Americans' opinions and interests in plug-in electric vehicle smart charging programs

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ABSTRACT

Power companies are developing plug-in electric vehicle smart charging programs to shift charging to off-peak hours, when demand is lower, and to align charging with renewable energy. An internet-based survey of more than 1,000 Americans ascertains opinions on supplier-managed charging (SMC) programs and the expected benefits of participating in a program. About a quarter of Americans say they would never accept SMC, but 8.8% would be willing to use an app or timer to stagger charging themselves. Up to 36.9% would cede some control to their supplier (17.6% at night only, 10.3% on grid-strained days only, and 8.9% every day to optimize the local grid). Multinomial logit models indicate that Americans with a household battery electric vehicle and wholesale-indexed energy rates are more willing to accept an SMC program. Tobit model results indicate the minimum required one-time and annual bill credits for participating in a future SMC program.

Keywords: *Plug-in Electric Vehicles, Smart Charging, Willingness to Pay, Charging behavior*

Abbreviations/Acronyms

The abbreviations used are defined as follows:

BEV	Battery electric vehicle
EV	Electric vehicle
GMC	Guaranteed minimum charge
ICEV	Internal combustion engine vehicle
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
SMC	Supplier-managed charging
TOU	Time-of-use
UMC	User-managed charging
VRE	Variable renewable energy
WTP	Willingness to pay

1. INTRODUCTION

The share of plug-in electric vehicles (PEVs), which include battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), is rapidly increasing worldwide (IEA, 2023). Although PEVs offer a new revenue source for the power industry and lower carbon emissions from transportation, an increase in electricity may also create challenges in providing reliable electricity. Many power grids are increasing their share of variable renewable energy (VRE) and have either limited or aging transmission infrastructure not designed for a clean-energy transition (Mai et al., 2018; Zhang et al., 2020). Fortunately, PEVs are considered flexible loads, meaning that their charging behavior can be influenced by infrastructure provisioning and price control, thereby affecting their impacts on power grid operations.

The location, supply, and type of charging infrastructure influence when and where drivers will charge their PEVs and their consequential impact on electricity demand (Powell et al., 2022). Building public and workplace charging stations can shift charging from nighttime to daytime, which may be advantageous in regions with an abundance of solar power. In 2021, utility-scale solar accounted for 17.1% of California's in-state generation (California Energy Commission, 2022), but due to spatio-temporal imbalances between supply and demand, the grid operator curtailed nearly 1.5 terawatt-hours (TWh) of solar power (or 5% of solar generation) (California Independent System Operator, 2023). Aligning PEV charging demand with solar production can reduce PEV's charging emissions and curtailment due to overgeneration, especially in temperate months when electricity demand is relatively low (because of decreased heating and cooling demand). Flexible PEV charging demand can also address balancing issues in the net load curve—the total electricity demand curve minus VRE generation—which is the amount of demand that the grid operator must supply from dispatchable sources, like natural gas peaker power plants. Filling in valleys in the net load curve by shifting PEV charging decreases ramping requirements (up or down) and thus system costs (Anwar et al., 2022; Dean and Kockelman, 2022; Powell et al., 2022; Tarroja and Hittinger, 2021). At the distribution system level, shifting charging to valleys in demand decreases the percentage of assets, such as transformers, that need to be augmented and delays when improvements are needed (Nacmanson et al., 2022).

The introduction of time-varying electricity prices, like time-of-use (TOU) or wholesale-indexed rates, may also motivate PEV drivers to avoid charging during peak hours because of higher electricity costs (Faruqui et al., 2017). Studies have found that most residential customers adapt to TOU rates by reducing electricity consumption during peak hours (Newsham and Bowker, 2010; Yunusov and Torriti, 2021), depending on the ratio of peak price to off-peak price (Faruqui et al., 2017). TOU adoption rates of 20–40% can increase PEV hosting capacity by 20% (i.e., the number of PEVs that can charge on a distribution power network before impacts on voltage or power quality) (Nacmanson et al., 2022).

The use of time-varying electricity prices is a form of passive smart charging since the driver responds to prices to alter charging behavior by either manually deciding when to plug or unplug the vehicle or using an app or timer to schedule charging (Anwar et al., 2022; Smart Electric Power Alliance, 2021). Advanced forms of smart charging can also include direct (or "active") control, where the local power supplier[1] alters charging behavior at smaller time steps to manage conditions in the distribution system. In this study, user-managed charging (UMC) refers to an app or timer program that shifts charging, controls charging speed, and/or staggers charging to avoid adding to the peak load or increasing emissions from electricity generation. Several smartphone apps are available to consumers to smart-charge their PEV (e.g., Optiwatt and FlexCharging). Supplier-managed charging (SMC) is when the charging schedule of the vehicle is coordinated and managed by the electricity supplier (or contracted third-party aggregator) to meet the objectives of the supplier, so long as customer-defined constraints, such as departure times and battery levels, are met.

The benefits of smart charging depend on PEV drivers' responses to smart charging programs and their willingness to enroll in a program, be it UMC or SMC. Despite research on the financial and technical requirements of smart charging, only a few studies have directly investigated consumer attitudes and willingness to participate in smart charging programs (Sovacool et al., 2017). To address this research gap in the literature, this study addresses the following research objectives:

1. Characterize attitudes towards PEVs, smart charging, PEV-power grid integration, and preferences for smart charging.
2. Quantify the minimum financial incentives for participating in a smart charging program managed by a power supplier (i.e., SMC).
3. Anticipate how power suppliers can use messaging to reduce opt-outs in an SMC program.

2. PRIOR LITERATURE AND CONTRIBUTIONS

Recently, researchers have started surveying the public to understand their perceptions of PEV smart charging and their willingness to participate in current or future hypothetical programs, including how they might adjust their current or expected charging behaviors. The studies either employ charging interventions with semi-structured interviews and questionnaires or identify respondents' preferred smart charging programs through web-based surveys. Table 1 compares recent studies that surveyed the public about PEV smart charging[2].

[1] A power supplier is also known as a power company or electric utility.
[2] This study focuses on smart charging that controls power flow to the vehicle (also called V1G) and ignores studies on bidirectional charging (also called V2G). Readers interested in a thorough review of study methodologies and results are referred to Anwar et al. (2022).

Table 1: Synthesis of studies surveying the public about PEV smart charging.

Author and Year	Research Method	Sample Size	Research Questions	Main Findings
Bailey & Axsen (2015)	WB-survey, LCCM	1470 new LDV buyers interested in PEVs [Canada]	- What are consumer attitudes toward SMC, including perceptions of VRE, charging inconvenience, and privacy?	- UMC support among 50% to 67% of respondents interested in purchasing a PEV. - Concerns over privacy & loss of control with UMC. - LCCM (4 segments) vary in UMC acceptance, value of renewables, power bill savings, & charging inconvenience. - Cost-minimizing UMC program garnered 63% to 78% enrollment vs. 49% to 59% with a renewable-priority UMC. - Avg. WTP 59 CAD/year for +10 km in GMC in night-only UMC (base of 84 km).
Schmalfuß et al. (2015)	Interview, Survey, SMC pilot	10 BEV owners [Germany]	- What are consumer perceptions of SMC benefits, costs, and ease within daily routine? - Do users trust SMC?	- 7/10 participants felt the perceived benefits of SMC balanced with costs of participation. - Frequency of charging increased with SMC and trust in SMC had no statistically significant change with the pilot.
Bauman et al. (2016)	Interview, SMC pilot	30 PEV owners [Canada]	- Would participants enroll in SMC if the algorithm did not consider battery levels? - What compensation would lead to participation in SMC?	- 72% of participants would not have enrolled in SMC if the supplier curtailed charging without considering battery levels. - Over half of participants would accept SMC for less than \$10/month (and over 2/3 would accept for less than \$15/month).
Will & Schuller (2016)	SEM	237 EV enthusiasts (41% PEV owners) [Germany]	- How do users perceive SC interventions in their charging behavior & what are the main factors driving the acceptance of SC programs?	- Awareness of grid operational benefits & VRE integration were important factors, while financial compensation was not significant (for early PEV adopters). - SC was associated with uncertainty & anxiety. Capacity to relinquish control depended on working patterns, financial resources, & charging access.
Delmonte et al. 2020	Semi-structured interviews	60 current PEV owners & PEAs [United Kingdom]	- What are PEV users' charging behaviors? - How do PEV users respond to UMC and SMC concepts? - What specific aspects of UMC and SMC are appealing to PEV users & off-putting to PEV users?	- SC engagement is conditional on lowering charging costs. - 2/3 prefer UMC due to personal control, while 1/3 prefer SMC because of societal benefits. - Cons of SMC are the loss of freedom and choice ("big brother") & detractors don't trust their power company.

			- How do responses differ between BEV & PHEV users?	- UMC with TOU rates is easier to grasp but more difficult to use – driver must time the EV & plug-in before off-peak – while SMC is more difficult to grasp but easy to use.
Kubli (2022)	WB-survey, LCCM	202 PEV drivers & PEAs [Switzerland]	- Which consumer segments are crucial to consider when designing SC solutions? - What compensation should operators offer to incentivize PEV drivers to adopt SC?	- LCCM (3 segments) identify 53.2% are driven by charging costs & are likely earliest adopters. - Incentives to switch from home to work/public charging cost more than avg. charging session. - WTP for faster charging (4 hr faster) at home under SMC mode is 2.62 CHF.
Libertson (2022)	WB-survey, semi-structured interview	1483 respondents, 27 interviews with PEV drivers [Sweden]	- What are PEV drivers' flexibility in delayed charging?	- About half of drivers were upset & frustrated that PEVs were not fully charged with SMC. PHEV drivers saw a delay in charging as increasing gas costs. BEV drivers spent more time finding other public chargers. - Custom SMC features can instill a sense of co-control & trust in charging.
Wong et al. (2023)	WB-survey	784 residents in states with ZEV mandates or high BEV adoption [33 U.S. states + DC]	- What are the charging patterns of PEV drivers now? - How can incentives influence SC among PEV drivers, potential adopters, & ICEV drivers?	- A combination of free charging equipment, GMC, & financial incentives increases acceptance in SC. - Nearly a quarter (23%) of PEV owners & 13% of ICEV drivers would participate in SC without any incentive.
Lavieri & Martins de Oliveira (2023)	WB-survey	1,000 drivers [Australia]	- What are general charging preferences & attitudes (if PEV, then what are your usual charging behaviors)? - What is the preferred charging option (unmanaged, UMC, SMC) and data collection (yes/no)?	- 51% of BEV drivers & 59% of PHEV drivers often or always charge to minimize downtime or maximize convenience, vs. 21% of ICEV drivers (they prefer min. charging costs). - 66% of PEV drivers feel comfortable ceding control vs. 32% of the public.

Abbreviations: CAD = Canadian dollar, CHF = Swiss franc, EV = electric vehicle, GMC = guaranteed minimum charge, ICEV = internal combustion engine vehicle, LCCM = latent class choice model, LDV = light-duty vehicle, PEAs = potential early adopters, PEV = plug-in electric vehicle, SC = smart charging, SEM = Structural equation modeling, SMC = supplier-managed charging, TOU = time-of-use electricity prices, UMC = user-managed charging, VRE = variable renewable energy, WB-survey = web-based survey, WTP = willingness to pay, ZEV = zero-emission vehicle. Note: Owners may include those who lease a PEV.

2.1 Smart charging intervention studies

Early interventions asked a small group of PEV drivers (30 or fewer people) to test a smart charging system at home to understand both technical feasibility and participant experience and to develop recommendations for future pilot programs (Bauman et al., 2016; Schmalfuß et al., 2015). The majority of participants felt that SMC's benefits balanced out with its costs (Schmalfuß et al., 2015) thanks to user-defined constraints, such as minimum battery levels that must be guaranteed at departure time and readily available data on their vehicle's battery levels on a smartphone app[3]. Following the intervention, 72% of drivers said they would participate in future SMC programs if the supplier considered user-defined constraints, like the vehicle's current battery level (Bauman et al., 2016).

SMC interventions were also at two public parking garage charging stations in Malmö, Sweden (Libertson, 2022). About half of the PEV drivers were upset that their PEVs did not fully charge. PHEV drivers felt this increased gas costs because SMC did not fully charge their batteries in time for departure, while BEV drivers had to spend additional time finding alternative public chargers. A subsequent web-based survey of Stockholm area residents with a PEV found that 40% would accept SMC, regardless of charging delay, mostly due to perceived environmental benefits (39%) and grid stability benefits (38%). Still, if public charging stations adopted SMC, people would compensate by installing home charging equipment, buying PHEVs over short-range BEVs, or buying long-range BEVs instead of short-range BEVs.

2.2 Participation incentives in smart charging programs

Other researchers have surveyed current and potential adopters of PEVs to understand consumer attitudes toward smart charging programs and identify important attributes among respondents. Research across different countries has consistently identified higher support for UMC than SMC because of concerns about loss of control, privacy, anxiety, and a lack of trust in their power supplier (Bailey and Axsen, 2015; Delmonte et al., 2020; Lavieri and de Oliveira, 2023; Will and Schuller, 2016). However, one study found that acceptance of SMC may now exceed that of UMC, depending on PEV use and when people are likely to adopt a PEV. Over half of surveyed Australian BEV drivers (59.6%) would prefer SMC to UMC, compared with less than a third (30.2%) of potential early PEV adopters (i.e., those who intend to buy a PEV in less than a year) and 23.6% of the general driving population (i.e., those who do not intend to buy a PEV in less than a year) (Lavieri and de Oliveira, 2023). Early studies may not have observed the effect of PEV ownership on smart charging acceptance due to relatively small numbers of EVs at the time of the study and participant samples that were identified as entirely potential early PEV adopters[4] (Bailey and Axsen, 2015) or recruited from PEV associations and newsletters (Will and Schuller, 2016).

Several studies have investigated the factors that increase participation, including financial incentives[5]. Delmonte et al. (2020) found respondents' engagement with smart charging was conditional on reducing charging costs and Kubli (2022) found the majority of individuals (53%)

[3] Participants in the study by Bauman et al. (2016) could see charging sessions on a web portal and set departure times and automatic opt-outs from charging curtailment based on the vehicle's battery level.
[4] Bailey and Axsen (2015) identified these drivers through a design space exercise, where the participants designed a PEV with a purchase price that was only relatively higher than ICEVs.
[5] Incentives may also include reduced electricity rates, subsidized or free charging infrastructure, sign-up payment, and monthly payments (Wong et al. 2023).

placed an emphasis on reducing charging costs over other charging attributes and would more likely alter their stated charging behaviors if given a time-varying electricity rate. Wong et al. (2023) found a 2% to 3.5% increase in an SMC program per $50 increase in credit, with an overall participation ceiling of 87% for current PEV drivers and 79% for potential early adopters of PEVs. Bauman et al. (2016) found that half of the participants in their 2015 SMC pilot would enroll in a similar program for a monthly credit of $10 (CAD), and over 67% would participate if receiving $15 or less per month. However, early PEV adopters may be more motivated to reduce costs than current PEV drivers, who reportedly prioritize convenience and fast charging (Lavieri and de Oliveira, 2023). While compensation may help in attracting PEV drivers to enroll in and stay with a smart charging program, power suppliers can provide drivers with charging information and user-centric controls to reduce anxiety relating to ceding control to a third party.

Lavieri and de Oliveira (2023) evaluated the likelihood of participants accepting SMC if an override feature were available in a smartphone app. Acceptance of SMC increased from 35% to 56% among current ICEV drivers. Up to 24% of PEV drivers would accept no compensation if given information on past and current vehicle charging patterns through a web portal (Bauman et al., 2016). While Wong et al. (2023) found that 26% of PEV owners/lessees and 13% of ICEV drivers would participate in an SMC program (for load reduction purposes) without a financial incentive, providing a guaranteed minimum charge by departure time increased the probability of the general population participating by 14.5 percentage points. Kubli (2022) found that nearly 28% of respondents preferred SMC to unmanaged or a form of guaranteed charge to reduce PEV charging peaks and align with solar power, so long as suppliers did not substantially increase charging duration (or hours the vehicle is available for mobility).

