as an investment in these benefits.

Usability testing revealed generally positive reactions to these outputs. For example, one user remarked, "I really like the social and environmental benefits. I would never take a lot of time to look up what the benefits would be, but seeing that, that's extremely interesting and really eye opening actually." Different users were drawn to different things, confirming the benefit of showing diverse social and environmental impacts and equivalencies. For example, the glacial ice melt CO_2 equivalency was particularly compelling to one user, while another was more interested in seeing the pounds of CO_2. The air pollution information resonated with a user whose grandson has asthma.

Remarks about the imagery (e.g., “cute pictures, “nice vibe”) and comments implying an emotional impact (“makes me want to drive an electric car”, “makes you stop and think”) validated our choice to include a salient, artistic, and evocative style of data visualization for social and environmental impacts. However, some comments suggested room for improvement in terms of clarifying the information and providing resources to learn more about CO_2 emissions and air pollution, which led us to add more salient information hovers with more details and links to other resources in those outputs. Two users expressed skepticism about the emissions impacts which are difficult to tackle within the site: One indicated the impact of their personal actions pales in comparison with those of large corporations (suggesting it may not matter), and the other was not convinced the lifecycle impact (beyond emissions) of EVs is lighter on the environment when considering production and waste issues.

Maximize Customization

Although there are (strategically) few inputs required before a user reaches the initial output, a customization panel located along the bottom of the screen allows further customization (Figure 15 through Figure 21). We aimed to include inputs for all factors that would significantly impact costs, particularly anything that differs substantially for EVs vs ICEVs. This was to ensure both reasonable accuracy overall and in terms of the relative costs of EVs and ICEVs. The latter is crucial to prevent misleading people, e.g., over-flattering EVs. There were some sacrifices to precision in service of keeping things simpler, such as excluding insurance costs (discussed further in the TCO Model section).

Wherever possible, we included meaningful default values for optional inputs so that users can assess and consider whether they want to change them. “Meaningful” defaults refers to both providing the source for default values so users can gauge whether it is credible, as well as tailoring the information when possible (e.g., default fuel prices based on user location). Another way we add meaning to the inputs, prompted by insights from our usability testing, is to describe how optional inputs impact costs so that the user might be more motivated to change them or at least understand why they are there.

The initial view of the customization panel upon landing on the output page displays a prompt in large, bold font to notify users of the ability to customize the output (Figure 15). There is a vertical menu on the left side of the panel with five icons depicting different categories of inputs: Car Manager, Financing, Driving, Fueling, and Driving Income (displayed for gig drivers only). Car Manager inputs (Figure 16) allow the user to change the electric and/or gas vehicle compared in the outputs, and to edit basic information about vehicle fuel efficiency.

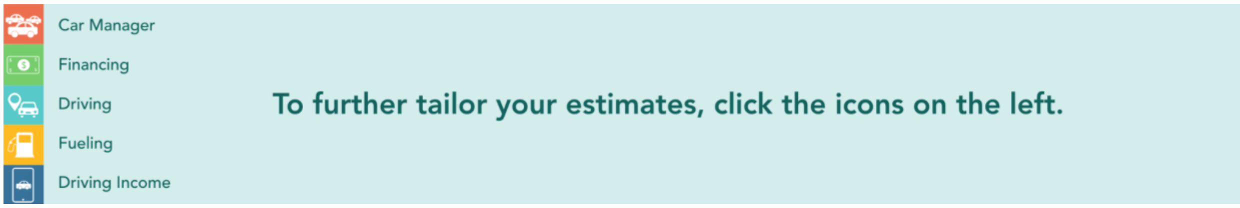

Figure 15. Landing View of Customization Panel at Bottom of Output Page

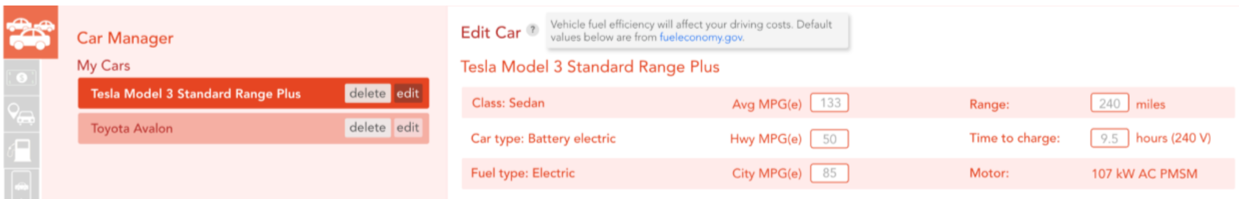

Figure 16. Car Manager Customization Panel: Editable Inputs for Vehicle Efficiency and Range

Financing inputs (Figure 17) include information related to EV incentive eligibility to provide users more tailored estimates for incentives. There is also a section in the panel for how the user plans to acquire their vehicle (purchase with cash or loan, or lease). Ideally, these costs would have default values based on a reliable general source of vehicle price data, but licenses to use such sources were prohibitively expensive. Thus, EV Explorer currently includes default prices for only a small subset of vehicles (gathered manually); otherwise, the user is prompted to populate these inputs when they click on Vehicle, Total, or Cumulative Costs outputs.

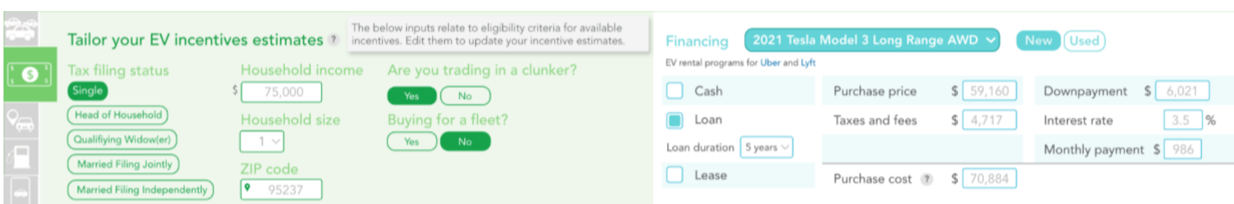

Figure 17. Financing and Incentives Customization Panel

Optional Driving inputs (Figure 18) include the ability to specify mileage, traffic conditions, and frequency for two daily profiles (heavier and lighter driving days) as well as long trips. Optional Fueling inputs (Figure 19) allow users to specify local fuel prices (the default is the average prices in the State where the user is located) and charging information. Charging information can be input in a basic or advanced window. The basic charging inputs specify what percent of charging users intend to do at home versus at workplace or public charging stations, whereas the advanced inputs allow users to specify percent of charging at multiple public stations and also enter charging membership, session fees, and a one-time home charger installation cost. For gig drivers only, links are provided in this panel to TNC charging programs, in the basic view.

Figure 18. Driving Information Customization Panel for More Precise Driving Cost Estimates

Figure 19. Fueling Information Customization Panel for More Precise Driving Cost Estimates

For gig drivers only, Driving Income inputs (Figure 20) allow users to edit the information they entered in the initial modal regarding their income. They can also edit the amount of rideshare driving and distribution of ridesharing driving across companies to see the impact of EV trip bonuses, currently offered only by Uber. An additional notification appears in this panel if the EV in the comparison is eligible for upgraded services on Uber or Lyft that offer higher pay rates (e.g., Uber Comfort, Lyft Lux).

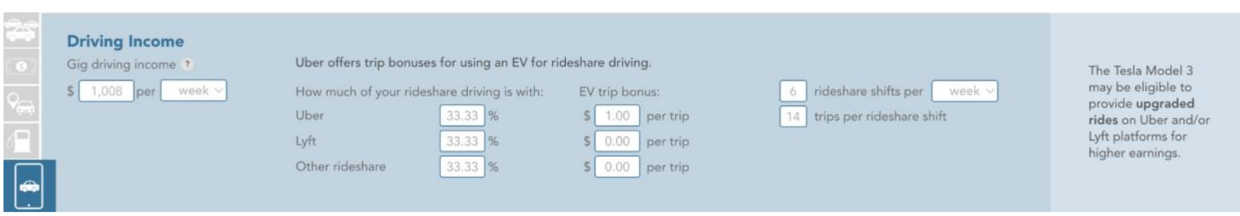

Figure 20. Driving Income Customization Panel for More Precise Driving Income Estimates

Website Development

Now that we have described the design and rationale behind EV Explorer 2.0, we move on to a description of the nuts and bolts of website development. The following sections detail the three key components of the development process: mockups, programming, and the TCO model.