2.3 Research gaps

Despite the potential opportunities for EV smart charging to increase power grid reliability, reduce charging emissions, and defer investments in storage and dispatchable generators, few works have investigated the motivations for drivers to participate in a smart charging program, regardless of EV use or intent to drive a PEV in the future. Researchers have focused on current PEV drivers or those intending to purchase a PEV in the near future in their sample (Bailey and Axsen, 2015; Delmonte et al., 2020; Kubli, 2022; Will and Schuller, 2016). Thus, these studies ignore the preferences and motivations of the anticipated late PEV adopters, who represent the majority of car buyers and drivers (Lavieri and de Oliveira, 2023). Early BEV models had substantially smaller ranges, which might explain why Bailey and Axsen (2015) found the largest group of their participants (33%) valued increases in guaranteed range when participating in an SMC program, compared to cost-motivated (27%) and renewable-focused users (19%). Later work has identified that while charging convenience and guaranteed range are important, financial incentives may motivate more people to adopt SMC, particularly those likely to adopt PEVs in the short term. It is imperative to also survey individuals who may not buy a PEV in the next few years since many auto companies will stop manufacturing ICEVs between 2030 and 2040, and governments around the world are proposing or implementing ICEV purchase bans (IEA, 2023).

Studies that survey or interview PEV drivers and potential adopters are few and concentrated in Western European countries, as shown in Table 1. The public's trust in science and technology, especially that promoted by the government, like PEVs (Drews and van den Bergh, 2016), and trust in institutions and companies, like one's power supplier or power grid operator, is regionally dependent. Thus, a stronger understanding of charging preferences and financial incentives could guide the design of smart charging programs and increase buy-in among current and future PEV drivers. Despite some behavioral work on PEV smart charging, only one study has investigated attitudes and preferences in the United States (Wong et al., 2023). Consequently, it is important to understand how Americans[6] perceive smart charging programs since their acceptance and willingness to alter PEV charging behavior will influence the transition to a transportation-clean energy system. In contrast to prior work, this study 1) presents respondents with seven PEV charging alternatives (instead of dichotomous choices, like UMC versus SMC), 2) segments results on the respondent's financial incentives for participation in SMC by preferred charging alternative, and 3) measures the respondent's willingness to pay opt-out fees from an auto-enrolled SMC program by studying the role of messaging to influence actions (i.e., social priming). Presenting multiple alternatives, including highlighting distinctions among SMC options, mirrors the decision-making environment prevalent in numerous households today (Wong et al., 2023). Analyzing preferred charging's impact on minimum financial incentives to accept SMC reveals subgroup variations, crucial for designing efficient smart charging initiatives, as advantages decrease with higher adoption (Anwar et al., 2022). Lastly, studying motivational messaging's effect on reducing the externalities of unmanaged charging identifies positive responders to position-based priming.

3. SURVEY DESIGN AND DATA PROCESSING

The data were collected via Qualtrics a web-based survey tool, from late November to early December 2022 across the United States. Respondents were recruited from Dynata's panel of American respondents, ages 18 and older, ensuring no duplicate responses. The survey asked respondents about their perceptions of EVs, smart charging benefits, SMC and UMC, and the power grid. Respondents listed their knowledge of SMC, their preferred PEV charging style, expected compensation with SMC, WTP to leave an automatically-enrolled PEV charging program, current travel patterns, and demographics.

The survey employed one screening question and one within-survey data quality check to minimize straight-lining in a section with multiple Likert scale questions. The screening question stated:

> This survey might introduce you to new concepts, namely "smart charging" of electric vehicles (EVs). Smart charging often shifts EV charging based on prices or allows the local power company to alter charging (like staggering timing, so not all EVs start charging at once). The goal is to lower power costs, lower emissions, and protect the power grid.
>
> What is smart charging?
>
> a) Charging whenever my EV requires it.
> b) Using an app/timer to charge only during off-peak hours to lower costs and emissions.

The screening question removed respondents who may not have thoroughly read the questions or understood this topic. A total of 1,394 complete responses were collected. After removing respondents that failed the data quality check (i.e., "please select slightly important") and did not meet other sanity checks[7], 1,050 responses remained eligible for further analysis. Dynata recruited

[6] People in the United States of America (USA) refer to themselves as Americans, which is not to be confused with the people of the Americas (the region).

[7] Sanity checks involved removing responses where the total number of workers in the household exceeded household size, where the 9-digit zip code contained all repetitive digits, and where short-answer responses indicated insincerity (e.g., a respondent self-reported their ethnicity as "non-human").

respondents to obtain a nearly representative sample of the United States population according to specific demographic classes in the 2021 1-year American Community Survey estimate (US Census Bureau, 2022). The unlinked classes used were gender, age, ethnicity, educational attainment, and the four U.S. Census Bureau regions[8]. Although additional variables like household residence structure type and vehicle-miles driven were not included in quotas, the clean survey was representative of the population.

To account for built environment impacts on vehicle purchasing decisions and perceptions of EV smart charging benefits, the respondents' zip codes were mapped to census block groups (CBG). Built environment attributes available at the CBG level were obtained from the Smart Location Database, available from the U.S. Environmental Protection Agency (Ramsey and Bell, 2014).

3.1 Smart charging concepts

In addition to the screening question, which briefly introduced the topic of smart charging, respondents were presented with the following text before answering any questions on charging preferences:

> Electric power companies can use prices to incentivize EV owners to charge their vehicles during low-cost hours to reduce the impacts of many EVs on the power grid. The power company can use time-of-use prices or pass down the real costs of producing electricity to the EV owner. Some EV owners use apps or timers to only charge during off-peak (or low-cost) periods. Instead of using prices to shift EV charging, power companies can directly control EV charging. Called supplier-managed charging, the goal is to reduce charging costs for the EV owner, use more renewable energy, and improve power grid reliability.

The introductory text provided (1) a rationale behind smart charging programs (i.e., reduce the impacts of many EVs on the power grid) and (2) explained two approaches that power suppliers are taking (e.g., passive smart charging through prices, adopted by users through apps/timers (UMC), and active smart charging through SMC). The survey instrument had the following key sections on smart charging:

- Section A: Importance of smart charging benefits to the respondent (5-point Likert-type scale: not at all important—extremely important), Prior knowledge of SMC (5-point Likert-type scale: no knowledge—extremely knowledgeable), and Interest in a smart charging program for current/future PEV (5-point Likert-type scale[9]: not at all interested—extremely interested).
- Section B: Preferred charging style (with nominal choices), Minimum one-time financial incentive to accept SMC (censored slider), and Minimum annual financial incentive to continue participation in SMC (censored slider).
- Section C: Opinion on different topics related to PEVs, clean-energy transition, and attitudes (5-point Likert scale: strongly agree—strongly disagree).

[8] The survey sample was population weighted/corrected using iterative post-stratification to match the marginal distributions of the sample to national level population margins (with gender levels (male, female, non-binary), age levels (18-24, 25-34, 35-44, 45-54, 55-64, 65+), highest education (high school, some college/associate's degree, bachelor's degree, master's/doctorate degree), and U.S. Census region (Northeast, Midwest, South, West)).

[9] Respondents with a PEV were asked about their interest in a program for their current PEV(s), while those without a PEV were asked about a future PEV. Thus, there was an additional option for those with a current PEV to capture those who already participate in a smart charging program. All results from this question grouped those already participating in programs with individuals that were "extremely interested" in participating in a smart charging program.

- Section D: Minimum monthly fee to leave an SMC program (censored slider).

Sections B and D in the survey required additional text, like easy-to-understand program constraints, to elicit reasonable responses from participants. Those prompts are provided in subsequent sections of this paper. The survey separated questions soliciting opinions and beliefs into Sections A and C to provide cognitive relief and distinguish between Section B and Section D (opt-in to SMC versus opt-out of SMC). The median completion time was nearly 15 minutes (with an average time of 30 minutes). Response times varied due to different survey paths (e.g., EV owners answered additional topics relevant to them). The appendix includes a sample of survey questions.

4. METHODOLOGY

The survey data was analyzed using three main approaches: 1) descriptive summary statistics, 2) models that estimated respondents' preferred EV charging style and their acceptance of SMC conditional on financial incentives, and 3) statistical tests of population means aimed at understanding the efficacy of motivational priming. Descriptive statistics illustrate the survey data's representativeness. Summary information also describes the distribution of respondents by EV ownership (yes/no), positions on various statements concerning the transportation-clean energy transition and the perceived importance of expected smart charging benefits.

The survey used a single question to determine respondents' preferred charging style, differing from a discrete choice experiment where variations across key alternative-specific attributes are presented. This survey also included an unordered set of EV charging choices. Consistent with theory of consumer behavior, the charging preference choice may be posed as an individual maximizing its utility function. Covariates were chosen based on both statistical significance and behavioral importance, even if the covariates were not statistically significant in this study. The multinomial logit (MNL), despite the restrictive independence of irrelevant alternatives (IIA) assumption[10], handles multiple, unordered choices (Ben-Akiva and Lerman, 1985). MNL models are employed in PEV choice problems, such as PEV charging location and car buying decisions (Lee et al., 2020; Lee et al., 2023). The nested logit (NL) model deviates from IIA by assuming some of the alternative's random error terms have a common error component shared between a group of alternatives (Koppelman and Bhat, 2006). In this survey, it is plausible that the three SMC alternatives have distinct random error components alongside a common random component for the SMC group. Modeler discretion and statistical hypothesis testing determined whether the MNL or a simpler NL model was preferred (Koppelman and Bhat, 2006). Specifically, the null hypothesis that the MNL is correct is rejected when $-2\,(LL^{MNL} - LL^{NL}) \geq \chi^2_n$, where n = the number of nests between the models. The charging preference question included "unsure" and "other" options to mitigate potential bias from uncertain or apathetic respondents. Consequently, these responses were excluded from the n = 922 sample for this and ensuing models.

Respondents provided their minimum annual and one-time bill credits necessary for accepting an SMC program. A Tobit model, also known as a censored regression model, estimated the preferred one-time and annual credits for SMC participation. This model was chosen due to the survey's use of a slider scale featuring a checkbox for values exceeding the maximum sliding scale ($200 and $20 for one-time and annual credits, respectively). Tobit models assume normality and

[10] If similarities between choices, like loss of control or increased energy consumption from pinging vehicle telematics for SMC, is not included in the measurable portion of the utility function the errors associated with the SMC alternatives will be correlated, violating the IIA property.

homoscedasticity in the distribution of residuals. When heteroscedasticity is present, it can introduce bias into the results (Amore and Murtinu, 2021; Arabmazar and Schmidt, 1981). Residual plots with censored regression models indicated a lack of homoscedasticity within the data. Thus, Messner et al.'s heteroscedastic censored regression model with a logistic distribution was used (2016). The left limit for the censored dependent variable was $0, while the right limits were $200 and $20, respectively.

$$y_i = \begin{cases} y_i^*, \; y_L < y_i^* < y_U, \\ y_L, \; y_i^* \leq y_L, \\ y_U, \; y_i^* \geq y_U, \end{cases} \tag{1}$$

where y_L and y_U are the respective censoring limits (lower and upper) and y_i^* is the latent variable.

A subset of explanatory variables based on expected behavioral relevance was initially included when estimating the Tobit model. Subsequently, covariates with the lowest statistical significance were removed using likelihood ratio tests, except for gender and race, as such covariates may offer statistical significance in future studies. In addition to statistical significance, practical significance values are shown to reflect the importance of covariates on the dependent variable (i.e., payments for SMC). Practical significance measures the change in payments due to a one-standard deviation change in each covariate. Covariates with standardized coefficients exceeding 0.5 are deemed "practically significant."

Finally, respondents provided their willingness to pay (WTP) to leave an SMC program where the power company automatically enrolls new PEVs for at-home charging. The survey randomly displayed one of two prompts for this WTP question to understand the effect of priming individuals on freedom or altruistic motivations. Welch's t-test, also called the unequal variances t-test, tested whether the mean opt-out fees of the two groups receiving different prompts were equal across several respondent and household-level attributes.

5. RESULTS

5.1 Statistics of Survey Respondents

Table 2 summarizes the respondent's demographic, household composition, residence, and vehicle variables from the complete data set (n = 1,050). The table also shows sample distributions between EV owners/lessees (n = 128) and non-EV owners/lessees. A comparison is given to U.S. census data and other appropriate data sources. The study uses some of these variables as covariates in models. The paper results are population-weighted using Table 2's sources to ensure its findings are representative of Americans' preferences and attitudes around the transportation-clean energy transition.

Table 2: Summary statistics of sample and comparison to nationally representative data sources.

Explanatory Variables	Sample			Population	Source
	EV owners/ lessees	Non-EV owners/ lessees	Full Sample		
Gender (of person filling out the survey)					
Male	53.1%	45.9%	46.8%	49.5%	ACS 2021 (1-Year)
Female	46.9%	53.1%	52.4%	50.5%	

Non-binary/other	0.0%	0.9%	0.9%	NA	
Age (of person filling out the survey)					
18–24 years of age	21.1%	15.3%	16.0%	17.1%	
25–34	35.2%	20.1%	21.9%	22.9%	
35–44	15.6%	17.5%	17.2%	16.9%	
45–54	10.9%	17.6%	16.8%	15.8%	ACS 2021 (1-Year)
55–64	11.7%	18.1%	17.3%	16.5%	
65+	5.5%	11.5%	10.7%	10.8%	
Highest level of education completed (of person filling out the survey)					
High school or less	24.3%	38.6%	36.9%	38.1%	
Some college/Associates degree	32.8%	30.8%	31.0%	29.5%	ACS 2021 (1-Year)
Bachelor's degree	24.2%	20.0%	20.5%	20.3%	
Master's degree or higher	18.7%	10.6%	11.7%	12.2%	
Race (of person filling out the survey)					
White	57.8%	78.1%	75.6%	61.2%	
Black	17.2%	11.4%	12.1%	12.1%	
Asian	16.4%	5.9%	7.1%	5.8%	ACS 2021 (1-Year)
American Indian	3.9%	1.0%	1.3%	1.0%	
Mixed	3.9%	2.1%	2.3%	12.6%	
Other/not disclosed	0.8%	1.6%	1.5%	7.2%	
Census Location					
Northeast U.S.	18.8%	22.3%	21.9%	17.2%	
Midwest	18.0%	18.8%	18.7%	20.7%	ACS 2021 (1-Year)
West	25.0%	16.8%	17.8%	23.7%	
South	38.3%	42.0%	41.6%	38.3%	
Household Income, pre-tax					
Less than $30,000	17.2%	21.5%	21.0%	21.2%	
Between $30,000 and 49,999	12.5%	19.3%	18.5%	15.3%	
Between $50,000 and 74,999	18.8%	21.3%	21.0%	16.8%	
Between $75,000 and 99,999	15.6%	11.9%	12.4%	12.8%	ACS 2021 (1-Year)
Between $100,000 and $149,999	14.0%	13.0%	13.1%	16.3%	
$150,000 and up	21.1%	9.8%	11.1%	17.7%	
Prefer not to answer	0.8%	3.3%	2.9%	NA	
Household Vehicles					
0 vehicles	0.0%	7.8%	6.9%	8.9%	
1	48.4%	39.2%	40.2%	33.5%	2017 NHTS
2	32.8%	34.7%	34.4%	33.1%	

3+	18.8%	18.3%	18.3%	24.4%	
Residence Type					2021 AHS
Detached House	68.8%	64.4%	65.9%	63.6%	
Attached House (e.g., townhouse, duplex)	7.8%	4.9%	5.2%	6.3%	
Apartment	21.1%	22.6%	22.4%	24.7%	
Mobile Home	1.6%	5.2%	4.8%	5.2%	
Other	0.8%	2.9%	2.7%	0.05%	
Household Size					2020 Census
1 household members	18.8%	19.1%	19.0%	28.3%	
2	20.3%	34.9%	33.1%	34.2%	
3	24.2%	19.8%	20.4%	15.4%	
4+	36.7%	26.1%	27.4%	22.2%	
Household Technology Present					
Smart thermostat	48.4%	20.0%	22.4%	18.3%	Walton (2022)
Solar power	14.1%	4.6%	5.6%	3.8%	2021 AHS

Notes: ACS = American Community Survey, NA = not available, NHTS = U.S. National Household Travel Survey. The American Housing Survey (AHS) excludes group quarters (e.g., nursing homes, dormitories, military housing). The respondents self-selecting non-binary/other gender were grouped with females into a non-male category in regression models. Non-EV owners/lessees include zero-vehicle households.

The survey asked respondents many questions related to their household structure type, their vehicle use, where their primary vehicle (if any) is parked at home, future car buying decisions, and barriers to buying or leasing a PEV and charging one at home. Summary statistics for these variables are found in the appendix, to focus on the novelty of the current paper—Americans' preferences and financial incentives needed to adopt smart charging programs.

5.2 Perceptions on the transportation-clean energy transition

Respondents answered questions about charging PEVs, from their participation in smart charging to how the power grid might support a high number of PEVs. The survey included seven statements where respondents recorded their agreement or disagreement using a five-point Likert scale (see Fig. 1 for a list of statements). More people agree (38.2%) than disagree (31.0%) that the power grid can support the government's EV adoption goals. Respondents from the Mountain and East South Central U.S. census divisions[11] were the least likely to agree with this statement relative to the U.S. average. Only three of the nine U.S. census divisions (Middle Atlantic, New England, and South Atlantic) had respondents agree more with this statement than the U.S. average—all on the U.S. east coast. Giving up some charging control with UMC or SMC can make the power grid more stable, but at the expense of privacy, like information about when one charges their vehicle

[11] The 9 U.S. census divisions are *New England* (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont), *Middle Atlantic* (New Jersey, New York, Pennsylvania), *East North Central* (Indiana, Illinois, Michigan, Ohio, Wisconsin), *West North Central* (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota), *South Atlantic* (Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia), *East South Central* (Alabama, Kentucky, Mississippi, Tennessee), *West South Central* (Arkansas, Louisiana, Oklahoma, Texas), *Mountain* (Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, Wyoming), and *Pacific* (Alaska, California, Hawaii, Oregon, and Washington).

and how much electricity is needed (Bailey and Axsen, 2015). More people (45.2%) agree than disagree (22.7%) that privacy is more important than ceding control for a stable power grid. Of the most privacy-minded individuals who would not accept SMC, even for a stable power grid, 36.8% believe the power grid cannot support the government's PEV goals. Individuals willing to give up some privacy to have a reliable power grid are more likely to recognize that individual actions might help the power grid manage the PEV transition (46.6%).

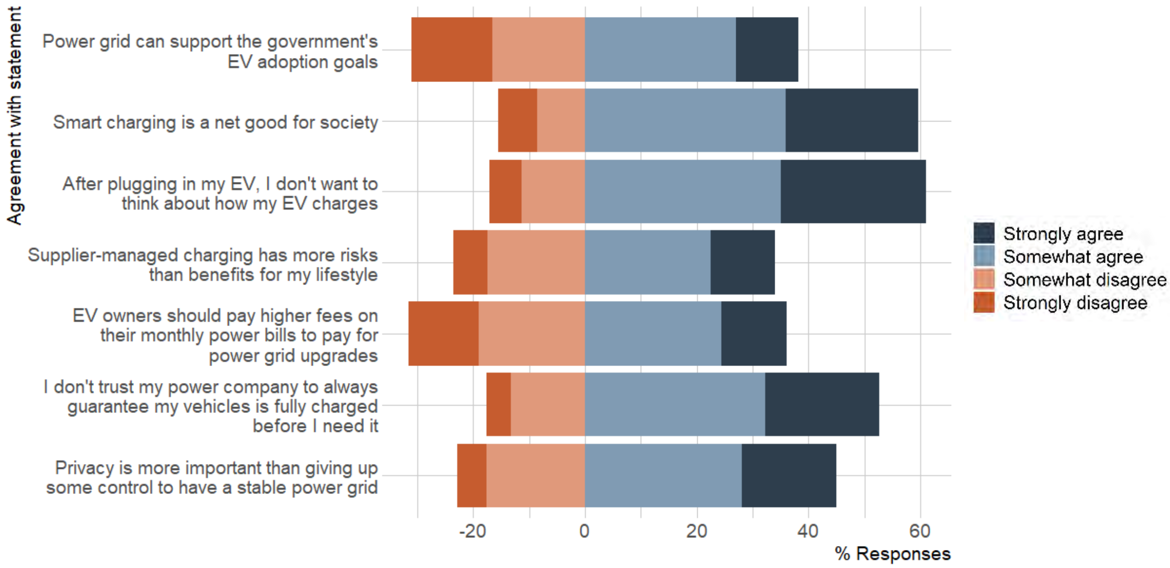

Fig. 1: Perceptions on smart charging and the transportation-clean energy transition (neither agree/disagree responses not shown).

PEVs can increase peak demand on the bulk power system and may overload transformers on the distribution power grid (Anwar et al., 2022). PEV drivers and potential early adopters may believe that existing power bill rates ($/kWh) and customer charges ($/month) should pay for potential upgrade costs since they are already paying more on their power bill for the additional electricity. This study finds that 36.1% believe PEV owners should pay higher fees on their monthly power bills to pay for power grid upgrades, while 31.6% disagree. Households with a PEV disagree less—the percent disagreeing with higher fees on their monthly power bill decreases to 27.4%. Only 26.9% of respondents that would definitely buy a PEV if making a car buying choice in the next five years agree that PEV owners should pay higher fees on their power bill to pay for power upgrades, compared to 50.9% of respondents that would definitely not buy a PEV. An added charge on a PEV owner's monthly bill to fund system upgrades can avoid the industry's first-come, first-serve upgrade process, which would saddle the user of a new PEV that overloads the transformer with an expensive bill (Hartnack and Hitchcock, 2023). Alternatively, power suppliers could increase fees for PEV users that do not adopt SMC to fund upgrades, which penalizes users that do not increase demand-side flexibility.

Many more people agree (60.1%) than disagree (15.4%) that managed charging is a net good for society. Further, of the 16.2% that somewhat disagree that the power grid can support EV targets, 51.9% believe that managed charging is a net good for society. Power suppliers and system operators should remain optimistic about creating smart charging programs since even a large share of the general public (i.e., mostly ICEV owners) believes it is a net good. Although managed charging can limit flexibility by requiring travel planning, most respondents do not wish to think about how their vehicle charges once plugged in (60.9%). On the other hand, ignoring how PEVs charge can be a characteristic of respondents who prefer unmanaged charging. Creating simple programs that require little interaction with the charging manager (either a timer for UMC or user-defined constraints for SMC) can reduce the cognitive burden of smart charging programs (Schmalfuß et al., 2015).

Over half (52.9%) do not trust their power supplier (i.e., local electric utility) to always guarantee their vehicle is fully charged before needing it, which could explain why nearly 34.3% believe SMC has more risks than benefits. Providing a guaranteed minimum charge level, like 90% for only one workday and 100% for the remaining weekdays, is shown to increase smart charging acceptance to 96% (Bailey and Axsen, 2015). However, some respondents may live in rural areas with frequent and long power outages or in low-priority neighborhoods for restoring power. The lack of trust in guaranteeing a PEV's full charge could be related to distrust in power reliability, which may become a new adoption barrier in the transition to PEVs and smart charging programs (Przepiorka and Horne, 2020).

5.3 Perceived importance of smart charging benefits

Respondents answered questions about how important expected PEV smart charging benefits are to them. The survey included seven statements where respondents ranked the perceived importance of benefits from not at all important to extremely important. The benefits included reducing one's electric bill, maximizing zero-carbon renewables, contributing to global climate goals, reducing air pollution from power plants, reducing the impact of PEVs on the grid, reducing expensive large-scale energy storage, and making the grid more reliable (see Fig. 2 for a list of benefits).

There is a correlation between the importance of smart charging benefits and general interest in smart charging[12] (Fig. A.3). The statement "smart charging can contribute to global climate goals" received the highest percentage of "not at all important" responses and could reflect the perspectives of respondents who dismiss the importance of actions aimed at addressing climate change. Accordingly, respondents who do not value this benefit at all are more likely to report "no interest at all" in a smart charging program (Fig. A.3).

The benefit with the highest share of "extremely important" responses was reducing one's electric bill, followed closely behind by reducing air pollution from power plants and making the grid more reliable. The ranked order suggests that respondents are more concerned about their near-term personal interests (e.g., finance, health, and comfort) than what lies in the future (climate change). Extant research on public perceptions of climate change finds a strong inverse relationship between behavioral change and the "psychological distance" (i.e., temporal, social, geographical distance, and uncertainty) of climate change impacts (Lorenzoni and Pidgeon, 2006; Spence et al., 2012). Individuals are also motivated by short-term gratification and heavily discount long-term rewards (Huckelba and Van Lange, 2020).

[12] Research on smart home technology indicates that individuals who recognize its benefits have higher interest towards new technology, such as smart thermostats, and are more willing to participate in power conservation programs (i.e., value compatibility) (Parag and Butbul, 2018).

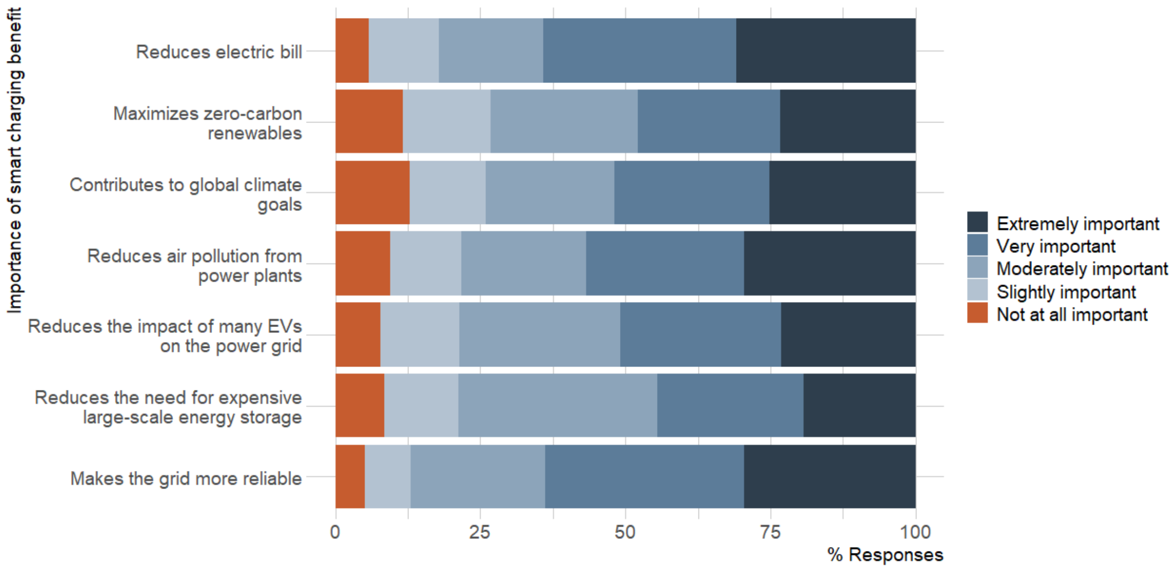

Fig. 2: Perceived importance of expected PEV smart charging benefits.

5.4 Preferences for PEV smart charging

Respondents, regardless of whether they currently owned a PEV or were a zero-vehicle household, were asked about their preferred PEV smart charging type. They were told to assume they drive a BEV with a range of 250 miles and can charge at home at a speed providing up to 20 miles of recouped range for every hour of charging (i.e., 12.5 hours from 0-100%)[13]. Respondents were provided with the following text and choice options (Fig. 3):

> Given your weekly driving and (expected) charging habits, *would you allow your local power company to directly control charging*? The power company would use this power to mostly stagger charging schedules to avoid peaks in energy demand from BEVs.


Yes, I do not care what happens as long as I wake up with a full charge but do not interrupt my charging during the day.


Yes, I would allow them to control my charger daily to optimize grid demand throughout my community.


Yes, I would allow them to control my charger only when needed, like to prevent grid strain on days of high energy demand.


Maybe, I would need more information to feel confident in giving up total control.

[13] The scenario of a 250-mile BEV charging at home with a speed of up to 20 miles/hour of charging (or Level 2) is based on the average 2022 BEV owner (Commission, 2023; Effler, 2023; IEA, 2023).

No, but I would be willing to stagger charging myself through an app/timer.

No, I want my vehicle to charge when plugged in and stop charging as soon as it reaches a full charge.

I am unsure/other: _____

Fig. 3: Preferred PEV smart charging option.

A quarter of people (25.6%) say they would never allow their local power supplier to interfere in charging their PEVs, but 8.8% would be willing to use an app or timer to stagger charging. Another quarter (25.3%) may cede control but need more information to feel confident in giving up total control. Up to 36.9% would accept SMC, but under different conditions. Most prohibit SMC during the day but give up control at night, so long as the vehicle is fully charged by the morning (17.6%). The next highest group would allow SMC only when needed, like during high grid strain days (10.3%). And a smaller share (8.9%) would permit their power company to help optimize the local grid daily.

Current EV drivers that indicated some interest in a managed charging program (n = 124) were more likely to accept an SMC program or UMC program with an app or timer than reject managed charging outright (Fig. 4). A similar result was found for BEV drivers in Australia (Lavieri and de Oliveira, 2023). As non-EV drivers obtain PEVs and gain firsthand charging experience, they may cede some control to their local power company. About two-thirds of zero-vehicle households (65.1%) are likely to obtain a vehicle for the respondent’s primary use in the future, and these respondents are more unsure about accepting any charging program. Designing smart charging programs with SMC override features, guaranteed minimum charge, and assurances on no significant charging delays, which increase acceptance of SMC among drivers (Kubli, 2022; Lavieri and de Oliveira, 2023; Wong et al., 2023), may also be effective with households that are currently car free.

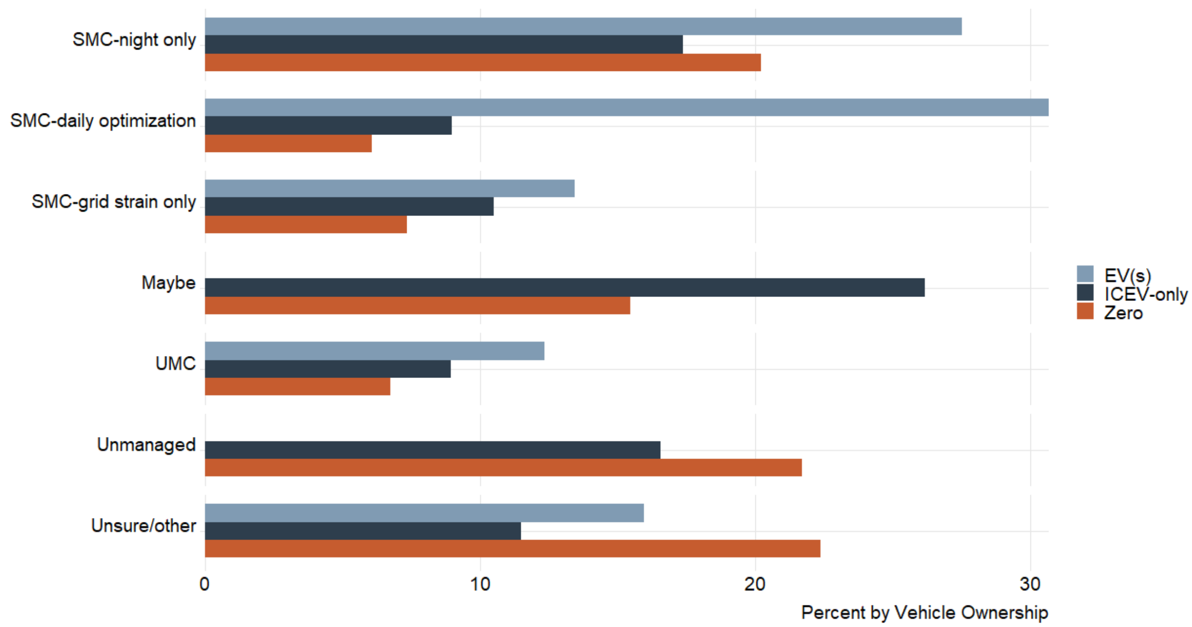

Fig. 4: Preferred PEV smart charging option by household vehicle status.