Website Mockups and Clickable Prototype

Website mockups and a prototype for EV Explorer 2.0 were created in Adobe XD. Specifically, Adobe XD allowed us to construct static images of the website design (mockups) and also a hi-fidelity clickable prototype containing visual and interactive elements which mimic the appearance and functionality of a real website. This meant we could establish a cohesive design system of visual elements that respond to mouse events (hover states, page transitions, toggle states) and simulate how users would normally interact with the live site.

This prototype was a fundamental tool, serving as a roadmap for product development, providing valuable insights during internal reviews, enabling effective team communication (e.g., between designers and developers), and providing a prototype for user testing. The mockups and prototype were used to establish user interface (UI) and user experience (UX) design specifications. Once the team was satisfied with the prototype's functionality and visual elements, high-quality mockups were exported as image references for website development. Front-end code snippets in HTML and CSS were also generated in Adobe XD for a smooth hand-off to developers.

Programming Overview

EV Explorer 2.0 is a fully functioning website hosted on an ITS-Davis webserver. EV Explorer is written entirely in JavaScript programming language. This means all calculations are done in the user's browser, which helps to make the tool responsive to use. D3 library is used for the output cost comparison charts.

The site uses Angular frontend framework. Frontend libraries like Angular enable professional websites to adapt seamlessly to different devices, windows and magnifications and faithfully translate the details of good web design (which is more difficult than it looks). Our team is still working on some sizing issues that occur on certain screen sizes, so users currently may need to slightly zoom out to see all elements.

EV Explorer uses Node.js (nodejs.org) to power its webserver and backend API (Application Programming Interface). As data are collected from the user and calculations and comparisons are performed, other data are retrieved from multiple sources, including the web browser, databases we built for the site, and external APIs. Modern web programming, combining many different asynchronous data sources, is powerful, but collecting and combining data in real time from multiple systems, each with their own, disparate data schemata, is a highly complex endeavor.

Data Sources

EV Explorer 2.0 makes use of several freely available public APIs that are also used in the original EV Explorer. Google Maps API is used to display user-input trip origin, destination, and route on a map as an aid to estimate mileage (in the non-gig driver pathway only). An API from fueleconomy.gov, a site co-sponsored by the US DOE and EPA, is used for vehicle fuel economy and electric range information. Default (but modifiable) fuel prices in the tool are state averages taken from the US Energy Information Administration (EIA). The user's state is determined based on their IP address using ipstack (ipstack.com).

Building out EV Explorer 2.0 to account for TCO, rather than energy costs only as in the original EV Explorer, required identifying additional data sources for vehicle acquisition and maintenance costs, as well as resale value. Vehicle MSRP and EV incentive data sources were prohibitively expensive. We manually gathered MSRP from caranddriver.com for a subset of vehicles–specifically, those to which the site defaults when a user chooses a vehicle body style instead of a specific model to compare and the comparison cars that show up next to a user-selected model. Ideally, and hopefully in the future for EV Explorer 2.0, a VCC should have MSRP data so the user does not have to find and input that information.

We deemed it a higher priority to include comprehensive incentive information for all EVs since users may not know how to find it otherwise, whereas vehicle purchase and lease prices are readily available via familiar channels (e.g., manufacturer websites and local car dealerships). We created our own comprehensive (at the time) database for vehicle incentives, manually gathering the data on federal, state, and local incentives. The IRC 30D New Qualified Plug-In Electric Drive Motor Vehicle Credit is the main federal tax credit. A list of vehicles qualified for the IRC 30D and the amount was gathered from fueleconomy.gov. For state and local credits, we gathered the incentive names, descriptions, links to program information, amount levels, and eligibility criteria from the DOE's Alternative Fuels Data Center (AFDC; afdc.energy.gov); the appropriate incentive(s) and amount(s) populate for the user based on the following inputs related to the eligibility criteria: tax filing status, household income, household size, zip code, if a clunker could be traded in, and fleet status (Figure 17).

Both databases (federal and state and local incentives) can be found on the Dryad data repository at https://doi.org/10.25338/B8363M. Each row in the State and Local Incentives database represents a unique combination of an incentive program and eligibility-related variables with a corresponding dollar amount. For example, the Used Plug-In Hybrid Electric Vehicle (PHEV) Incentive for Peninsula Clean Energy gives $1,000 to any San Mateo resident, but $4,000 to low-income residents.[3] Since there are two different values dependent on income, this would be two separate rows in the database.

We relied heavily on the 2020 AFLEET tool by the Argonne National Laboratory. This is where we gathered data for calculating vehicle maintenance costs and resale value as well as social and environmental impacts (GHG emissions, local air pollution, and gasoline use). The formulas

[3] https://afdc.energy.gov/laws/12217

we use for maintenance and resale value are detailed in the next section on the TCO model. Appendix C details our calculations for social and environmental impacts. Our calculations for vehicle lifetime GHG emissions are not as precise as is possible with the AFLEET tool. We simplified by using the average emissions for a model year 2020 vehicle of each drivetrain, so the resulting comparisons reflect user mileage and grid energy sources based on user location but not vehicle age.

EV Explorer 2.0 also provides users with links to pertinent sources, starting in the first modal screen when the user is tasked with selecting a vehicle model or body style to explore. There is a prompt, “Not sure which car to choose?” with a link to Plug-in America’s PlugStar Shopping Assistant tool (by Zappy Ride)[4] to help users looking to identify an EV suited to their needs. The incentives output provides links to each incentive program for which the user may be eligible (from AFDC). As previously mentioned, links are provided to learn more about each of the social and environmental impacts, including to articles from the Union of Concerned Scientists about vehicle lifetime GHG emissions[5] and local air pollution[6], an article and an article from Ocean Today about oil dribble[7]. In the Fueling Customization Panel, we link to a recent JD Power article about home charger installation costs and incentives[8].

For the gig driver pathway, and ridehailing drivers specifically, the site includes links to Uber and Lyft webpages in several locations for different purposes, including:

- links to information about vehicle eligibility requirements if the user selects a vehicle or body style that may be ineligible for driving on those platforms,
- links to information about EV charging programs in the Fueling Customization Panel,
- links to information about upgraded ride services when the EV in the comparison may be eligible to provide these services, and
- links to TNC rental programs next to the inputs for vehicle purchase or lease.

For the latter, we created a database of EVs eligible to provide upgraded ride services by referencing Uber and Lyft websites (available at https://doi.org/10.25338/B8363M).

Total Costs of Ownership Model

TCO has three main components: the capital cost associated with purchasing a vehicle, operating cost of the vehicle, and a resale value. In case of EVs, if a EV buyer decides to install a home charger, it is typically accounted for in the capital cost component along with the purchase cost since it is a one-time cost incurred by a vehicle buyer. Operating costs include

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4 https://plugstar.com/guide
5 https://blog.ucsusa.org/dave-reichmuth/are-electric-vehicles-really-better-for-the-climate-yes-heres-why/
6 https://www.ucsusa.org/resources/cars-trucks-buses-and-air-pollution
7 https://oceantoday.noaa.gov/oilintheocean/
8 https://www.jdpower.com/cars/shopping-guides/what-does-an-ev-home-charger-cost#:~:text=After%20all%2C%20recharging%20your%20EV,cost%20of%20materials%20and%20labor

fuel, insurance, vehicle registration, and maintenance. The resale value of the vehicle depends on the depreciation rate that may vary by fuel type and vehicle segment.

The TCO model developed for EV Explorer 2.0 builds from the framework in Chakraborty et al (2021), which was developed for the vehicle purchase scenario (vehicle purchased new with zero downpayment and financed for a 5 year loan period). Inputs for the capital cost component came from a teardown analysis and other public sources of data, e.g., operating cost estimated based on annual miles data from a 2019 California Vehicle Survey, fuel cost data from the EIA database, and resale value estimates from the 2020 AFLEET tool. In case of EVs, the probability of home charging was estimated from a cohort survey of EV owners administered by the UC Davis Electric Vehicle Research Center. The TCO/mile for a vehicle buyer with ownership period of 5 years was estimated as:

$$\boldsymbol{TCO_{p,c} = \frac{CC_{p,c} + OC_{p,c} - RV_{p,c}}{AM}}$$

Where $CC_{p,c}$ = annual capital cost of a vehicle; $OC_{p,c}$ = annual operating cost of a vehicle; $RV_{p,c}$ = discounted and annualized resale value of a vehicle with powertrain technology *p* and vehicle segment *c*; AM = annual mileage. For BEVs, the TCO is estimated for three different range categories. For PHEVs, it is estimated for a 40-mile and 80-mile vehicle.