Note: EV owners not at all interested in a smart charging program (n = 4, or 3%) did not answer questions on future charging behaviors.

Educational attainment can explain one's resistance to smart charging. Those preferring unmanaged charging (i.e., PEV charges as soon as it is plugged in and stops charging once it is full), on average, have not earned higher education degrees. Almost a third (32.3%) of those with some grade/high school education prefer unmanaged charging, versus 10.2% with a doctoral degree, 13.4% with a master's degree, and 12.9% with a bachelor's degree. Similarly, new vehicle buyers in Canada who were identified as belonging to an anti-SMC latent class were less highly educated than other segment members (Bailey and Axsen, 2015).

As this study and prior research demonstrates (Lavieri and de Oliveira, 2023), EV owners are more willing to accept SMC than non-EV owners. EV SMC programs may avoid charging vehicles during hours of the year with the highest demand for electricity. Households with a workable smart thermostat, which can be programmed to raise the indoor temperature during the hottest days of the year to reduce cooling power demand, may be more willing than other households to accept SMC on grid strain days. This study finds individuals with smart thermostats (14.4% compared to 9.1% without) are more willing to accept SMC of their future PEVs during times of high energy demand, such as grid strain days. Regions with smart thermostat load reduction programs may see higher participation rates in a PEV smart charging program because households can understand the impact of demand response on cooling and compare it to their PEV[14].

In section 5.3, this study reported that reducing one's electric bill received the highest share of "extremely important" responses. Although many people are cost-driven, many people (37.3%) could not identify how they pay for electricity consumption out of a list of typical options (e.g.,

[14] Behavioral research is needed to understand whether the sequential ordering of demand response programs impacts the acceptance of PEV smart charging programs with a demand response component.

fixed/flat, tiered, TOU, and wholesale-indexed prices). Of those that were knowledgeable about their power bill, people with a wholesale-indexed power bill were more likely to accept SMC for grid strain days and every day to optimize local power grid conditions.

5.4.1 Model results for preferred PEV smart charging

The multinomial logit (MNL) mode specification was compared to a nested logit (NL) model, where the three SMC alternatives were nested under the supplier-managed branch. The logsum parameter for this nest was 0.757. The standard hypothesis test, as indicated in the methodology section, is as follows: $-2(-1435.27 - -1433.82) = 2.9$ is less than the critical value of 3.8, concluding the hypothesis that the MNL model is correct cannot be rejected. For this model, the negative alternative specific constants (ASCs) imply a preference for unmanaged charging (all else constant), with UMC more negatively perceived with respect to unmanaged charging than the SMC and “maybe [SMC]” alternatives. For example, households with a BEV overcome the negative constants for SMC-night only and SMC-daily optimization when they also pay wholesale energy prices. A full-time male worker who is not middle-aged can overcome the negative ASC for SMC-night only. If one ignores the attitudinal variables, a full-time worker that pays TOU energy prices and has at least four household vehicles, one of which is a BEV, can overcome the negative ASC for UMC.

The MNL model includes many socioeconomic variables, including gender, age, education, employment and vehicle access. Gender is not particularly significant in characterizing the preferred PEV charging method relative to unmanaged charging. However, males are more willing to accept an SMC program to optimize local grid conditions and night-only intervention (all else being constant). Individuals ages 35 to 54 who are also unemployed (all else constant) are more willing to accept SMC-daily optimization and less resistant to SMC-night-only programs relative to other choices. Individuals ages 55 to 64 are less willing to accept SMC-night-only programs. The coefficients for other choices and age groups relative to the base of 18–34 years old and unmanaged PEV charging were statistically insignificant. Individuals that completed a degree higher than a high school degree (or equivalent) were more willing to accept SMC-daily optimization; however, education does not reduce the need for more information to make an informed decision about an SMC program. Full-time and part-time workers are willing to choose UMC, but full-time workers are also willing to accept SMC-night only and SMC-grid strain only.

Table 3: Preferred smart charging program (using MNL and population weights)

Covariates	Coefficient	t-stat	p-value
Constants (unmanaged PEV charging as base)			
SMC-night only	-0.501	-0.87	0.385
SMC-daily optimization	-2.542	-2.68	0.007
SMC-grid strain only	-1.075	-1.58	0.115
UMC	-4.855	-4.73	0.000
Maybe [SMC]	-1.182	-1.49	0.135
Gender (non-male as base)			
Male (SMC-night only)	0.318	1.81	0.070
Male (SMC-daily optimization)	0.576	2.40	0.016
Age (18 to 34 years old as base)			
Age 35-54 (SMC-night only)	-0.436	-2.16	0.031
Age 35-54 (SMC-daily optimization)	0.407	1.74	0.083
Age 55-64 (SMC-night only)	-0.713	-2.73	0.006
Education Attainment (HS or less as base)			

Associate degree (SMC-daily optimization)	0.677	2.13	0.034
Bachelor's Degree (SMC-daily optimization)	0.963	2.82	0.005
Bachelor's Degree (Maybe)	0.550	3.03	0.002
Master's and up (SMC-daily optimization)	1.012	2.78	0.005
Employment (Non-employed as base)			
Full-time (SMC-night only)	0.348	1.87	0.061
Full-time (SMC-grid strain only)	0.381	1.65	0.098
Full-time (UMC)	0.461	1.62	0.104
Part-time (UMC)	0.669	2.06	0.039
# of Household Vehicles			
SMC-night only	0.187	1.61	0.107
SMC-daily optimization	0.225	1.55	0.122
SMC-grid strain only	0.293	2.11	0.035
UMC	0.436	3.17	0.002
Maybe	0.295	2.75	0.006
BEV Owner			
Yes (SMC-night only)	0.773	1.23	0.217
Yes (SMC-daily optimization)	1.294	2.07	0.038
Yes (UMC)	1.921	3.39	0.001
Smart Thermostat			
Yes (SMC-grid strain only)	0.378	1.55	0.122
Time-of-Use Prices for Power Bill			
Yes (UMC)	0.786	2.98	0.003
Wholesale Prices for Power Bill			
Yes (SMC-daily optimization)	1.845	3.13	0.002
Yes (SMC-grid strain only)	1.508	2.65	0.008
Prefer not to think about how my EV charges, once my EV is plugged in (disagree-agree)			
SMC-night only	0.440	2.40	0.016
Supplier-managed charging has more risks than benefits for my lifestyle (disagree-agree)			
SMC-night only	-0.457	-4.17	0.000
SMC-daily optimization	-0.651	-4.85	0.000
SMC-grid strain only	-0.722	-5.47	0.000
UMC	-0.143	-1.07	0.286
Maybe	-0.388	-3.81	0.000
Smart charging can maximize zero-carbon renewables (importance)			
SMC-night only	0.241	2.39	0.017
SMC-daily optimization	0.480	3.56	0.000
SMC-grid strain only	0.545	4.22	0.000
UMC	0.192	1.57	0.116
Maybe	0.261	2.79	0.005
Smart charging can make the grid more reliable (importance)			
SMC-night only	0.341	2.95	0.003
SMC-daily optimization	0.086	0.57	0.569
SMC-grid strain only	0.297	2.00	0.046
UMC	0.560	3.71	0.000
Maybe	0.220	2.11	0.035
PM2.5 Annual Average (μg/m^3)			
SMC-daily optimization	0.163	2.30	0.022
UMC	0.178	2.32	0.021
Gini Index			

Maybe	3.068	2.27	0.023
Traffic Proximity and Volume			
SMC-grid strain only	1.11E-04	2.30	0.022
Extremely inconvenient to install a home charger			
SMC-night only	-0.036	-0.13	0.895
SMC-daily optimization	-1.266	-2.64	0.008
SMC-grid strain only	-0.753	-1.89	0.058
UMC	-0.439	-1.14	0.255
Maybe	-0.857	-3.12	0.002

N = 922
LL (all constants [AC]) = -1652.00, LL (final) = -1435.27
ρ^2 (AC) = 0.1298, Adj. ρ^2 (AC) = 0.0964
AIC = 2980.55, BIC = 3246.01

Households with more vehicles tend to prefer UMC, SMC-grid strain only, and "maybe" SMC relative to unmanaged charging, while SMC-night only and SMC-daily optimization are not statistically significant at the 10% level. Having more household vehicles can provide travel security if the respondent's primary vehicle is not fully charged because of a managed charging program. Of the household vehicle variables that were statistically significant at a 95% confidence interval, all are minimally invasive choices. Individuals with a household BEV are more likely to accept UMC and SMC-daily optimization, although there is less certainty that they will accept SMC-night only.

The next set of covariates deals with load-shifting behavior. Households with a smart thermostat may accept SMC-grid strain over other choices since many power suppliers use smart thermostats for peak load reduction a few days a year. In the future, this variable might be statistically significant at a higher confidence level, especially if the variable is more specific (i.e., the household participates in a load reduction or demand response program). If the individual's power bill uses time-of-use prices, they are more willing to accept UMC with an app or timer. Once the driver sets up their charging schedule with UMC, the cognitive burden is negligible, and the individual does not have to worry about their supplier interfering in charging, even if direct charging control is rare. Households with wholesale power prices may be more risk-tolerant or have more demand-side flexibility (and load control) than the average household. As a result, they are willing to accept SMC offerings like daily optimization and grid-strain events to shift charging and help the power grid.

The addition of observed attitudes and perception variables[15] significantly improves the modeling specification. Individuals who increasingly do not want to think about how their PEV charges once plugged in prefer SMC-night only to other options, even UMC[16]. Individuals who increasingly agree that SMC has more risks than benefits are more likely to choose UMC or "never" accept a

[15] Attitudes and perception variables in models may cause endogeneity issues. For example, the perceived importance of grid reliability may be influenced by the duration and frequency of power outages experienced by an individual. This variable is likely to influence the stated choice of the individual. Even if the parameter estimate on this grid reliability variable is biased, it still serves a purpose in understanding future behaviors. For these reasons, care was taken in selecting which variables should be included in the models (i.e., "Are they sufficiently different from one another?" and "Are they likely to explain behaviors in choice and incentives?"). The direction of the results aligns with reasonable behavioral expectations.

[16] UMC with non-aware charge staggering is known to create peaks of EV demand at night (FleetCarma, 2019). This paper suggests that power companies should identify individuals with a "plug-and-ignore" mindset for targeted enrollment in an SMC-night-only program. This strategy can mitigate new nighttime demand peaks due to the rise in EV adoption.

managed charging program. The sign for UMC is negative relative to unmanaged charging, even if not statistically significant. In other words, if an individual believes that SMC has more risks than benefits, they are unlikely to accept or even consider any managed charging program, even a user-managed program. Smart charging can reduce the curtailment of VRE and make the grid more reliable by increasing demand-side flexibility. The more important the SC benefit of maximizing VRE, the more likely an individual is to accept SMC offerings or consider SMC (maybe). The more important the SC benefit of increasing the reliability of the power grid is to an individual, the more willing they are to accept or consider accepting smart charging; however, SMC-daily optimization is not statistically significant in this sample.

The next set of variables are built environment indicators from the Smart Location Database, provided by the U.S. Environmental Protection Agency (EPA) (Ramsey and Bell, 2014). Individuals residing in areas with a higher annual average concentration of fine particulate matter are more receptive to UMC and SMC-daily optimization[17]. EPA's composite variable for traffic proximity and volume (i.e., "traffic congestion exposure severity") has a statistically significant positive relationship with SMC-grid strain. The Gini index is a correlation coefficient that measures income inequality, where 0 represents complete equality and 1 represents complete inequality. Individuals living in regions with higher income inequality are hesitant to choose SMC and need more information. Income inequality's negative effect on trust and a persons' altruism is well-known (Buttrick and Oishi, 2017) and may require individuals in inequal regions to receive more education on the design, intent, and features of an SMC program before acceptance levels rise. Lastly, households were asked how convenient it would be to install a charger at home if there was not already one. Individuals that believe it is extremely inconvenient to install a charger at home in their current location (and were told in the prompt to imagine they have a BEV-250 vehicle with a charger at home) are unwilling to manage EV charging. Creating EV-ready building codes, subsidizing EV installation, and developing inclusive utility investment programs to address disparities in residential charging access are solutions that can capture people receptive to SMC (Clean Energy Works, 2023; Frommer, 2018; Lopez-Behar et al., 2019).

This model implies that BEV ownership and retail energy prices are critical factors that explain smart charging preferences; however, ICEV households paying flat energy prices can still prefer smart charging programs to unmanaged charging. To understand the importance of BEV ownership and wholesale-indexed electricity prices, the estimated model was used to predict the preferred alternatives for all adults if these variables were all independently true or false. If all households had a BEV, the probability of respondents choosing UMC would increase by nearly 47 percentage points. If all households paid wholesale energy prices, the predicted probability of choosing SMC for daily grid optimization would increase by nearly 42 percentage points. Fig. 5 shows the change in the probability of the preferred PEV smart charging choice if all households owned or leased a BEV, relative to having no BEVs. Similarly, the figure shows the scenario where all households paid wholesale-indexed energy rates relative to households paying all other retail rate types. These findings indicate that experience charging a BEV and paying the "true cost" of electricity through wholesale-indexed rates greatly reduces the need for additional information to decide on ceding charging control to one's local power supplier.

[17] Conversely, individuals living in regions with cleaner air may be less motivated to participate in smart charging programs aimed at curbing air pollution stemming from distant power plants; however, other motivating factors may be present. Future research should explore the strength of this implication for environmental justice.

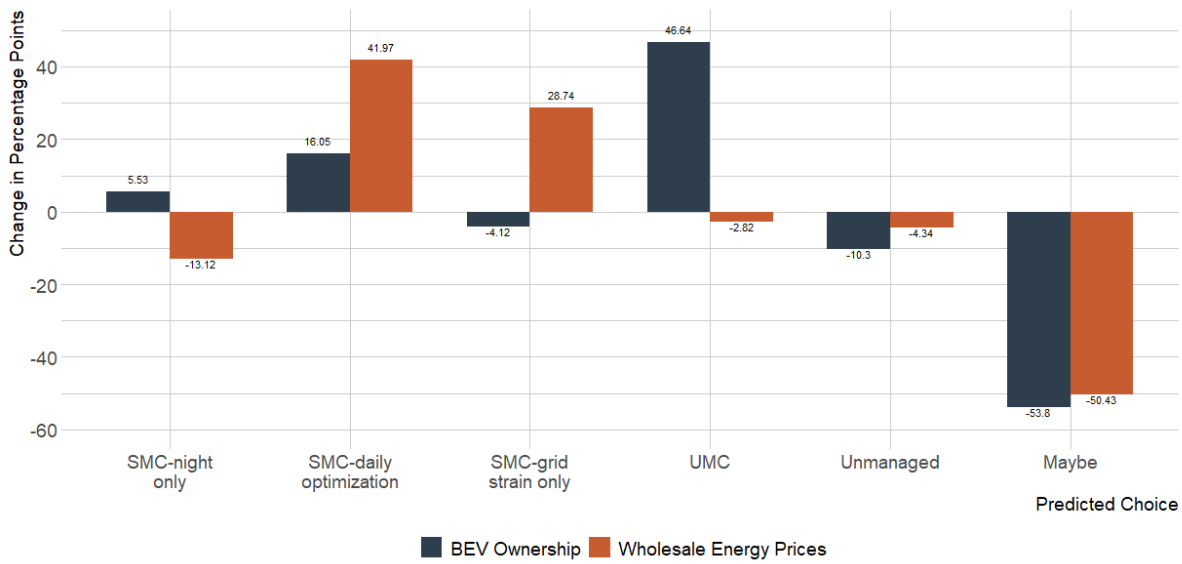

Fig. 5: Predicted shifts in preferred alternatives with shifts in BEV ownership and wholesale-indexed energy price indicator variables (0% to 100%).