Developing a TCO model for TNC drivers

The aim was to use the above TCO framework and adapt it to the TNC driving use case so that EV Explorer 2.0 can provide accurate cost estimates for TNC drivers that fully account for the potential savings with an EV compared to a gas car. Specifically, we aimed to account for impacts of higher mileage, likely dependence on DC fast public chargers, and used car and lease acquisition models. The first major goal of our adaptation of the above TCO was to increase the precision of operating (fuel and maintenance) cost estimates. Fuel cost is a major differentiating factor between ICEVs and EVs and particularly important when miles traveled by the vehicle owner is high as in the case of gig drivers. There can be substantial difference in maintenance costs between ICEVs and EVs as well and our past VCC usability research indicated maintenance cost estimates for EVs in existing VCCs were higher than EV users reportedly experienced, which diminishes the estimated savings with an EV compared to a gas car.

The other major adaptation to the TCO model was to build in consideration of alternative vehicle acquisition systems. Rather than solely focus on the vehicle purchase model, we needed to include used vehicle purchase and vehicle lease acquisition methods, which required modifying the upfront capital cost component in the model. We had hoped to also identify and evaluate the TCO associated with business models like short-term rentals or the “pay-per-mile” model of the insurance sector. However, we decided to leave out these business models from the analysis since the TCO from these rental models are highly dependent on the driving needs of the user, the deals offered by rental companies, length of the contract, and multitude of variable factors making these models more suitable for scenario analysis rather than an outcome-based model required for a VCC. Moreover, since car rental models are still rare for TNCs and existed mostly as pilot programs in limited geographies, it is difficult to find reliable data for the cost components. Therefore, the above TCO framework was adapted for the following three scenarios: (i) New vehicle purchase, (ii) Used vehicle purchase, and (iii) Vehicle lease.

The calculations were done in Excel and used in the VCC as inputs for the appropriate output tab. The main steps in the estimation process, the data used, and the assumptions for the three scenarios are described here. Details on the cost estimation process and the formulae used for each of the cost components are available at https://doi.org/10.25338/B8363M.

(i) New vehicle purchase

Capital costs

The capital cost component of the TCO calculation for the Vehicle Cost output only accounts for the cost associated with vehicle purchase. Assuming a loan term of 5 years (by default, but modifiable by the user), the loan amount is estimated to be user-inputted purchase price - downpayment - incentive rebates (if eligible). An annual interest rate of 5% is assumed for the loan financing calculation, though in practice the rate depends on the loan term and credit score of the borrower (thus, this is also a user-editable input).

Operating costs

For ICEVs, fuel efficiency depends on the vehicle model year and fuel price depends on the PADD region of the driver. In case of BEVs, range and MPGe of a vehicle depends on the model year of the vehicle and electricity price vary by utilities. As mentioned in the previous section on Data Sources, the data for vehicle efficiency is obtained from fueleconomy.gov while electricity price data is from EIA. Fuel cost for PHEV, depend on utility factor (share of electric miles driven) that in practice depends on the vehicle range and on the charging behavior of the driver. For estimation purposes, we assume the utility factor based on the driving information a user inputs in the model (i.e., trip or daily mileage or annual mileage divided by 365) until and unless the user specifies more nuanced daily driving patterns in the Driving Customization Panel, at which point the utility factor is changed to reflect those daily profiles and provide more tailored estimates.

Other VCCs use an average per-mile cost for maintenance, which differs by drivetrain and may increase with vehicle age. However, as previously mentioned, we found that VCC users with EV experience were shocked by what they reported as unrealistically high estimates for EV maintenance costs. To try to correct for this, we developed a different method for estimating maintenance costs, based upon user-inputted mileage and cost of specific maintenance measures using data from AFLEET on the recommended number of miles for the following measures/replacements: oil change, oil filter, tire rotation, fuel filter, air filter, cooling system, tires, brake pads, headlights, transmission service, timing belt, spark plugs, brake rotors, battery replacement for conventional engines, and battery replacement for EVs. Total cost is calculated based on total user-inputted mileage.

We do not include other operational cost components, i.e., insurance and annual vehicle registration costs. These are mainly dependent on driving behavior and characteristics of the user and the vehicle registration rate of the area where the vehicle is registered respectively. The difference by fuel/powertrain type is marginal and does not contribute a significant difference in total or cumulative costs between EVs and ICEVs.

We allow the user to add a one-time home charger installation cost to the Driving Cost output via a toggle and editable input in the Fueling Customization Panel, advanced window. We place this within the operational cost component instead of the capital costs (in our Vehicle Costs output) for a strategic reason. Specifically, since EVs are often more expensive than gas vehicles, even after incentives, we did not want to add another capital cost to the equation when the user is considering vehicle costs. By placing it in the Driving Costs output, the differential is overtaken by fuel savings.

Resale value

For resale value estimation, we assume a depreciation rate of 23% in the first year and 15% in the subsequent years (Burnham, 2021). As EVs (short-range BEVs in particular) can have a higher depreciation rate than ICEVs, the depreciated value of a BEV with less than a 100-mile range is multiplied by an adjustment factor of 13% (Rush et al., 2022).

(ii) Used Vehicle Purchase

For the capital cost of used vehicles, we would reduce the purchase cost based on depreciation rate described above given the vehicle model year if we had a data source for vehicle MSRP. Since we do not currently have an MSRP data source, the Vehicle Cost output relies on the user inputting a purchase price for a used car, just as they must for most new cars. Regarding operating costs, both fuel efficiency and battery efficiency deteriorates with vehicle age. Therefore, ideally these two metrics can be adjusted based on scaling factors available in the literature. For now, EV Explorer uses the statistics from fueleconomy.gov which do not vary based on vehicle age. Maintenance is calculated in the same manner as for new vehicles. The resale value of a used vehicle is estimated assuming a 15% year-in-year depreciation rate with the 13% adjustment factor for short-range BEVs.

(iii) Vehicle Lease

The vehicle acquisition cost in case of lease contract includes the down payment and the monthly lease payment, which is calculated in the tool from the down payment and interest rate (both editable user inputs). In case of EVs, the monthly lease payment also accounts for any purchase incentive(s) for which it is eligible. Upfront costs include the down payment and monthly lease payment for the first month as well as an initial drive-off cost that comprises of an acquisition fee, documentation fee, and vehicle registration fee. We consider average values[9] for these cost components for a default total of $645, which the user can edit.

The monthly lease payment also accounts for the residual value of the vehicle estimated by the dealer/financer. To estimate residual value we assume the same depreciation rate as in case of

[9] www.creditkarma.com/auto/i/cost-to-lease-a-car&sa=D&source=docs&ust=1678825959555125&usg=AOvVaw3VGFES7LlPiEEYCRA2Xgt1

new or used vehicle purchase and a lease term of 36 months. The accuracy of the lease payment estimate depends on the accuracy of vehicle price reported by the user since in practice the residual value is estimated on the basis of MSRP. Therefore, again, an MSRP data source is crucial to both maximize user-friendliness and value of a VCC as well as accuracy. Another thing to note, residual value calculation in lease contracts also depends on the mileage limit set for the vehicle, but it was difficult to find a consistent formula in the literature that dealers may use for the estimation process, so we do not account for it.

Operational costs for leased vehicles are estimated similar to the other two cases (purchase new or used vehicles). A leasee can pay for a maintenance package that includes all the required maintenance costs, but we do not include a way to account for this at this time; it is assumed that the leasee behaves like a regular vehicle owner in terms of maintenance.

In case of lease, there is no resale value but the leasee needs to pay a disposition fee. In addition, he or she may have to pay a mileage limit fee if the mileage limit set in the lease contract is exceeded and a fee for excess wear and tear of the vehicle when applicable. We account for these end of lease costs in the TCO estimation assuming average cost estimates of a $350 disposition fee and $0.175/mile fee for exceeding mileage limits.[10] These are both accounted for as "end-of lease fees" factoring into the Total Costs and Cumulative Costs outputs.

Usability Testing

Usability testing was conducted to inform the design of EV Explorer 2.0, troubleshoot for programming bugs and errors, and test the effectiveness of the final design in terms of user experience, including interest, ease of use, enjoyment, and comprehension. We also tested Uber's VCC (EV Cost Calculator Guide) to compare users' response to several specific elements with their response to comparable information EV Explorer 2.0. The Uber EV Cost Calculator Guide was developed by Zappy Ride who is the leader in VCC development. Zappy Ride also developed an EV Cost Calculator for Plug-in America (PlugStar) and Pacific Gas & Electric (PG&E EV Savings Calculator). The two tools were tested with the same participants, within the same sessions.