5.5 Financial incentives for supplier-managed PEV smart charging

After individuals selected their preferred PEV charging program, they were told to assume they participated in an SMC program. Again, they had the same information (e.g., they drive a BEV with a range of 250 miles and can charge at home at a speed providing up to 20 miles of recouped range for every hour of charging). Respondents selected the preferred one-time bill credit for participating in an SMC program using a slider scale, from $0 to $200, with the option to mark "more than $200." Respondents were provided with the following text:

> *Your local power company gives you a one-time bill credit ($) if you participate in an EV smart charging program. The power company studies your EV charging patterns for one month and creates a custom charging schedule for you. This allows the power company to charge EVs at a lower cost without impacting your travel needs. Details:*
>
> - For overnight charging, you allow the power company to charge your EV whenever, so long as you receive a full charge by the morning. Your vehicle is charged sometime between the hours of 10 PM and 6 AM.
> - For daytime charging, the power company can interrupt charging during extreme events (no more than 5 times a year). Otherwise, your charging is not affected.
> - Must stay enrolled in the program for at least 1 year to receive the one-time credit.
>
> *What is the smallest one-time bill credit ($) you would accept to allow your local power company to modify your EV charging when plugged in*?

The range in one-time bill credit was adjusted down from the potential per-vehicle value of smart charging found in the literature, which primarily centers on the California market, where electricity prices are higher than the national average (Anwar et al., 2022). While all respondents selected their preferred one-time credit to accept SMC, not everyone is willing to accept SMC, let alone UMC. Due to the declining marginal value of managed charging with increasing PEV penetration

(Szinai et al., 2020), it may be advantageous for power suppliers to study the value of smart charging locally and use price discrimination to reward those offering the highest value (see appendix Figs. A.5 and A.6 for empirical cumulative distribution functions, where the right-censored data is re-scaled to $201 and $21, respectively).

People who previously said they would be willing to cede control to their power company for the benefit of the community (SMC-daily optimization) and during grid-strained days (SMC-grid strain only) are willing to accept a lesser one-time credit—an average of $96.33 and $99.57, respectively (Table 4). Those that would only permit control at night (SMC-night only) ask for an average of $100.38. The three groups that previously preferred SMC do not ask for high one-time bill credits—9.3% to 20.0% of these respondents selected the checkbox for "more than $200," versus 23.9% to 38.9% of respondents choosing the non-SMC choices. Although SMC may entail higher administrative and technical costs than UMC, the value to utilities is higher, and the supplier may have a greater return on investment. Instead of paying UMC users an extra $26 to $30 per vehicle to participate in SMC, the power company may decide to shift more drivers from the unmanaged category to UMC[18].

Respondents answered how much money they would require each year for ongoing participation on top of the one-time incentive. The slider question was scaled down from $0 to $20, with an option to mark more than $20. Those who allow SMC-daily optimization require more annual compensation than those allowing SMC-grid strain only, which reflects the higher chance of intervention by the power company and possible inconvenience ($13.50 to $12.89). A higher share of people requires a yearly credit above the slider scale, which was set at $20 for this survey.

Table 4: Preferred minimum one-time and annual bill credit for SMC participation (population-weighted and segmented by PEV charging preferences).

Preferred PEV Charging Program	**One-time credit: Mean (St Dev)***	**One-time credit: >$200**	**Yearly credit: Mean (St Dev)****	**Yearly credit: >$20**
SMC-night only	$100.38 (59.81)	20.0%	$12.82 (6.01)	43.5%
SMC-daily optimization	$96.33 (52.49)	9.3%	$13.53 (5.69)	21.0%
SMC-grid strain only	$99.57 (48.20)	15.5%	$12.89 (5.87)	39.6%
UMC	$126.43 (63.98)	32.9%	$14.38 (6.83)	57.5%
Maybe	$109.14 (58.51)	23.9%	$15.09 (6.11)	49.2%
Unmanaged	$94.64 (65.93)	38.9%	$12.95 (8.12)	55.3%

*excludes those selecting the checkbox for more than $200
**excludes those selecting the checkbox for more than $20

5.5.1 Model results of incentives for supplier-managed PEV smart charging

This section reports the Tobit models that estimate the one-time payments (Table 5) and annual payments (Table 6) that an individual requires to accept a form of SMC, as outlined in the previous section. Covariates with standardized coefficients greater than 0.5 are considered "practically significant" and are bolded in the Tables.

Females who do not identify as Asian/Pacific Islander/Asian American, are between 18 and 24 years old, do not trust their power company to always guarantee a fully-charged EV, and perceive

[18] Although those preferring unmanaged charging accept a smaller one-time credit for SMC than those willing to participate in SMC, it unlikely that many would shift from unmanaged to SMC without the intermediate step of UMC. Financial incentives to shift unmanaged charging to UMC may be lower than $26 to $30/vehicle.

smart charging's benefit of increasing grid reliability as important (all other predictors constant), are estimated to have higher minimum one-time payments to allow their local power company to modify EV charging (i.e., SMC). Asian American males who agree that EV owners should pay higher fees on power bills and are interested in long-range BEVs exclusively place a lower value on one-time bill payments to permit SMC. The model indicates those who would agree to pay additional monthly power fees to upgrade grid infrastructure and those preferring long-range BEVs need less of a financial incentive to permit their local power company to modify their charging behavior.

Females who do not identify as White Hispanic/Latino, agree that smart charging is a net good for society, and perceive smart charging's benefit of increasing grid reliability as important (all other predictors constant), are estimated to have higher minimum annual payments to allow their local power company to modify EV charging (i.e., SMC). Young adults between 18 and 24 with a maximum household pre-tax income of $30,000 and agree the power grid can support the government's EV adoption goals place a lower value on annual bill credits to permit SMC.

Table 5: Minimum one-time bill credit for SMC participation.

Covariates	Coef.	Std. Coef.	Z-stat
Intercept	84.607	--	10.25
Male	-5.050	-0.25	-1.27
Asian/Pacific Islander/Asian American	-15.174	**-0.75**†	-2.82
Age 18-24	14.330	**0.71**†	2.26
Household Income ($150k and up)	0.788	0.04	2.20
Annual VMD (in 1,000 miles)	6.345	0.31	3.30
Ideal BEV Range (in 25 miles)	-13.547	**-0.67**†	-3.24
Agree that EVs pay added fees on power bills to pay for grid upgrades	-8.050	-0.40	-1.92
Don't trust power company to always guarantee a fully-charged EV	22.667	**1.12**†	5.57
Importance of smart charging increasing grid reliability (1-5 scale)	5.776	0.29	3.24

N = 922
LL (all constants [AC]) = -5801.44, LL (final) = -5753.31
Pseudo R-Square = 0.008
AIC = 11528.62, BIC = 11583.10

Note: All Std. Coef., which are greater than 0.5, are in bold with the † symbol, and indicate practically significant predictors. Results are population weighted/sample corrected. VMD = Vehicle-miles driven.

Table 6: Minimum annual bill credit for SMC participation.

Covariates	Coef.	Std. Coef.	Z-stat
Intercept	13.086	--	17.07
Male	-0.807	-0.46	-2.20
Age 18-24	-1.019	**-0.58**†	-2.02
White Hispanic/Latino	-2.003	**-1.14**†	-1.44
Household Income ($30k and under)	-0.918	**-0.52**†	-2.08
Ideal BEV Range (in 25 miles)	0.768	0.44	4.38

Agree the power grid can support the government's EV adoption goals	-1.334	**-0.76†**	-3.27
Don't trust power company to always guarantee a fully-charged EV	2.021	**1.15†**	5.54
Agree that smart charging is a net good for society	0.833	0.47	2.01
Importance of smart charging increasing grid reliability (1-5 scale)	0.421	0.24	2.48

N = 922
LL (all constants [AC]) = -3341.23, LL (final) = -3289.91
Pseudo R-Square = 0.015
AIC = 6601.83, BIC = 6656.31

Note: All Std. Coef., which are greater than 0.5, are in bold with the † symbol, and indicate practically significant predictors. Results are population weighted/sample corrected.

5.6 Automatic enrollment in a supplier-managed charging program

The survey asked respondents about their willingness to pay (WTP) to leave an SMC program where the power company automatically enrolls new PEVs for at-home charging. Although power companies are unlikely to automatically enroll new PEVs, the question can help understand how resistant individuals are to incurring fees for their PEV charging impacts and their willingness to accept SMC without financial incentives. The survey randomly displayed one of two prompts: freedom attitudes versus the base (altruistic attitudes that were introduced throughout the survey). Table A.2 in the appendix shows that randomization did not introduce bias.

The base paragraph (altruistic attitudes) is as follows:

> Assume now that your power company automatically enrolls you in its EV smart charging program (same terms as before). *The power company does this to prevent EVs from charging when electricity demand is high. Doing so reduces the costs that all customers pay*. Instead of a one-time credit for voluntary participation, you can pay a monthly fee to leave the smart charging program. *What is the highest fee you would pay to charge whenever you want?* If you would not pay to leave the program, select $0.

The test paragraph (pro-freedom) is as follows:

> Assume now that your power company automatically enrolls you in its EV smart charging program (same terms as before). Instead of a one-time credit for voluntary participation, you can pay a monthly fee to leave the smart charging program. *How much do you value the freedom to charge as you want?* If you would not pay to leave the program, select $0.

As shown in Table 7, there was a statistically significant change in the average willingness to pay a monthly opt-out fee to charge one's EV across several respondent and household-level attributes due to differences in the prompt. Americans ages 18–24 or 35–64 who have at most a high school education and are not Black reported statistically different average fees. Homeowners, respondents who would prefer UMC with an app/timer or need more information before accepting SMC, and respondents who self-reported their energy rate as either tiered or indexed to the wholesale market also reported statistically different average fees. Respondents who receive the altruistic text, on average, are more likely to report higher minimum opt-out fees regardless of their demographics or position on different EV-power grid statements. For example, the population mean for the pro-freedom group was smaller than the altruistic group across all responses to the statement "smart charging is a net good for society," with a statistically significant difference at $\alpha = 0.06$ for strongly agree to neither agree nor disagree responses. The results show that public opinion on monthly fees to leave an SMC program can be meaningfully moved by priming individuals with altruistic explanations for an opt-out SMC program. However, individuals who were willing to accept SMC (without first considering any financial incentives) and were exposed to a pro-freedom prime were not more likely to pay a smaller monthly opt-out fee than those viewing the altruistic text. The results indicate that some individuals with altruistic behaviors have entrenched views and may not be moved by pro-freedom messaging.

The pro-freedom text group saw a slight increase in WTP in individuals who strongly 1) consider how their EV charges, 2) believe SMC offers more benefits than risks for their lifestyle, 3) think EV owners should not pay higher power bill fees for grid upgrades, and 4) prioritize a stable power grid over privacy. Conversely, all other groups had a slight decrease in mean WTP in the direction from altruistic to pro-freedom text. Within demographic subgroups, individuals aged ages 45–54 and Asian Americans displayed a significant increase in WTP to leave an SMC program with the pro-freedom prime, while other statistically significant subgroups showed a decrease. A rationale for this directional priming is that more individuals in these demographic groups elect to pay extra for the freedom to freely charge as they want because of the perceived value of flexibility. Some pay less with pro-freedom priming not because of undervaluing charging freedom, but because of a reluctance to pay extra for it. On the other hand, those in the altruistic text group who would leave the program are willing to raise their opt-out fee because of the potential for higher costs for all. Over a quarter (26.6%) of people in the altruistic text group said they would not pay a monthly fee to leave an auto-enrolled SMC program, while a slightly higher percentage (31.4%) in the pro-freedom text group would not pay. While clarifying the rationale behind the auto-enrolled SMC program leads to higher opt-out fees, more people do not want to incur a financial penalty to charge freely when told that leaving the auto-enrolled SMC program costs money. Although it is possible frugal people were concentrated in the pro-freedom group, it is more plausible that fees outweigh the psychological importance of freedom. Assignment to either group had negligible effects on those with at least some college education, ages 25–34, renters, and Black Americans, but still generated differences in the average monthly opt-out fees they would be willing to pay to charge freely.

Table 7: Monthly WTP to leave auto-enrolled SMC program.

		Altruistic text	**Pro-freedom text**	**Welch's *t-test***
Respondent Demographics	**Gender**			
	Male	$4.05	$3.60	**2.9**
	Non-Male	$4.09	$3.62	**3.1**
	Age			
	18 to 24	$5.18	$3.73	**6.7**
	25 to 34	$4.70	$4.49	0.9
	35 to 44	$4.22	$3.54	**2.3**
	45 to 54	$3.45	$4.12	**2.5**
	55 to 64	$3.54	$2.59	**3.3**
	65 years and over	$2.46	$2.72	1.0

	Ethnicity			
	White	$4.05	$3.39	**5.0**
	Black	$4.49	$4.76	1.1
	Asian	$3.21	$4.12	**2.4**
	Other	$4.36	$3.40	**2.0**
	Highest Education Attained			
	High school or less	$4.28	$3.41	**4.6**
	Some college	$4.34	$4.01	1.6
	Bachelor's degree	$3.75	$3.57	0.8
	Master's degree or higher	$3.25	$3.27	0.1
Household Attributes	**Residential Ownership**			
	Homeowner	$3.96	$3.23	**4.3**
	Renter	$4.47	$4.40	0.4
	Other Living Arrangement	$4.05	$3.77	0.9
	Household Vehicle Ownership			
	ICEV	$3.94	$3.58	**2.9**
	EV	$4.96	$4.33	**2.4**
	Zero-Vehicle	$3.96	$3.00	**2.1**
	Household Energy Rate Type			
	Flat	$4.07	$3.74	1.6
	Tiered	$4.58	$3.89	**2.5**
	TOU	$3.69	$3.56	0.6
	Wholesale	$4.90	$4.10	**1.9**
	Unsure*	$3.98	$3.40	**2.8**
Charging Preference	**Preferred Charging Style**			
	SMC-night only	$3.81	$3.55	1.0
	SMC-daily optimization	$4.76	$4.28	1.6
	SMC-grid strain only	$5.45	$4.79	1.2
	UMC	$4.56	$3.10	**3.4**
	Maybe	$4.28	$3.76	**2.2**
	Unmanaged	$2.95	$3.12	0.6
EV-Power Grid Statements	**Power grid can support the government's EV adoption goals**			
	Strongly agree	$3.94	$4.51	**1.8**
	Somewhat agree	$4.89	$4.26	**3.4**
	Neither agree nor disagree	$4.23	$3.38	**4.2**
	Somewhat disagree	$3.59	3.80	0.7
	Strongly disagree	$2.70	$1.94	**2.7**
	Smart charging is a net good for society			
	Strongly agree	$3.97	$3.60	1.6
	Somewhat agree	$4.78	$4.02	**3.9**
	Neither agree nor disagree	$3.54	$3.15	**2.0**
	Somewhat disagree	$4.05	$3.85	0.5

	Strongly disagree	$2.83	$2.74	0.2
	After plugging in my EV, I don't want to think about how my EV charges			
	Strongly agree	$3.67	$3.50	0.8
	Somewhat agree	$4.32	$3.88	**2.3**
	Neither agree nor disagree	$4.17	$3.41	**3.7**
	Somewhat disagree	$4.38	$3.59	**2.2**
	Strongly disagree	$3.10	$3.31	0.4
	Supplier-managed charging has more risks than benefits for my lifestyle			
	Strongly agree	$3.22	$2.45	**2.3**
	Somewhat agree	$3.83	$3.59	1.2
	Neither agree nor disagree	$4.46	$3.81	**3.7**
	Somewhat disagree	$4.35	$3.55	**2.7**
	Strongly disagree	$2.96	$4.56	**3.1**
	EV owners should pay higher fees on their monthly power bills to pay for power grid upgrades			
	Strongly agree	$3.06	$2.91	0.5
	Somewhat agree	$4.58	$3.58	**4.5**
	Neither agree nor disagree	$3.98	$3.71	1.5
	Somewhat disagree	$4.79	$4.20	**2.2**
	Strongly disagree	$2.89	$3.12	0.6
	I don't trust my power company to always guarantee my vehicle is fully charged before I need it			
	Strongly agree	$3.46	$3.16	1.1
	Somewhat agree	$4.33	$3.82	**2.4**
	Neither agree nor disagree	$3.84	$3.32	**2.8**
	Somewhat disagree	$5.02	$4.47	**2.0**
	Strongly disagree	$3.75	$3.47	0.6
	Privacy is more important than giving up some control to have a stable power grid			
	Strongly agree	$3.22	$3.09	0.5
	Somewhat agree	$4.46	$4.42	0.2
	Neither agree nor disagree	$4.17	$3.63	**2.8**
	Somewhat disagree	$4.54	$2.77	**7.1**
	Strongly disagree	$2.56	$4.40	**3.0**

Note: Welch's *t-test* values that are statistically significant at the 5% level are bolded. *Although unsure is not an energy rate, it is included to show that respondents who do not manage household energy payments or do not need to know (i.e., the electric bill doesn't greatly impact their household budget decisions) could be influenced by motivational text to accept different levels of monthly opt-out fees in an auto-enrolled SMC program.