Twelve current and former gig drivers were recruited using convenience and snowball sampling. Uber Technologies, Inc. provided a contact list with email addresses for 45 of their drivers who had rented an EV to provide ridehailing services. Drivers who completed the usability test were also asked to connect us with other drivers who they thought might be interested in participating. Participants were provided a $200 Amazon gift card as a thank you for their time.

A pre-session questionnaire was programmed in UserZoom to collect background information on the participants before they started the usability testing session. Participants lived in

[10] www.nolo.com/legal-encyclopedia/leasing-car-29967-2.html&sa=D&source=docs&ust=1678825959558965&usg=AOvVaw04fOr2Fk6j18fP6Ke0GKzk

California (*n* = 4), Utah (*n* = 3), Arizona (*n* = 3), and Utah (*n* = 2). They ranged in age from 19 to 61 years old (*M* = 41). They ranged in gig-driving experience, from 1-3 months to 5-6 years (*M* = 1-2 years), and intensity–driving between 5 and 60 hours per week (*M* = 20). Figure 21 shows the number of participants who drove for each gig service. Most reported having another job in addition to gig driving.

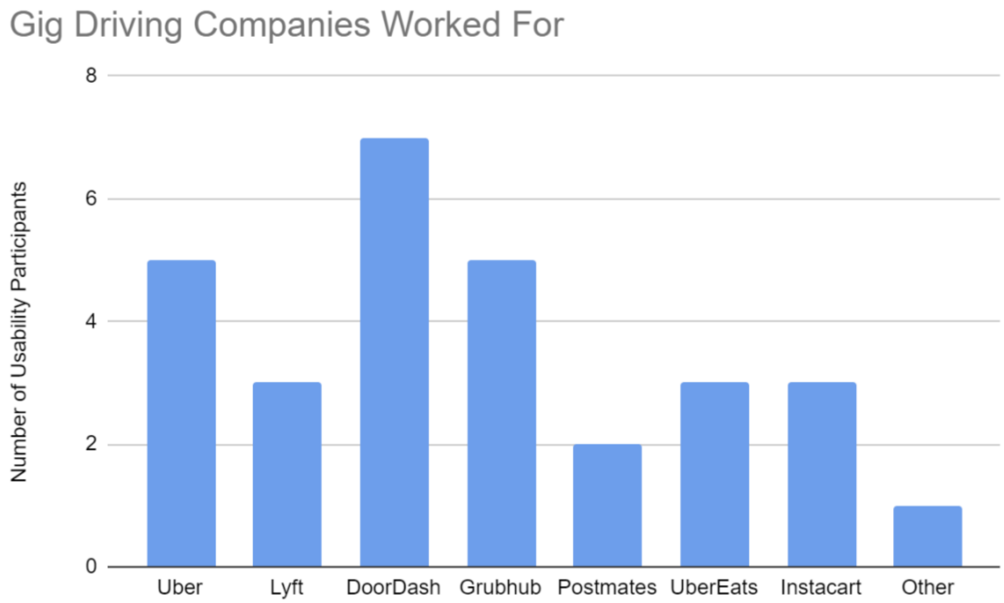

Figure 21. Gig companies represented by usability participants

Five participants had previously rented an EV for ridehailing (four from Hertz), with the most cited reason being to evaluate gas cost savings. Four of the participants currently drove an EV for gig services; all four drove a Tesla (three specified the Model 3, one didn't specify model). Participants mainly purchased their cars for gig driving; none reported that they typically lease. Most anticipated replacing their gig-driving cars within the next year or two.

Testing was conducted with UserZoom, a user experience research software. An unmoderated usability testing approach was used in which participants complete tasks and answers questions on their own (without a researcher present), at their own pace, and at a time and location of their choosing. We programmed tasks for the users to complete, which were displayed to participants in a small window overlaid on the websites as they explored them. UserZoom recorded participants' voices and screens as they went about performing tasks and answering questions regarding the two VCCs. Participants took 50 min on average (19 min, 92 max) to complete the session.

A series of questions in both the pre- and post-session questionnaire assessed participants' intention to buy or lease a vehicle of each drivetrain for their next car (gas, hybrid, PHEV or BEV), similar to our past research with EV Explorer (Sanguinetti et al., 2017). Consistent with that prior research, there was evidence of a shift in intentions to purchase or lease an ICEV or EV after interacting with the two VCCs in the usability testing sessions. Specifically, participants reported that they were less likely to buy or lease a gas car for their next car, and more likely to purchase or lease a BEV, compared to their pre-test responses (Figure 19 and Figure 20). The sample size is small, so no tests for statistical significance were computed.

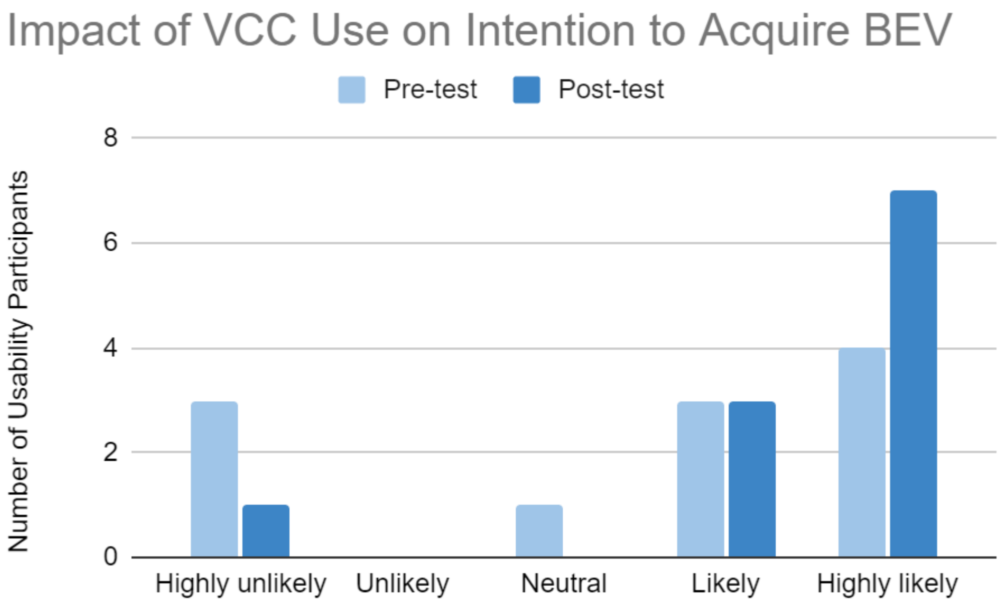

Figure 22. Usability participants' reported intention to acquire a BEV for their next vehicle before and after engaging with both VCCs (Uber's and EV Explorer 2.0).

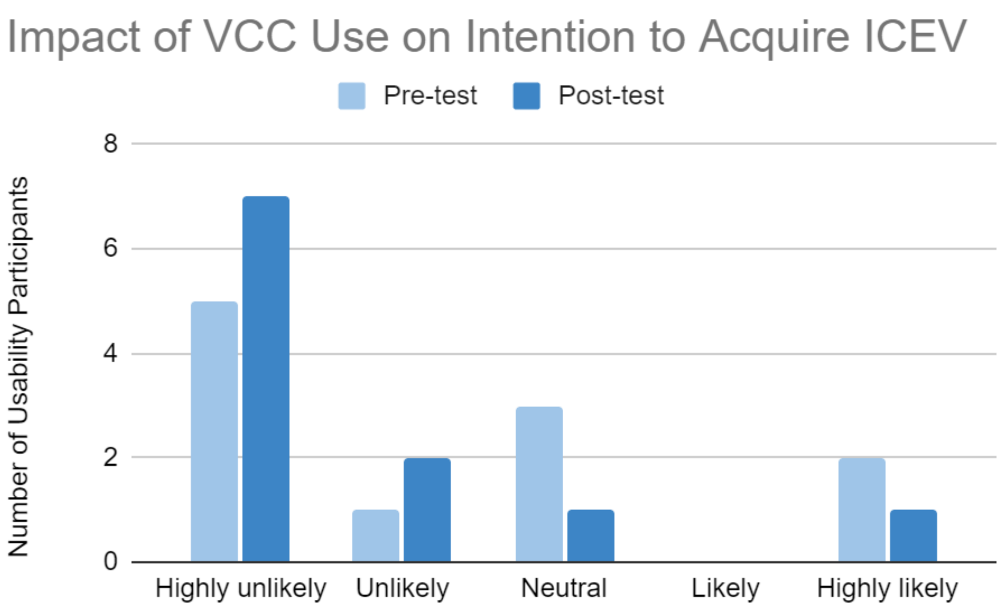

Figure 23. Usability participants' reported intention to acquire an ICEV for their next vehicle before and after engaging with both VCCs (Uber's and EV Explorer 2.0).