6. LIMITATIONS

The study has several limitations that might impact the outcomes. First, the survey sample exhibits some bias as it was exclusively distributed online to a potential respondent pool maintained by a survey sampling company. The survey responses from this particular group might not accurately represent the perspectives of other similar individuals. Additionally, the survey relies on respondents' self-reported data for various variables, such as annual miles driven, income, and preferences/intentions regarding future behavior. External factors that may influence EV charging preferences include local electricity rates and the absence of other electric utility rebates. However, there are serious data reliability concerns when collecting self-reported electric bill costs and knowledge of electric utility rebates. For example, nearly 40% of respondents were unsure how their electric bill's energy charge was calculated. Instead, future work should ask residents to identify their electric utility so that researchers can link this data with average electric utility-level metrics in future models.

As noted by Lavieri and de Oliveira (2023), the literature would benefit from longitudinal studies investigating differences between stated and revealed charging preferences. Such studies could enhance the realism of hypothetical scenarios in surveys and consequently bolster the credibility of findings. Longitudinal data might also establish the direction of causality between EV charging behaviors and attitudes toward the transportation-clean energy transition. Furthermore, researchers should study any discontinuance with smart charging programs as they develop, which may help identify characteristics of smart charging programs to evaluate in future stated preference surveys. Innovative strategies to address the concerns of former SMC users may also effectively address (un)reported apprehensions among those who hesitate to embrace UMC or SMC programs.

This study did not design a discrete choice experiment that varied important attributes of PEVs, such as vehicle range, home charging accessibility and speed, and other incentives available to PEV users, like rebates for home charging equipment. While preferred charging styles and financial incentives are compared across the same baseline (e.g., 250-mile range BEV with home charging equipment that provides up to 20 miles of range for every hour of charging) and could increase the generalizability of results, a sophisticated discrete choice experiment would capture charging preference heterogeneity under different EV ownership settings. Furthermore, this study examined the preferred EV charging style in relation to the acceptance of SMC. Future studies could prompt respondents to indicate their preferred charging style independent of a program like SMC. Additionally, researchers could gather more information by having respondents rank their preferred charging styles based on the expected frequency of use, provided the ranking set is small. Finally, a more sophisticated model is warranted, preferably after collecting a richer dataset from a discrete choice experiment. The MNL model's limitations are well known, and the authors encourage future researchers to examine other models, such as a mixed logit model if high quality data is obtained for multi-choice observations for each individual (Hensher and Greene, 2003; Mauerer and Tutz, 2023). While the Likert-type value statements improve model fit, these observed variables could mask latent variables, such as trust or green lifestyle, which were not modeled in this study. Additionally, while the models estimated in this study have low predictive fit, they can be a starting point in understanding who may choose to accept smart charging and what financial incentives they may need to cede charging control. Identifying a few significant predictors allows power companies to narrow recruitment efforts for phased-in EV smart charging programs and is a practical application of this research study.

7. CONCLUSION AND POLICY IMPLICATIONS

This study used summary statistics, multinomial logit, and Tobit models to understand the impact of demographics, travel characteristics, built-environment factors, and transportation-clean energy nexus opinions and attitudes on Americans' preferred PEV charging program and desired payment for participating in an SMC program. A *t-test* was performed between attributes for individuals receiving different paragraphs prompting them to answer with their WTP to leave an auto-enrolled SMC program.

The estimated MNL model finds that households paying time-varying power bills, like TOU, prefer UMC with an app or timer relative to other options. Households with wholesale-indexed rates may be more risk-tolerant and prefer SMC to optimize local grid conditions daily or only during grid strain days. Households with a BEV have experience charging their vehicle and may have a more informed stated preference regarding an SMC program, even though they are not widely available, unlike UMC programs. These households are willing to accept UMC and SMC for grid optimization and night-time interventions, but there was no statistically significant covariate for grid strain days. Individuals that believe it is extremely inconvenient to install a charger at home and are told to imagine they have a 250-mile-range BEV with a charger at home may be willing to accept SMC for daily optimization or grid strain days, but only if they can get past the home charging barrier. Cities need to ensure that buildings have the electrical wiring to support EV adoption, while power suppliers need to lower capital costs and regulatory barriers (e.g., permits) to support the retrofit of existing residences.

Attitudinal variables greatly improved model fit but are hard to measure in the real world to predict the adoption of managed charging programs. The results indicate that individuals who do not want to think about how an EV charges are more willing to accept night-only SMC, which can help avoid TOU-created electricity demand spikes from PEVs. The more important the benefit of maximizing renewables or increasing power grid reliability, the more likely an individual is to accept SMC offerings or consider SMC. Power companies could survey their customers annually or when sending out monthly bills to receive this attitudinal data. This information could allow them to tailor incentives to the local market to increase smart charging adoption while ensuring the cost of incentives is less than the added value.

Individuals that prefer SMC offerings may be more altruistic than those accepting UMC, and they would expect less money for their participation in a future SMC program. Perhaps the lower payment is because they were already willing to participate in SMC and would not require additional compensation for less flexibility. Since individuals preferring UMC demand more compensation to participate in an SMC program, power companies could seek higher enrollment in UMC through lower off-peak prices rather than paying consumers to adopt SMC. Tobit models found that Asian American males who agree that EV owners should pay higher fees on power bills and are interested in long-range BEVs tend to accept smaller one-time bill credits to permit SMC. Perhaps individuals who believe EVs may impact the power grid need less financial incentive to permit their local power company to modify future charging behavior. Females who do not identify as White Hispanic/Latino, agree that smart charging is a net good for society, and perceive smart charging's benefit of increasing grid reliability as important (all other predictors constant) are estimated to have higher minimum annual payments to allow their local power company to modify EV charging. Power suppliers can use this information to advertise to those likely to embrace SMC programs at a lower cost.

A novel smart charging prompt asked respondents to assume they were automatically enrolled in an SMC program with their new 250-mile-range BEV. Respondents who receive the altruistic text, on average, are more likely to report higher minimum opt-out fees regardless of their demographics or position on different EV-power grid statements. Non-Black Americans aged 18–24 or 35–64 with at most a high school education, homeowners with tiered or wholesale-indexed electricity rates, and Americans who prefer UMC with an app/timer or might accept SMC if given more information all showed a statistically significant decrease in their WTP to leave the auto-enrolled program when conditioned on pro-freedom values of paying to charge as they want. The altruistic text reflected the survey's mention of the benefits of smart charging (i.e., reducing power costs for all by shifting EVs from charging when the power demand is already high). Individuals who believe there are societal benefits to smart charging are willing to pay more per month to leave the SMC program because they are cognizant of the potential impact they have on their neighbors. However, those who do not believe smart charging is a net good for society are less affected by position-salient messages. Although it is unlikely that power companies will automatically enroll customers in a PEV SMC program, priming respondents to reflect on how their actions impact the collective can help them internalize those externalities. Moreover, the reported WTP to leave this program may inform the design of monthly fees for unmanaged charging.

The survey design centered on consumer flexibility in smart charging programs. When respondents were asked whether they would allow their local power supplier to directly control charging, the choices were not binary (i.e., yes or no). This choice structure is important since many individuals have two or more charging options today. Respondents were told that adjustments to PEV charging would not interfere with their travel needs and would be made based on historical data. Providing respondents with several alternatives in response to this question, namely never managed, unmanaged charging, UMC, and three SMC alternatives that were not rigid contracts (e.g., must be plugged in for 8 hours overnight at least three days a week), revealed nuanced preferences that other studies missed. The survey data on preferred one-time and yearly credits for SMC participation may indicate minimum incentive levels if power companies ignore individual preferences and uniformly alter PEV charging (i.e., contract-based PEV smart charging). Future surveys should continue to understand consumer needs and preferences through this approach to provide power companies with more flexible and low-cost smart charging options.

8. CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Matthew D. Dean: Conceptualization, Survey Design, Methodology, Data Curation, Formal analysis, Investigation, and Writing. **Kara Kockelman:** Conceptualization, Supervision, Survey Design, Paper Editing, and Project Administration.

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10. DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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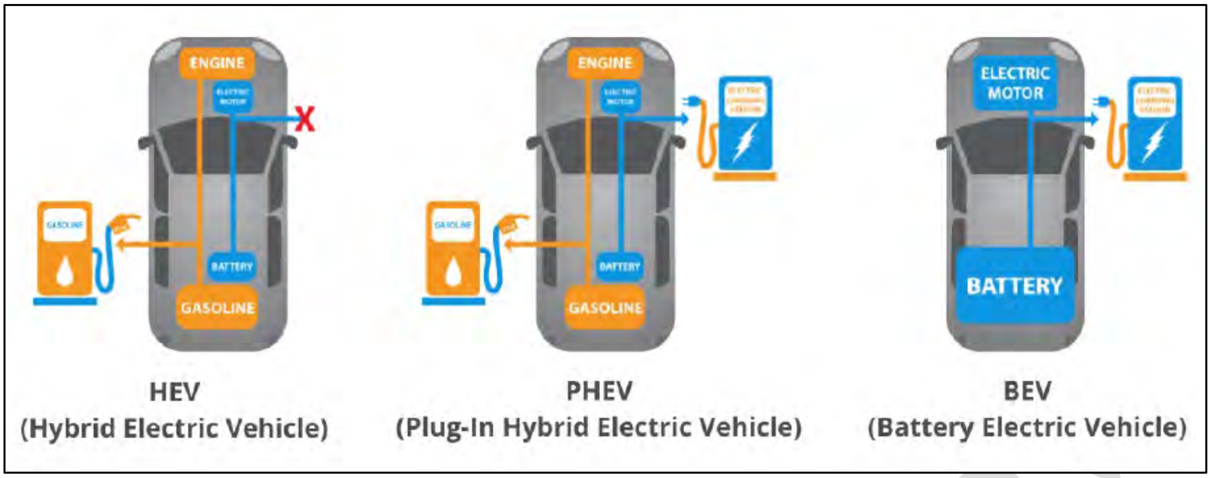
12. APPENDIX

12.1 Survey paths for PEV and non-PEV households

The survey asked respondents different questions based on whether the household had PEVs. For example, households with a PEV answered questions about their current charging behavior. The following paragraphs include a sample of questions to illustrate the survey paths and language used to explain smart charging concepts. Page breaks and survey section breaks are not shown.

Q12 This survey **asks about vehicle types** and **may ask you to assume you have a battery electric vehicle (BEV)**. Please review the following information before continuing the survey.

Gasoline/Diesel Power. Powered entirely by an internal combustion engine.
Hybrid-Electric. Powered by a combination of an internal combustion engine and electric motor. The battery of the electric motor is charged by recovering braking energy.
Plug-In Hybrid-Electric. Powered by a combination of an internal combustion engine and electric motor. The battery of the electric motor is charged from the electricity grid. The electric-only range is typically 10-40 miles.
Battery Electric/Fully Electric. Powered only by an electric motor. The battery of the electric motor is charged from the electricity grid. The range on a single charge can be as low as 50 miles or as high as 520 miles, depending on the vehicle.



Q13 **Does your household own/lease an electric vehicle?**
Please include hybrid electric vehicles (**HEVs**), plug-in hybrid electric vehicles (**PHEV**s) or battery electric vehicles (**BEVs**). Please do NOT include fuel cell electric vehicles.

- O Yes, my household **owns/leases an EV (HEV, PHEV, and/or BEV)**.
- O No

Display This Question:
If Q13 = "Yes, my household owns/leases an EV (HEV, PHEV, and/or BEV)."

Q14 **What type of EV(s) does your household own/lease?** (Please select all that apply) We also would like to know the **all-electric range of your household plug-in EVs**. For example, the Tesla Model Y 74 kWh battery can provide 326 miles of range on a single charge. The Nissan LEAF standard 40 kWh battery can provide 149 miles.

- ☐ Hybrid electric vehicle (**HEV**)
- ☐ Plug-in hybrid electric vehicle (**PHEV**), with an **all-electric range (in miles) of:**
- ☐ Battery electric vehicle (**BEV**), with a **range (in miles) of:**

Display This Question:
If Q13 = "Yes, my household owns/leases an EV (HEV, PHEV, and/or BEV)."
And If Q14 = "Battery electric vehicle (BEV), with a range (in miles) of:"
Or Q14 = "Plug-in hybrid electric vehicle (PHEV), with an all-electric range (in miles) of:"

Q15 **How often is the plug-in EV you drive the most charged at home?** The EV I drive the most is charged at home ...

- O **every day** ("top off" charging).
- O **more than 3 times per week** (but not every day).
- O **twice a week**.
- O **once a week**.
- O **less than once a week**.
- O Other: ________________________________
- O My household **doesn't charge** my EV at home.

Display This Question:
If Q15 != "My household doesn't charge my EV at home."
And Q15 is Displayed

Q16 **When is the EV you drive the most typically plugged in at home?** (Please select all that apply) The EV I drive the most is typically plugged in at home on ...

	weekdays	weekends
... during the morning hours (6 AM - 10 AM)	☐	☐
during midday hours (10 AM - 2 PM)	☐	☐
during afternoon hours (2 PM - 5 PM)	☐	☐
during evening hours (5 PM - 9 PM)	☐	☐
during night hours (9 PM - 6 AM)	☐	☐

Display This Question:
If Q15 = "My household doesn't charge my EV at home."

Q17 How **convenient** would it be to **charge a plug-in EV** at **home**?

- O Extremely convenient
- O Somewhat convenient
- O Neither convenient nor inconvenient
- O Somewhat inconvenient
- O Extremely inconvenient

Display This Question:
If Q17 is Displayed

Q18 Please rank the **most significant barrier(s)** to charging your plug-in EV at **home**. Drag and drop the items into the two categories: a barrier or not a barrier.

List of possible barriers	Ranked list of barrier(s)	NOT a barrier (unranked)
______ New **electrical wiring** required/not configured to charge an EV		
______ Need **landlord permission**		
______ Charging equipment too **costly**		
______ Physical **space** limitation		
______ No **dedicated/reserved parking space**		

Other (please write in)

Display This Question:
If Q13 is "No"

Q19 **If you had a plug-in EV, could you charge your vehicle at home?**

- O Yes, there is **already a charger** at my home (could apply to multi-family units).
- O Yes, I **could install a charger** at my home.
- O No, I **have no way** to charge an EV at home.

Display This Question:
If Q19 != "Yes, there is already a charger at my home (could apply to multi-family units)."

Q20 How **convenient** would it be to **charge a plug-in EV** at **home**?

- O Extremely convenient
- O Somewhat convenient
- O Neither convenient nor inconvenient
- O Somewhat inconvenient
- O Extremely inconvenient

Display This Question:
If Q20 is Displayed

Q21 Please rank the **most significant barrier(s)** to charging a plug-in EV at **home**. Drag and drop the items into the two categories: a barrier or not a barrier.

List of possible barriers	Ranked list of barrier(s)	NOT a barrier (unranked)
______ New **electrical wiring** required/not configured to charge an EV		
______ Need **landlord permission**		
______ Charging equipment too **costly**		
______ Physical **space** limitation		
______ No **dedicated/reserved parking space**		
Other (please write in)		

Q22 **When is your household likely to buy (or lease) a new (or used) vehicle for your primary use?**

- O In less than 1 year
- O In 1 to 3 years
- O In 3 to 5 years
- O In 5 to 10 years
- O In more than 10 years
- O I am very unlikely to buy/lease a vehicle in the

Q23 **If your household had to buy a vehicle in the next 5 years**, would it be a **plug-in EV** (either a plug-in hybrid [PHEV] or battery electric vehicle [BEV])?

My household would ...