Conclusion

This research developed EV Explorer 2.0, an online vehicle cost calculator (VCC). The tool was built to embody best practices identified in research on existing VCCs as well as innovative features not seen in other tools and with particular focus on addressing the ridehailing driving use case. For example, this is the first VCC where older vehicle models can be selected, supporting use cases where users are interested in purchasing used vehicles. It is also the second VCC tailored to TNC drivers and the first to attempt to meet the needs of this special population as well as the general population of car buyers. Future development goals for EV Explorer 2.0 include updating our incentive database and acquiring a data source for vehicle MSRP.

Future research plans include further user testing. User testing targeted a special segment of gig drivers who were considered likely users of the tool–specifically, gig drivers with an interest in EVs. More research with likely users can reveal further best practices. Further research with gig drivers more generally would support development of VCCs and other programs that can be integrated to raise awareness of EV benefits among gig drivers who may not yet be interested.

There are two main audiences with which we are sharing EV Explorer 2.0 and corresponding goals for dissemination of the tool and research. We hope that TNCs, other gig driving companies, and advocacy groups will promote EV Explorer 2.0 to gig drivers. We are also sharing our work with VCC developers in government and industry in hopes they can use the strategies and insights reported herein to develop or improve their own VCCs. Ultimately, we hope this tool and research will support and empower gig drivers by informing them about the potential TCO savings and social and environmental benefits of EVs and support gig driving companies to continue developing goals and programs to transition to zero-emissions services.

References

Allcott, H. and Mullainathan, S., 2010. Behavior and energy policy. Science, 327(5970), pp.1204-1205.

Allcott, H., 2011. Consumers' perceptions and misperceptions of energy costs. American Economic Review, 101(3), pp.98-104.

Attari, S.Z., DeKay, M.L., Davidson, C.I. and Bruine de Bruin, W., 2010. Public perceptions of energy consumption and savings. Proceedings of the National Academy of Sciences, 107(37), pp.16054-16059.

Bansal, P., Sinha, A., Dua, R. and Daziano, R.A., 2020. Eliciting preferences of TNC users and drivers: evidence from the United States. Travel Behaviour and Society, 20, pp.225-236.

Burnham, A., 2021. AFLEET: Assess the impacts of conventional and alternative fuel vehicles. (DOE-ANL-CH11357). Argonne National Lab.(ANL), Argonne, IL (United States).

Chakraborty, D., Buch, K. and Tal, G., 2021. Cost of Plug-in Electric Vehicle Ownership: The Cost of Transitioning to Five Million Plug-In Vehicles in California.

Egbue, O. and Long, S., 2012. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy policy, 48, pp.717-729.

Eppstein, M.J., Grover, D.K., Marshall, J.S. and Rizzo, D.M., 2011. An agent-based model to study market penetration of plug-in hybrid electric vehicles. Energy Policy, 39(6), pp.3789-3802.

Erdem, C., Şentürk, İ. and Şimşek, T., 2010. Identifying the factors affecting the willingness to pay for fuel-efficient vehicles in Turkey: A case of hybrids. Energy Policy, 38(6), pp.3038-3043.

Gabaix, X. and Laibson, D., 2006. Shrouded attributes, consumer myopia, and information suppression in competitive markets. The Quarterly Journal of Economics, 121(2), pp.505-540.

Hagman, J., Ritzén, S., Stier, J.J. and Susilo, Y., 2016. Total cost of ownership and its potential implications for battery electric vehicle diffusion. Research in Transportation Business & Management, 18, pp.11-17.

Hamza, K., Laberteaux, K.P. and Chu, K.C., 2021. On modeling the cost of ownership of plug-in vehicles. World Electric Vehicle Journal, 12(1), p.39.

Hawkins, T.R., Gausen, O.M. and Strømman, A.H., 2012. Environmental impacts of hybrid and electric vehicles—a review. The International Journal of Life Cycle Assessment, 17(8), pp.997-1014.

Hawkins, T.R., Singh, B., Majeau-Bettez, G. and Strømman, A.H., 2013. Comparative environmental life cycle assessment of conventional and electric vehicles. Journal of industrial ecology, 17(1), pp.53-64.

Hidrue, M.K., Parsons, G.R., Kempton, W. and Gardner, M.P., 2011. Willingness to pay for electric vehicles and their attributes. Resource and energy economics, 33(3), pp.686-705.

Hjorthol, R., 2013. Attitudes, ownership and use of Electric Vehicles–a review of literature. TØI report, 1261(2013), pp.1-38.

Jaramillo, P., Samaras, C., Wakeley, H. and Meisterling, K., 2009. Greenhouse gas implications of using coal for transportation: Life cycle assessment of coal-to-liquids, plug-in hybrids, and hydrogen pathways. Energy Policy, 37(7), pp.2689-2695.

Knobloch, F., Hanssen, S.V., Lam, A., Pollitt, H., Salas, P., Chewpreecha, U., Huijbregts, M.A. and Mercure, J.F., 2020. Net emission reductions from electric cars and heat pumps in 59 world regions over time. Nature Sustainability, 3(6), pp.437-447.

Kurani, K.S., Caperello, N. and TyreeHageman, J., 2016. New car buyers' valuation of zero-emission vehicles: California.

Larrick, R.P. and Soll, J.B., 2008. The MPG illusion. Science, 320(5883), pp.1593-1594.

Notz, D. and Stroeve, J., 2016. Observed Arctic sea-ice loss directly follows anthropogenic CO2 emission. Science, 354(6313), pp.747-750.

Onat, N.C., Kucukvar, M. and Tatari, O., 2015. Conventional, hybrid, plug-in hybrid or electric vehicles? State-based comparative carbon and energy footprint analysis in the United States. Applied Energy, 150, pp.36-49.

Pavlenko, N., Slowik, P. and Lutsey, N., 2019. When does electrifying shared mobility make economic sense. The International Council on Clean Transportation.

Petersen, J.E., Frantz, C. and Shammin, R., 2014. Using sociotechnical feedback to engage, educate, motivate and empower environmental thought and action. Solutions, 5(1), pp.79-87.

Plötz, P., Schneider, U., Globisch, J. and Dütschke, E., 2014. Who will buy electric vehicles? Identifying early adopters in Germany. Transportation Research Part A: Policy and Practice, 67, pp.96-109.

Rezvani, Z., Jansson, J. and Bodin, J., 2015. Advances in consumer electric vehicle adoption research: A review and research agenda. Transportation research part D: transport and environment, 34, pp.122-136.

Rush, L., Zhou, Y. and Gohlke, D., 2022. Vehicle Residual Value Analysis by Powertrain Type and Impacts on Total Cost of Ownership (No. ANL/ESD-22/2). Argonne National Lab.(ANL), Argonne, IL (United States).

Saarenpää, J., Kolehmainen, M. and Niska, H., 2013. Geodemographic analysis and estimation of early plug-in hybrid electric vehicle adoption. Applied Energy, 107, pp.456-464.

Sanguinetti, A. and Kurani, K., 2021. Characteristics and Experiences of Ride-Hailing Drivers with Electric Vehicles. World Electric Vehicle Journal, 12(2), p.79.

Sanguinetti, A., Alston-Stepnitz, E. and Cimene, A., 2020. Facilitating electric vehicle adoption with vehicle cost calculators (No. NCST-UCD-RR-20-13). National Center for Sustainable Transportation (NCST)(UTC).

Sanguinetti, A., Nicholas, M.A., Tal, G. and Favetti, M., 2016. EV Explorer: Evaluating a Vehicle Informational Tool.

Taiebat, M., Stolper, S. and Xu, M., 2022. Widespread range suitability and cost competitiveness of electric vehicles for ride-hailing drivers. Applied Energy, 319, p.119246.

Turrentine, T.S. and Kurani, K.S., 2007. Car buyers and fuel economy?. Energy policy, 35(2), pp.1213-1223.

Wu, G., Inderbitzin, A. and Bening, C., 2015. Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments. Energy Policy, 80, pp.196-214.

Data Summary

Products of Research

The main product of this research is the website, EV Explorer 2.0. In addition to adopting or adapting existing data sources, several new datasets were created for this research, e.g., we developed a database of electric vehicle incentive information (federal and local incentives for purchase or lease). We also developed a new TCO model and formulae to process data from AFLEET to calculate social and environmental impacts of gas versus electric vehicles.

Data Format and Content

Datasets are available as an Excel file at https://doi.org/10.25338/B8363M. TCO formulae are also available at https://doi.org/10.25338/B8363M. Social and environmental impacts calculations are detailed in Appendix C.

Data Access and Sharing

The website URL is https://gis.its.ucdavis.edu/evexplorer2. The major datasets and models generated in this research are all provided in the Appendices and at https://doi.org/10.25338/B8363M, and are available for others to use.

Reuse and Redistribution

The major datasets and models generated in this research are available for others to use. Any published use of the data or formulas should reference this report and the following archived data source:

> Sanguinetti, Angela (2023), Developing a vehicle cost calculator to promote electrical vehicle adoption among transportation network company (TNC) drivers, Dryad, Dataset, https://doi.org/10.25338/B8363M

Use of datasets we gathered from other sources and formulas that interface with other sources (e.g., AFLEET, fueleconomy.gov, and Uber and Lyft websites) should reference those other data sources as well as this report. The university owns the website code; it is not available to share. However, those interested in the code can reach out the researchers for more information and we will share what we can while abiding by the relevant university policies.

Appendix A: VCC Design Review and Best Practices

The following is an overview of the systematic VCC analysis and identified best practices VCC UX design from Sanguinetti et al. (2020).

Table A-1. VCC UX Design Best Practices

	User Inputs								**Cost Inputs**							
	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	

Outputs

- Highlight operational savings of an EV v. a similar ICEV.
- Compare acquisition costs in a standalone output, highlighting incentives.
- Compare cumulative TCO, highlighting breakeven time.

- Ensure EV maintenance cost estimates are realistic (and editable).
- 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 initial outputs.
- Integrate salient, emotionally-evocative information about social and environmental benefits.
- Include and define life-cycle emissions estimates.

User Experience

- Required inputs should be minimal and high leverage in terms of tailoring outputs.
- Consider flexible input formats to minimize cognitive demand.
- Maximize optional inputs to maximize customization.
- Optional inputs should be separate from required inputs to lessen perceived demand.
- Optional inputs (or paths to reach them) should be salient in the output view.
- Do not display irrelevant inputs.
- Optional input default values should be as tailored and accurate as possible.
- Annotate input default values with sources and tips to help users understand and modify them.
- A VCC does not have to have other functions (consider providing links to other resources for finding charging stations, determining range sufficiency, etc., rather than trying to fit too much in).

Inputs

Vehicle Selection and Specification

- Require vehicle selection (user must choose make-model-year OR vehicle category).
- Provide comprehensive choice of vehicle models, years, and drivetrains.
- Point consumers to other resources to find an EV model that suits their needs.
- Include optional inputs for vehicle efficiency-related specs.
- Allow modification of maintenance cost estimates.

Driving

- Require driving inputs designed to estimate total mileage accurately and avoid underestimates.
- Communicate the implications of daily driving for PHEV fuel costs.
- Use flexible formats for mileage inputs (e.g., user specifies denominator: miles per day/year/etc.).

Fueling

- Include optional inputs for fuel prices with location-specific defaults (ask for zip code).
- Only display inputs for fuels used by the vehicles being compared.
- Annotate default prices with explanations/data source (e.g., PG&E off-peak rate).
- Use off-peak rate as editable default for home charging.

- Allow users to easily indicate if exclusively home or public charging.
- Provide optional inputs to factor in time-of-use and multiple public chargers.

Financing

- Include optional inputs for new and used vehicle acquisition costs.
- Include different inputs based on acquisition type (e.g., loan or lease).
- Annotate vehicle price defaults with qualifying information about trim levels, etc.
- Estimate used car resale value.
- 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

Appendix B: EV Explorer 2.0 Documentation

Pathways

Regular
Gig driver

Background Inputs

Location

The app uses an API to lookup the user's location based on their IP address. This provides the user's state, zip code, latitude, and longitude and is used for determining incentive eligibility, looking up fuel pricing, and setting the map center.

Fuel and Electricity Pricing

The app uses an API to lookup the latest state average prices for regular gasoline, super gasoline, premium gasoline, diesel, and electricity based on the user's location. This is used for calculating driving costs.

Note: Currently only electricity and regular gasoline prices are used, meaning that no matter what fuel a vehicle uses, the default (editable) cost will be based on regular gasoline.

Note: The electricity price obtained from the API is used as the starting home electricity price. The default (editable) public electricity price is then set to 25% more than the home price.

User Inputs

Gig Driver

Pathway: All

Are you a gig driver?

- A: No, I only drive for myself and for my family
- B: Yes, I drive for gig economy services

Choosing A puts you on the regular pathway, choosing B puts you on the gig driver pathway.

Vehicle

Pathway: All

Select a vehicle or car body style.

Vehicle Selection Mode

User chooses a vehicle from year, make, model, and option dropdowns. By default the app limits the list of vehicles to choose from to electric vehicles only. But there is a selector to display all vehicles as well.

If the user chooses an EV or PHEV, then a gasoline vehicle is chosen for comparison. If the user chooses a gasoline vehicle, then an electric vehicle is chosen for comparison. The comparable vehicle is of a similar body style to the chosen vehicle. See the spreadsheet called “Current Comparable Cars” to see the specifics.

Body Style Selection Mode

User chooses a body style out of 8 available options: sedan, coupe, minivan, wagon, van, crossover, SUV, and truck.

The app maps the chosen body style to a list of preselected vehicles with a similar body style. See the spreadsheet called “Current Preselected Cars” to see the specifics.

Note: In either selection mode, if there is no comparable car in the table, the default vehicle for the opposing fuel type is used. See the spreadsheet called “Current Default Cars” to see the specifics.

Note: The app has a list of purchase prices to use for some vehicles. If the user selected vehicle or the app chosen comparable vehicle is in that list, the purchase price will be used automatically for the relevant calculations. Otherwise, the user will need to provide it in order to see the dependent outputs. See the spreadsheet called “Current Purchase Prices” to see the specifics.

Mileage

Pathway: Regular

The user can input mileage driven directly or the app derives their mileage using a user inputted trip.

Mileage Mode

User inputs a mileage and a frequency (day, week, month, or year).

Trip Mode

The user inputs a start location, destination location, and how many times they make the trip per some period (day, week, month or year.) There is also a checkbox to consider a one way trip instead of a round trip.

The start and destination locations are populated using Google Maps API Places Autocomplete.

Gig Driving

Pathway: Gig driver

The user inputs the following:

- Gig driver services they drive for out of the following
    - Uber

    - Lyft
    - DoorDash
    - GrubHub
    - Postmates
    - Uber Eats
    - Instacart
    - Other Rideshare
    - Other Deliveries
- Annual mileage
- Percent of miles that are gig driving
- Percent of miles that are personal driving
- Gig driving income per some period (week, month, or year)

If the user selects a rideshare service (Uber, Lyft, or Other Rideshare) then they also input the following

- Number of rideshare shifts per some period (week, month, or year)
- Number of trips per rideshare shift

Note: The user must select at least one gig driving service and fill out all applicable fields to continue.

Customization

Car Manager

Pathway: All

Allows a user to add, remove, or edit the selected vehicles. The user can customize inputs for each vehicle that affect the driving costs and environmental impact.

Financing

Pathway: All

Allows the user to customize inputs that affect incentives as well as the cost of the selected vehicles.

Driving

Pathway: All

Allows the user to customize inputs related to their driving, which will affect driving costs for selected vehicles.

Fueling

Pathway: All

Allows the user to customize inputs related to fuel costs, which will affect driving costs for selected vehicles.

Driving Income

Pathway: Gig driver

Allows the user to customize inputs which will affect driving income for selected vehicles.

Calculations

Purchase/Lease Cost

- Purchase cost in cases of cash or loan purchase is calculated as the sum of purchase price and an editable term for taxes and fees, which is auto-populated based on the purchase price. Default taxes and fees includes California sales tax and registration costs. Editable default loan terms are five years at 5% interest; monthly payment is given as a function of purchase cost and loan terms.
- Lease cost is based on MSRP, signing fees, downpayment, and interest rate, and end-of-lease fees (including any excess mileage costs based on editable mileage limit and typical per-mile fee).
- Total purchase or lease costs are provided in the Vehicle Costs and Cumulative Costs output chart. In the Total and Cumulative Costs chart, renewed lease with same terms specified in customization panel is assumed (up to the specified timeframe in the output chart). End-of-lease fees are tagged onto the final year in a lease term for Total Costs and averaged over the timeframe in Cumulative Costs, for a total number of fee charges equaling the number of full lease terms within the specified timeframe. For example, if the chart shows a 15-year period it will include 3 charges if the lease term is 3 years.