- O **definitely** buy a plug-in EV
- O **probably** buy a plug-in EV
- O **probably NOT** buy a plug-in EV
- O **definitely NOT** buy a plug-in EV
- O I **don't know** if I my household would buy a plug-in EV

Display This Question:
If Q23 != "definitely buy a plug-in EV"
And Q23 != "probably buy a plug-in EV"

Q24 **Please rank the top 3 reasons why your household would ${Q23/ChoiceGroup/SelectedChoices} in the next 5 years.**

- ☐ Insufficient number of charging stations
- ☐ No at-home charging options
- ☐ Long-distance trips
- ☐ High purchase price
- ☐ Need for travel planning
- ☐ Fear of getting stranded (0% battery)
- ☐ Risk of battery degradation & replacement costs
- ☐ Long charging times
- ☐ Concerned about battery waste & mining
- ☐ Cost to add charging at home

Display This Question:
If Q23 = "definitely buy a plug-in EV"
Or Q23 = "probably buy a plug-in EV"

Q25 You said your household would ${Q23/ChoiceGroup/SelectedChoices} for your use in the next 5 years (if you had to). **Out of 100%, how likely would this new vehicle be a plug-in hybrid electric vehicle (PHEV) versus a battery electric vehicle (BEV)?**

For example, the new vehicle is 70% likely to be a PHEV and 30% likely to be a BEV.

% likely to be a **PHEV** : _______
% likely to be a **BEV** : _______
Total : 100%

Display This Question:
If Q25 is Displayed

Q26 Would this **new plug-in EV be your primary vehicle** or someone else's in the household?

- O It will be my **primary vehicle** (this new EV is driven most often by you)
- O It will be **someone else's primary vehicle**
- O It will be our **household's backup vehicle** (no one person uses it the most)

Q27 **Assume now that you would definitely buy a new battery electric vehicle** (BEV). What is the **range (in miles)** that you would like to have? Range is the maximum distance you can drive starting from a full battery.

Remember that a BEV is powered only by an electric motor.

▼ 50 to 99 miles
100 to 124 miles
125 to 149 miles
...
400 or more miles

Q28 **Where would you charge** this new battery electric vehicle?

For example, I would charge 95% of the time at home, 0% at work, and 5% at public chargers.

I would **charge _% of the time at home**. : _______
I would **charge _% of the time at work**. : _______
I would **charge _% of the time at public chargers** : _______
Total : 100%

Q29 If you had to buy a new battery electric vehicle (BEV), you said you would like to have one with a range of ${Q27/ChoiceGroup/SelectedChoices}. Range on a single charge is just one aspect of driving an electric vehicle. Other important aspects include the number of public charging stations and the time to charge (from 0-100%).

If you had to only pick 2 out of the 3 options (long-range BEVs, sufficient number of public charging stations, and fast charging), **which 2 would you pick?** The option not selected remains the status quo.

- ☐ **Long-range BEVs** (like current gas-powered vehicles)
- ☐ **Fast charging** (like the time to pump gas)
- ☐ A **sufficient number of public charging stations** (like gas stations)

Q30 Which ***best*** describes your **employment status**?

- O Employed, working 40 or more hours per week (including self-employed)
- O Employed, working 1-39 hours per week
- O Student, working part time
- O Student, not working
- O Not employed, looking for work
- O Not employed, not looking for work
- O Retired
- O Disabled, not able to work

Display This Question
If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"

Q31 In a typical week, **how often do you work from home (WFH)?**

- O I WFH **every working day**
- O I WFH **1-2 days a week**
- O I WFH **3-4 days a week**
- O I **do not or rarely WFH**

Display This Question
If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"
Or Q30 = "Student, not working"
And If Q31 != "I WFH every working day"

Q32 **How do you typically get to work/school?** For example, if you take your bike on public transit please select the two options. I usually ...

- ▢ **drive** to work/school by myself
- ▢ **carpool** to work/school with others (includes dropping off kids at daycare or vanshare commuting programs)
- ▢ **walk or bike** to work/school
- ▢ take **public transit** to work/school

Display This Question
If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"
And If Q31 != "I WFH every working day"
And If Q32 = "drive to work/school by myself"
Or Q32 = "carpool to work/school with others (includes dropping off kids at daycare or vanshare commuting programs)"

Q33 **Can you (or could you) charge a plug-in EV at work/school?** Please answer based on the **most visited work location** if you have multiple job sites or your **in-office** work location if you work from home (WFH) some days of the week. If you typically park off-site, like at a third-party garage/lot, please answer whether you can charge at this off-site location or similar off-site locations.

- O **I don't know**
- O **Yes**, I can charge an EV at work/school **in the same lot/garage** as I normally park.
- O **Yes**, I could charge an EV at work/school but would have to park in a **different lot/garage**.
- O **No**, I do not (or would not) charge because there are **not enough chargers** (or I cannot reserve access).
- O **No**, I could not charge an EV at work/school (**no chargers** at my work or school).

Display This Question
If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"
And If Q31 != "I WFH every working day"
And If Q32 != "drive to work/school by myself"

Or Q32 != "carpool to work/school with others (includes dropping off kids at daycare or vanshare commuting programs)"

Q34 **If you drove to work, could you charge a plug-in EV at work/school?** Please answer based on the **most visited work location** if you have multiple job sites or your **in-office** work location if you work from home (WFH) some days of the week. If you typically park off-site, like at a third-party garage/lot, please answer whether you can charge at this off-site location or similar off-site locations.

O **I don't know**

O **Yes**, I can charge an EV at work/school **in the same lot/garage** as I would normally park.

O **Yes**, I could charge an EV at work/school but would have to park in a **different lot/garage**.

O **No**, I do not (or would not) charge because there are **not enough chargers** (or I cannot reserve access).

O **No**, I could not charge an EV at work/school (**no chargers** at my work or school).

Display This Question
If Q13 = "Yes, my household owns/leases an EV (HEV, PHEV, and/or BEV)."
And If Q14 = "Battery electric vehicle (BEV), with a range (in miles) of:"
Or Q14 = "Plug-in hybrid electric vehicle (PHEV), with an all-electric range (in miles) of:"
And If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"
And If Q31 != "I WFH every working day"
And If Q32 = "drive to work/school by myself"
Or Q32 = "carpool to work/school with others (includes dropping off kids at daycare or vanshare commuting programs)"

Q35 **How often do you charge the plug-in EV you drive the most at work/school? I charge the plug-in EV I drive the most at work/school ...**

O **every workday**

O **a few times per week**

O **once a week**

O **a few times per month**

O Other: ________________________________

O I **don't charge** my EV at work.

Display This Question
If Q33 = "Yes, I can charge an EV at work/school in the same lot/garage as I normally park."
Or Q33 = "Yes, I could charge an EV at work/school but would have to park in a different lot/garage."
Or Q33 = "No, I do not (or would not) charge because there are not enough chargers (or I cannot reserve access)."
And If Q35 is Displayed
And Q31 != "I WFH every working day"

Q36 **Is workplace charging a benefit provided to employees or do you pay for the cost of charging yourself?**

- O **My employer** pays for the cost of EV charging at work.
- O **I directly pay** for the cost of EV charging at work.

Display This Question
If Q30 = "Employed, working 40 or more hours per week (including self-employed)"
Or Q30 = "Employed, working 1-39 hours per week"
Or Q30 = "Student, working part time"

Q37 **Do you work an overnight shift for your job at work/school?** An example of an overnight shift is 10 PM to 6 AM.

- O **No**, I never work an overnight shift at work/school.
- O **Yes**, I sometimes work an overnight shift at work/school.
- O **Yes**, I only work an overnight shift at work/school.

Display This Question
If Q37 = "No, I never work an overnight shift at work/school."
And Q31 != "I WFH every working day"

Q38 **During weekdays, when do you typically leave in the morning and arrive back home?** For example, I usually leave home around 8:30 am and arrive home around 6:00 pm.

- O On a typical weekday, **I leave home around ___________________**
- O On a typical weekday, I **arrive home around ___________________**

Display This Question
If Q37 != "No, I never work an overnight shift at work/school."
And Q31 != "I WFH every working day"
And Q37 is Displayed

Q39 **During overnight shifts, when do you typically leave in the evening and arrive back home?** For example, I usually leave home around 8:00 pm and arrive home around 6:00 am.

- O On a typical **weekday**, I **leave home** around ___________________
- O On a typical **weekday**, I **arrive home** around ___________________

Q40 **Electricity Prices**
Currently, most EVs are charged at home. The cost of charging (or "refueling") depends on the price your electric power company sets. On average, Americans pay 13 cents per unit of electricity (kWh) used. A full charge (i.e., 0-100% range) of a 250-mile battery-electric vehicle (BEV) for example, would cost approximately $8.30. For a gas-powered vehicle with 30 mpg fuel efficiency driving 250 miles to have lower fuel costs, gas prices would have to be less than $1 per gallon. **We are interested in how prices may influence charging habits. The next page will ask you about your household's electric bill.**

Q41 Residential electric bills usually contain at least two charges. The first is a customer charge ($). The second is a **volume-based charge ($/kWh)**. **How does your local power company set the price for the amount of electricity consumed in a month ($/kWh)?** Please ignore any additional fees that may be applied to consumption (like fuel add-ons and taxes).

- O **Fixed prices**: pay the same price per unit of electricity ($/kWh)
- O **Tiered prices**: the cost per kWh changes as you use more electricity (for example, $0.07/kWh for the first 1200 kWh and $0.12/kWh after 1200 kWh)
- O **Time-of-use (TOU) prices**: costs are higher during "peak hours" (for example, $0.20/kWh from 4 PM - 8 PM and $0.10/kWh all other hours)
- O **Wholesale prices**: you pay for the actual cost of electricity in the wholesale energy market, which changes price every 15 min to an hour.
- O **Unsure**, I have no idea how my household's monthly electric bill is calculated.
- O Other (for example, TOU with tiered prices) _____________________

Display This Question
If Q13 = "Yes, my household owns/leases an EV (HEV, PHEV, and/or BEV)."
And Q14 != "Hybrid electric vehicle (HEV)"
And Q15 != "My household doesn't charge my EV at home."

Q42 **Do you pay a different price for at-home EV charging?**

- No, the energy is **added** to my household's energy consumption.
- Yes, we pay a **separate tiered price** for our EV demand.
- Yes, we pay a **separate time-of-use (TOU) price** for our EV demand.
- Yes, we pay a **separate wholesale price** for our EV demand.
- Yes, we pay a **separate unlimited charging package** for our EV demand.
- Unsure
- Other (please specify) ________________________________

Q55 Given the choices and information presented in the survey, **we are interested to know if you have changed your mind on plug-in EVs**. **If your household had to buy a vehicle for you in the next 5 years**, would it be a **plug-in EV** (either a plug-in hybrid [PHEV] or battery electric vehicle [BEV])? My household would ...

- **definitely** buy a plug-in EV
- **probably** buy a plug-in EV
- **probably NOT** buy a plug-in EV
- **definitely NOT** buy a plug-in EV
- I **don't know** if my household would buy a plug-in EV

Display This Question
If Q55 = "definitely buy a plug-in EV"
Or Q55 = "probably buy a plug-in EV"

Q56 You said your household would ${Q55/ChoiceGroup/SelectedChoices} for your use in the next 5 years (if you had to). **Out of 100%, how likely would this new vehicle be a plug-in hybrid electric vehicle (PHEV) versus a battery electric vehicle (BEV)?**

For example, the new vehicle is 70% likely to be a PHEV and 30% likely to be a BEV.
% likely to be a **PHEV** : _______
% likely to be a **BEV** : _______
Total : 100%

12.2 Additional Survey Data

This section of the appendix reports results collected from the survey that were not part of the paper's key outcomes. However, readers may find this data useful in benchmarking the study's results to current EV purchasing decisions and reported barriers in EV adoption literature.

12.2.1 Vehicle purchase decisions and PEV barriers

A nationally representative survey of Americans conducted between January and February of 2022 found that 71% of Americans expressed an interest[19] in buying or leasing a BEV (Butler, 2022). Additionally, 14% would "definitely" buy a BEV, up from 4% in a 2020 survey from the same survey company (Butler, 2022). This survey, conducted in November and early December of 2022, found that 10.8% of Americans would "definitely" buy a plug-in EV (BEV or PHEV) if the household were buying a vehicle within the next five years. If one includes the neutral statement with "probably" and "definitely," the results indicate that 59.9% have a non-negative likelihood of buying a plug-in EV, which is lower than at least one other nationally representative consumer survey. Policymakers setting EV adoption targets, researchers forecasting EV's added load on the electricity system, and auto manufacturers ramping up production of EVs to meet new demand may use this consumer information, along with other surveys, to better predict EV purchasing demand.

Electrifying personal vehicles will not impact all Americans, especially the estimated 12% of U.S. households unlikely to buy or lease a new or used vehicle. Only one-third of zero-vehicle population-weighted households (34.9%) are very unlikely to obtain a vehicle for the respondent's primary use in the future. The reasons for remaining car-less or holding on to the household's existing vehicle(s) include age, health, financial, and car-free independence. Households that were already likely to obtain a new or used vehicle for the respondent's primary use in the next five years were more likely to buy a PEV if the household faced a car-buying decision in this same timeline. Fig. A.1 plots the likely PEV buyers in blue on the positive axis and unlikely PEV buyers in orange on the negative axis, ignoring unsure responses in the five-point Likert scale.

[19] Interest included "definitely," "would seriously consider," and "might consider" statements.

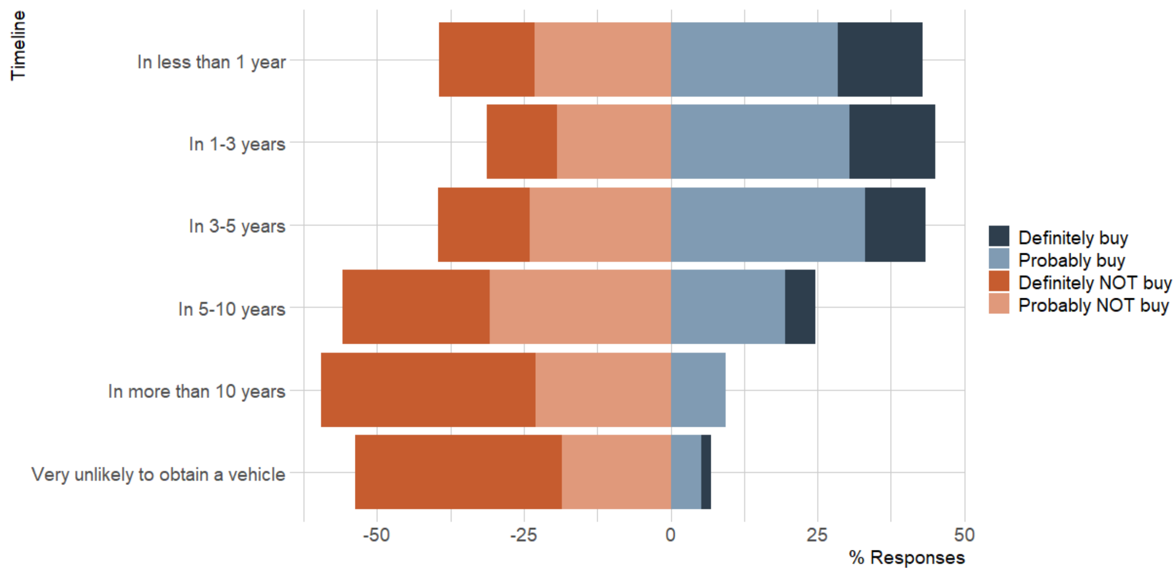


Fig. A.1: Car buying timeline for respondent's primary use versus likelihood the next household vehicle is a PEV if needing to buy a vehicle in the next five years.

Personal factors that increase the likelihood of buying a PEV are whether a household already owns a PEV, the ability to charge at home, and where the household parks their vehicle(s) at home (Ge et al., 2021; Lee et al., 2023). Households that would definitely buy a PEV if pressed to purchase a vehicle in the next five years were slightly more likely to park their primary vehicle in the driveway or garage at home (78.7%) compared to 76.8% of households that would probably buy a PEV. ICEV-only households and those reporting no way to charge a future PEV at home (i.e., could not install a charger) were more unlikely to buy a PEV in the next five years (40.3% and 55.5%, respectively) compared to those that could install a charger (33.1%). While at-home charging access remains a critical barrier, the results suggest some ICEV households may buy a PEV – either by relying on public and work/ school charging or because the household anticipates moving and incorporating home charging access as a criterion in their residential search selection process. Having an EV increases the likelihood of buying a PEV in the next five years (84.0% versus 36.6% are definitely or probably going to buy a PEV), even though some research has found discontinuance among EV owners (Hardman and Tal, 2021).