Incentives

For each vehicle, check for eligible incentives and total the incentive amounts. Checks two sets of incentives.

Federal:
Uses the vehicle's model and model year to determine eligibility.

Other:
Uses the following to determine eligibility:

- State
- Zip code
- Battery capacity
- Range
- Tax filing status
- Income
- Fleet
- Purchase type

The various incentives have a variety of eligibility criteria, so not all inputs will be needed for each incentive.

Driving Income

Trip Pay

This is the gig driver income over some time period (week, month, or year) annualized. The default is to show over 5 years, but users can adjust the time frame via the dropdown menu in the blue box with the sentence summary of the output.

Trip Bonus

This is the bonus given to EV drivers on the Uber platform, $1 per trip.

Distance Driven on Fuel Type and Fuel Costs for PHEVs

For PHEVs, distance driven with gas v. electricity is calculated according to the vehicle's electric range and editable inputs for number of times the user will charge per day (gig driving pathway) or daily or trip mileage (non-gig driving pathway; user chooses to enter mileage totals or trip profiles). It is assumed non-gig drivers will start each day with a charged vehicle. The difference between the user's trip(s) or average daily mileage and the vehicle's electric range (multiplied by number of charges per day for gig drivers) is assumed to be gas-powered. Thus, gas price is multiplied by that portion of the mileage for a given output chart and setting and summed with electricity costs for the other mileage portion.

Electricity Costs

Electricity costs are determined by editable electricity prices and mileage for a given output and setting (e.g., electricity costs * annual mileage * 5 for an output showing 5 years). If a user specifies multiple charging profiles, the portion of the mileage represented by each (e.g., 50% home charging) is multiplied by the respective electricity price and summed together. For gig drivers, there are also factors for charging session and membership fees. The former is multiplied by the percent that charging station represents of all specified charging profiles and both are multiplied by a factor of time to total the time specified in a given output chart.

Maintenance Costs

Maintenance costs are determined by vehicle manufacturer specified itemized costs. Costs are incurred for each item at the end of the mileage term for manufacturer recommended maintenance measure (e.g., oil change at X miles; oil change cost is multiplied by a mileage factor to repeat every 3 miles, extrapolated out over the timeframe of a given output chart).

Net Value

Calculated as the purchase price minus depreciation over 5 years. The depreciation rate for the first year is 23% and for the second through fifth year it is 15%. This is only used for a purchase type of cash or loan.

Note: If the vehicle is an EV with a range of less than 100 miles, then the vehicle is depreciated 13% on top of the 5 year depreciation described above.

End of Lease Fees

Calculated as a mileage fee plus a disposition fee. The disposition fee is $350. The mileage fee is calculated as the yearly miles in excess of the lease's mileage limit (default limit is 12,000 miles/year) times the extra mileage rate of $0.175/mile. These fees are applied multiple times if the user is viewing calculations for a time period that encompasses multiple lease periods (continued leasing with the same lease terms is assumed).

Outputs

Vehicle Costs

Pathway: All

This output shows a selector with three possible displays:

Lease Cost

Displays a horizontal bar graph comparing the cost of selected vehicles.

Displays the following text next to the graph: "Before EV incentives the [selected EV] would cost your $[difference in least cost between selected EV and Non EV] [more|less] than the [selected Non EV]".

Incentives

Displays a horizontal bar graph showing the incentives for selected vehicles.

Displays the following text next to the graph: "You may be eligible for up to $[selected EV incentive amount] in incentives for the [selected EV]. Enter more information below for a better estimate of available incentives."

Net Cost

Displays a stacked horizontal bar graph showing the purchase/lease cost and incentive values if applicable. The bars are labeled with the purchase/lease cost. If the vehicle has incentives, the net cost (purchase/lease cost minus incentives) is also displayed.

Displays the following text next to the graph: "After EV incentives the [selected EV] would cost your $[difference in least cost between selected EV minus incentives and Non EV] [more|less] than the [selected Non EV]".

Driving Costs

Pathway: All

Displays a stacked horizontal bar graph showing the driving costs for selected vehicles over a period of time. Below the graph are buttons which allow the user to select which driving costs are displayed. Driving costs consist of gasoline, electricity, and maintenance.

Displays the following text next to the graph: "You will [spend|save] $[difference in driving costs between selected EV and selected Non EV] in driving costs with the [selected EV] compared to the [selected Non EV] in [select to change the period of time for the driving cost calculation]". The user can use the select to choose from 1 to 15 years for the calculation. The default is 5 years.

Driving Income & Costs

Pathway: Gig driver

Displays a horizontal bar graph showing the driving income and driving costs for selected vehicles over a period of time. The graph has 3 bars per vehicle: driving income, driving costs, and net driving income. There is a legend below the graph. On the legend there is a selector to see details. This changes the display to a stacked horizontal bar graph. Driving income is made of trip pay and trip bonuses. Driving cost is made up of gas, electricity, and maintenance. Net driving income remains the same.

Displays the following text next to the graph: "You will [spend|save] $[difference in driving costs between selected EV and selected Non EV] in driving costs with the [selected EV] compared to the [selected Non EV] in [select to change the period of time for the driving cost calculation]". The user can use the select to choose from 1 to 15 years for the calculation. The default is 5 years.

Total Costs

Pathway: All

Displays a stacked horizontal bar graph showing the total costs for selected vehicles over a period of time. Below the graph are buttons which allow the user to select which costs are displayed. Costs consist of vehicle costs, gasoline, electricity, and maintenance. Vehicle costs are the same as the net cost numbers in the vehicle costs output. Gasoline, electricity, and maintenance are the same as in driving costs.

Note: If the purchase type is cash or loan, there is an additional selector called "subtract resale value" which toggles between showing purchase price minus incentives and purchase price minus depreciation for vehicle costs. (See "Net Value" calculation)

Note: If the purchase price is lease, there is an additional cost called end of lease fees is displayed on the graph along with its corresponding button.

Displays the following text next to the graph: "You will [spend|save] $[difference in total costs between selected EV and selected Non EV] in total costs with the [selected EV] compared to the [selected Non EV] in [select to change the period of time for the total cost calculation]". The user can use the select to choose from 1 to 15 years for the calculation. The default is 5 years.

Cumulative Costs

Pathway: All

Displays a line graph showing the cumulative cost for selected vehicles over 10 years. The graph also displays the break even point (where the lines intersect) if applicable.

If there is a break even point between the selected vehicle, display the following text next to the graph: “If you keep the car for at least [break even point years], the [selected EV] will cost less than the [selected Non EV].”

Social & Environmental Benefits

Pathway: All

This output shows a selector with three possible displays. Each display has a different sentence and image. Emissions is displayed by default. The number of years used for these calculations defaults to 5 years. In the regular pathway, the number of years can be changed in the driving costs output or the total costs output. In the gig driver pathway, the number of years can be changed in the driving income & costs output or the total costs output.

Emissions

Displays the following text: “If you choose the [selected EV], you will reduce [lbs of CO2 difference between selected EV and selected Non EV] lbs of CO2 by preventing [lbs of ice difference between selected EV and selected Non EV] lbs of ice from melting in [number years the calculation was performed for] years compared to the [selected Non EV].”

Air Quality

Displays the following text: “If you choose the [selected EV], you will improve your community’s air quality in [number years the calculation was performed for] years compared to the [selected Non EV] by eliminating [lbs of CO difference between the selected EV and selected Non EV] lbs of CO, [lbs of NOx difference between the selected EV and selected Non EV] lbs of NOx, and [lbs of VOC difference between the selected EV and selected Non EV] lbs of VOC emissions that are hazardous to human health.”

Gas

Displays the following text: “If you choose the [selected EV], you will save [gallons of gas difference between the selected EV and selected Non EV] gallons of gas in [number years the calculation was performed for] years compared to the [selected Non EV]. This ensures that you do not contribute to waterway pollution or cause harm to aquatic life from oil dribble and oil spills.”

Appendix C: Calculations for Social and Environmental Impacts

EMISSION CALCULATIONS FOR VCC CALCULATOR: AFLEET 2020 TOOL

Objective: Estimating the well-to-wheel emissions by fuel type for passenger cars and trucks (includes crossovers, SUVs, Vans, light-duty pickup trucks) using the AFLEET 2020 tool.

Fuel Types: Gasoline, Conventional Hybrids, PHEVs, BEVs, BEVs with Range Extender (EREV), and FCEVs

Inputs Tab: KEY VEHICLE and FUEL INPUTS

1. Change the **state** to California and **county** to San Francisco (representative of the Western Interconnection [WECC] region). Even the ALFEET tool uses electricity regions to determine the Source of Electricity for PHEVs, EVs, and FCVs.
2. Annual Vehicle Mileage can be changes from 12,400 miles to a higher value in the "Background Data" tab under *Average Annual Vehicle Miles Traveled* (Row 219): source of data for AFLEET https://info.ornl.gov/sites/publications/files/Pub44660.pdf (this is an input from EVE2).
3. Average Fuel Economy: Can change the gasoline fuel economy. Default value is 30.9 mpg for Cars, 18.7 for LD pickup trucks, and 22.7 for SUVs. For the remaining fuel types a multiplier effect is used based on GREET Model data. These multiplier factors are also there in the Background data tab of AFLEET tool. (Look-up table for vehicle make, model, year from fe.gov)
4. Years of planned ownership: Default value is 15 years
5. To get the well-to-wheel or lifetime emission for PEVs, need to change the Electric Vehicle Charging Inputs (Row 168 of Input Tab) – can change these values but probably not required.

   For now I have chosen that a BEV driver uses 1 Level 2 charger each at a "parking lot and "Workplace" during a week (weekly utilization rate and charging time varies across these locations) and 1 DCFC in a "Parking lot".
6. Emission Calculations: We can do both Well-to Wheel and Lifecycle for light-duty vehicles.

1 - Well-to-Wheels Petroleum Use and GHGs & Vehicle Operation Air Pollutants
2 - Well-to-Wheels Petroleum Use, GHGs, and Air Pollutants
3 - Well-to-Wheels & Vehicle Production* Petroleum Use, GHGs, Air Pollutants (*LDVs only)

7. For lifecycle costs, need to change the option in Row 120 of Inputs tab from 1 to 3:

Well-to-Wheels (WTW) = Upstream + Vehicle Operation; Upstream (or Well-to-Pump (WTP)) = fuel feedstock recovery, fuel production, and transportation; Vehicle Operation (or Pump-to-Wheels (PTW)) = vehicle operation; Vehicle Production (or Vehicle Cycle) = raw material recovery, material processing, vehicle component production, vehicle assembly, disposal, and recycling. https://greet.es.anl.gov/

VEHICLE LIFECYCLE EMISSION ESTIMATION BY FUEL TYPE AND BODY TYPE

The tables here are for California, Passenger Car segment, and Model year 2020. Need to change it to passenger truck as required in the input tab.

- The GHG emissions (short ton/year) is for a vehicle lifetime of 15 years (well-to wheels + vehicle production). Fuel usage=annual miles/mpg
- Gram to short ton conversion =907184.7, gasoline LHV=112,194, and gram to pound=453.6
- Total lifetime passenger car miles=173,151, SUV=183,363 miles
- CS: charge sustaining, CD: charge depleting
- **GHG emission over vehicle lifetime (g)/total lifetime miles (Row 1860-1893 and column starting from AP of Background data) for each fuel type**
- The state emission factors, national emission factors, and alternative fuel vehicle (AFV) multipliers vary by **model year of vehicle – 1990 to 2020 model years. Need to identify the factors by state, model year, different fuel types, and body types- LDV passenger car and truck.**

LIFECYCLE GHG EMISSIONS

REQUIRED INPUTS

- location (state, from location API)
- vehicle fuel economy (mpg/mpge from fueleconomy.gov numbers)
- annual mileage (direct user input or calc from google directions api)
- drivetrain (Type from fueleconomy.gov, used to select the appropriate formula below to use)

DESIRED OUTPUT

1. Total GHG emissions in pounds over 5/15 years of operation

– lifecycle & Well-to Wheels Petroleum Use and GHGs

2. Vehicle Operation Air Pollutants

1. Lifecycle GHG for gas vehicle (tons)

=Well-to wheel +Vehicle Production

$$=\sum_{i=1}^{T} \quad [112{,}194 * \frac{\frac{95{,}101}{10^6}}{907184.7} * \frac{annual\ miles}{MPG}] + \sum_{i=1}^{T} \quad 36.321 * annual\ miles\ /907184.7;$$

T=15 years

2. Lifecycle GHG for HEV (tons)

=Well-to wheel +Vehicle Production

$$=\left[\sum_{i=1}^{T} \quad 112{,}194 * \frac{\frac{95{,}101}{10^6}}{907184.7} * \frac{annual\ miles}{MPG}\right] + \left[\sum_{i=1}^{T} \quad \frac{37.248 * annual\ miles}{907184.7}\right]; \text{T=15 years}$$

3. Lifecycle GHG for PHEV (tons)

=Well-to wheel +Vehicle Production

=GHG from ICEV + GHG from Electric + Vehicle Production

$$=\left[\sum_{i=1}^{T} \quad \left(\frac{112{,}194}{907184.7} * \frac{Total\ GHG\ from\ gasoline}{10^6} * Gasoline\ usage\right) + \left(\frac{Total\ GHG\ from\ grid\ mix}{10^6} * Electricity\ usage\right)\right] + \left[\sum_{i=1}^{T} \quad GHG\ emission\ over\ vehicle\ cycle\ for\ PHEV\ (g) / total\ lifetime\ miles * annual\ miles\ /907184.7\right]$$

$$=\sum_{i=1}^{T} \quad 112{,}194/907184.7 * \frac{95{,}101}{10^6} * \left[\frac{Annual\ miles}{Fuel\ economy\ in\ CS\ mode} * (1 - \%\ of\ CD\ miles) + Annual\ miles * \frac{Gasoline\ Use\ in\ CD\ mode}{100} * \%\ of\ CD\ miles\right] + [\ 100{,}200/10\wedge 6 * (annual\ miles * electricity\ use\ in\ CD\ mode/100 * \%\ of\ CD\ miles] + \sum_{i=1}^{T} \quad [39.606 * annual\ miles\ /907184.7]; \text{T=15 years}$$

Fuel Economy - CS Mode	MPGGE	53.2
Electricity Use - CD Mode	kWh/100mi	25
Electricity Use - CD Mode	GGE/100mi	0.8
Gasoline Use - CD Mode	GGE/100mi	0.9
PHEV CD Range	miles	23.2
Charges/day	charges/day	1.0
Days driven/week	days driven/week	5.0
Share of CD miles	%	49%
Gasoline Usage	GGE/vehicle	176
Electricity Usage	kWh/vehicle	1528
Electricity Usage	GGE/vehicle	46

4. Lifecycle GHG for BEV

= Well-to wheel +Vehicle Production

$$= \left[\sum_{i=1}^{T} \quad 112194/907184.7 * 100200/10\wedge 6 * Electricity\ usage\right] + \left[\sum_{i=1}^{T} \quad 60.138 * annual\ miles\ /907184.7\right]; \text{T=15 years}$$

If EV 100 = 56.939

If EV 300 = 60.138; EV 300 number for EV with >250 mile range

TAILPIPE AIR POLLUTANT EMISSIONS – Only Vehicle Operation

Carbon Monoxide (CO), Nitrogen Oxide (NOx), and VOC in pounds – varies by the age of the vehicle. Need to sum up for the number of years of vehicle operation.

1. **Gasoline**

$=\sum_{i=1}^{J} \quad State\ emission\ factor\ * National\ emission\ deterioration\ rate\ (\%\ of\ Age\ 0\ emissions)_i\ * annual\ miles/453.6;$ J= years of operation

2. **HEV**

$=\sum_{i=1}^{J} \quad State\ emission\ factor\ * National\ emission\ deterioration\ rate\ _i\ * AFV\ multiplier\ * annual\ miles/453.6$ J= ; years of operation

3. **PHEV**

=$\sum_{i=1}^{J} \quad State\ emission\ rate\ *\ national\ deterioration\ rate(i)\ *\ AFV\ multiplier\ * annual\ miles/453.6\ *$ [(1-% of CD miles) + (%CD miles * Gasoline use in CD mode/100 * Fuel Economy in CS mode)] ; years of operation

2. **BEV**

=$\sum_{i=1}^{J} \quad State\ emission\ factor\ * National\ emission\ deterioration\ rate\ _i\ * AFV\ multiplier\ * annual\ miles/453.6;$ years of operation

Link to the Input file with state emission factor, national emission deterioration rate, and AFV multiplier for CO, NOx, and VOC

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