Households that would probably or definitely not buy a PEV in the next five years ranked their top three barriers, concerns, or fears out of a list of ten. The survey options were obtained from a ranked list of twenty barriers in a 2019 survey of Italian adults (Giansoldati et al., 2020). This survey selected the top eight barriers from the study in Italy, range anxiety (fourteenth place) and problems with battery disposal (fifteenth place). Range anxiety was selected because of its continued mention in the literature, although auto manufacturers are increasingly offering long-range BEV options. Some stylistic changes were made, like rewording range anxiety to "fear of getting stranded (0% battery)" and battery disposal with "concerned about battery waste and mining."

The top three reasons for not buying a PEV in the next five years are high purchase cost (68%), lack of at-home charging options (38%), and high cost of home charger installation (32%) (Table A.1), which aligns with well-cited barriers in other surveys (Butler, 2022). The fear of battery degradation and battery replacement cost was higher than in the Italian sample. Since Giansoldati et al. (2020), news outlets have reported on potentially high battery replacement costs, but these estimates are with out-of-warranty BEVs with discontinued battery packs that must be sourced from third-party suppliers and are in short supply, which can lead to confusion among consumers about the true battery replacement cost (Mueller, 2022).

Table A.1: Ranking of barriers to buying a PEV (n = 668).

Ranking	Top Barriers/Concerns for buying a PEV	Percent Chosen
1	High purchase cost	68%
2	No at-home charging	38%
3	Cost to install a home charger	32%
4	Insufficient number of public chargers	31%
5	Fear of getting stranded (0% battery)	30%
6	Fear of battery degradation & replacement cost	26%
7	Long-distance trips	23%
8	Long charging times	16%
9	Concerned about battery waste and mining	11%
10	Need for travel planning	6%

Note: Results for this table are not population-weighted.

12.2.2 Preferred BEV range and BEV-charging ecosystem

Respondents were told to assume they would definitely buy a new BEV in the next five years when asked to specify the ideal range out of a dropdown list (“50 to 99 miles up” to “400 or more miles” by a step size of 24 miles). Population-weighted households not planning on obtaining a PEV, if faced with a car buying decision in the next five years, made up more than half (53.7%) of the responses for “400 or more miles,” suggesting range anxiety fears persist even if not top of mind for consumers. Butler (2022) found that 47% of Americans cited vehicle range as a reason for hesitancy to buy or lease an all-electric vehicle. Individuals that would definitely buy a PEV for their primary use were more likely to report 300-324 as their ideal battery range, which is the second-highest choice. Older Americans preferred the highest range option, and the share of females opting for a range below 250 miles was larger than males. The average respondent expects to charge this future BEV 70.3% at home, 7.4% at work, and 22.3% at public charging stations.

Range and expected charging location frequency are two elements of owning/leasing a BEV alongside charging duration. Some consumers use range anxiety as a rhetorical reaction to justify their aversion to EVs because it conflicts with their psychological views on vehicles (Noel et al., 2019). For example, consumers claim range anxiety for long-distance trips even though they are exceedingly rare because they perceive EVs as limiting their freedom to drive unimpeded. Building public charging stations and increasing charging speed may not be an appropriate policy response to influence these consumers since they are influenced by psychological and societal aspects and not technical aspects of EVs. To test if range is still king, individuals were asked to pick two of the three elements they would prefer: long-range BEVs (like current gas-powered vehicles), fast charging (like the time to pump gas), or a sufficient number of public charging stations (like gas stations). The option not selected remains the status quo.

Fig. A.2 is a Sankey diagram that visualizes the migration of respondents' ideal BEV range to their preferred two-of-three PEV ecosystem elements. The most popular PEV world includes long-range BEVs and fast charging, followed by fast charging and plenty of public chargers. The least popular option is long-range BEVs with many public chargers. The first option reduces the burden of having to charge in frequency and downtime. The second most popular choice sacrifices range, but only if charging is quick and public chargers are ubiquitous. Respondents that prefer BEVs with a range of less than 150 miles prefer an ecosystem with fast charging (85.7%) to reduce the burden of frequent charging. Although these same people preferred short-range BEVs, about 45% would increase range with fast charging. People preferring 150-mile to 249-mile BEVs were the most diverse in choosing which technical elements to improve in an ideal BEV world. Out of the respondents that prefer BEVs with a range of at least 250 miles, 20.5% to 27.5% are willing to sacrifice battery range if charging speed increases and public chargers are widely available. This question shows clear technological and policy solutions that can reduce vehicle range and, thus, battery weight and demand for raw materials per vehicle. Decreasing battery weight increases fuel efficiency (Shiau et al., 2009) and reduces the risk of severe injury and death, especially for non-motorized road users and motorcyclists (Liu et al., 2022).

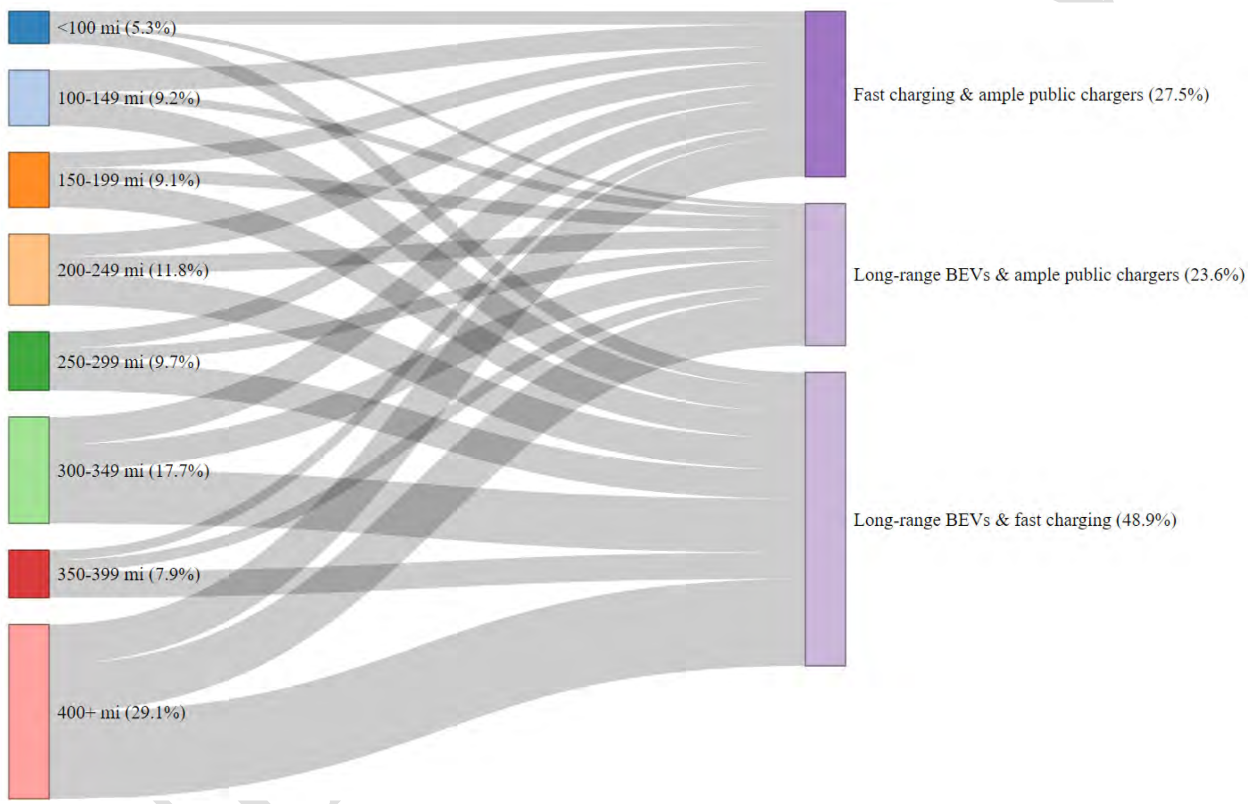


Fig. A.2: Sankey diagram to explain migration between ideal BEV range and the two out of three elements of a PEV ecosystem to improve.

Note: Results for this figure are not population-weighted.

12.2.3 Segmented results of perception data

Fig. 2 shows the perceived importance of smart charging benefits. Immediately following this Likert-type question, respondents were asked to report their prior knowledge of supplier-managed smart charging (SMC), using a scale of no knowledge to extremely knowledgeable. The next question inquired whether the respondent would be interested in a smart charging program (for their current or future PEVs). Fig. A.3 plots the distribution of responses to the perceived benefits by interest in a smart charging program. Respondents selecting "not at all important" to smart charging benefits were more likely to state they were not at all interested in a smart charging program. Respondents who perceived various benefits as extremely important to them were more interested in a smart charging program.

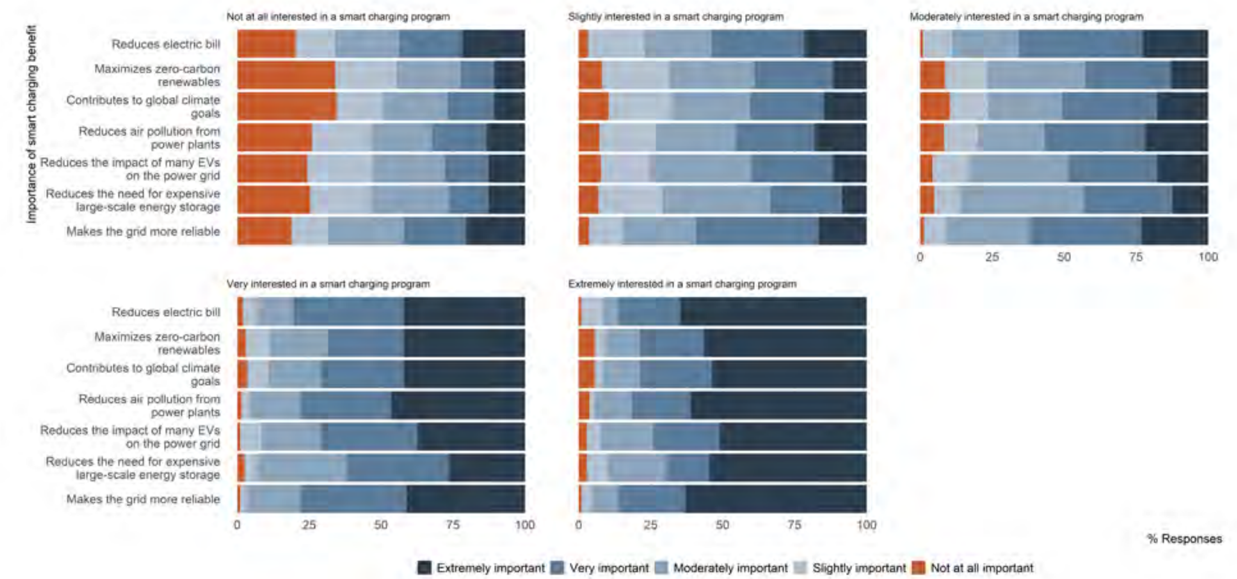


Fig. A.3: Perceived importance of expected PEV smart charging benefits segmented by interest in a generic smart charging program.

Note: Results for this figure are not population-weighted.

Fig. 1 shows perceptions on smart charging and transportation-clean energy transition topics for all respondents. Fig. A.4 visualizes the results separately for households with an EV and those without an EV (including zero-vehicle households). Households with an EV (top of Fig. A.4), relative to non-EV households, are more likely to agree that the power grid can support the government's EV adoption goals and that smart charging an EV is a net good for society. Households with an EV are also more likely to oppose monthly EV fees to pay for power grid upgrades and trust their power company to always guarantee their vehicle is fully charged before needing it. EV owners are also more likely to have a stronger (dis)agreement on statements like ceding privacy for a stable power grid and SMC risks exceed benefits, likely informed from charging experience.

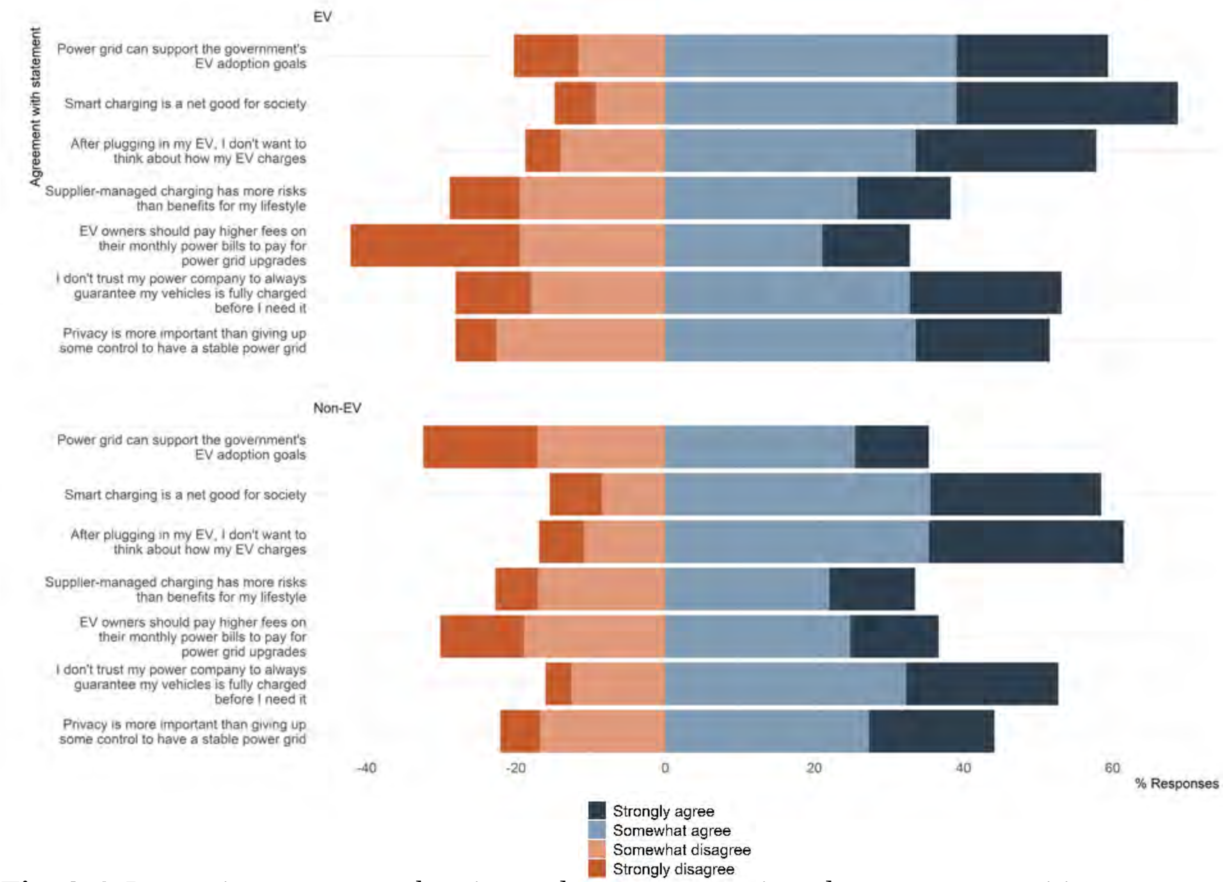


Fig. A.4: Perceptions on smart charging and the transportation-clean energy transition segmented by EV ownership status (neither agree/disagree responses not shown).

12.3 Empirical cumulative distribution function plots

Due to the declining marginal value of PEV smart charging (Szinai et al., 2020), power companies could estimate the value of smart charging locally and use price discrimination to reward those offering the highest value at the lowest price. Fig. A.5 plots the empirical cumulative distribution function (CDF) plots for a one-time bill credit after participating in a customized smart charging program for one year. Fig. A.6 plots the yearly participation credit for each additional year of participation.

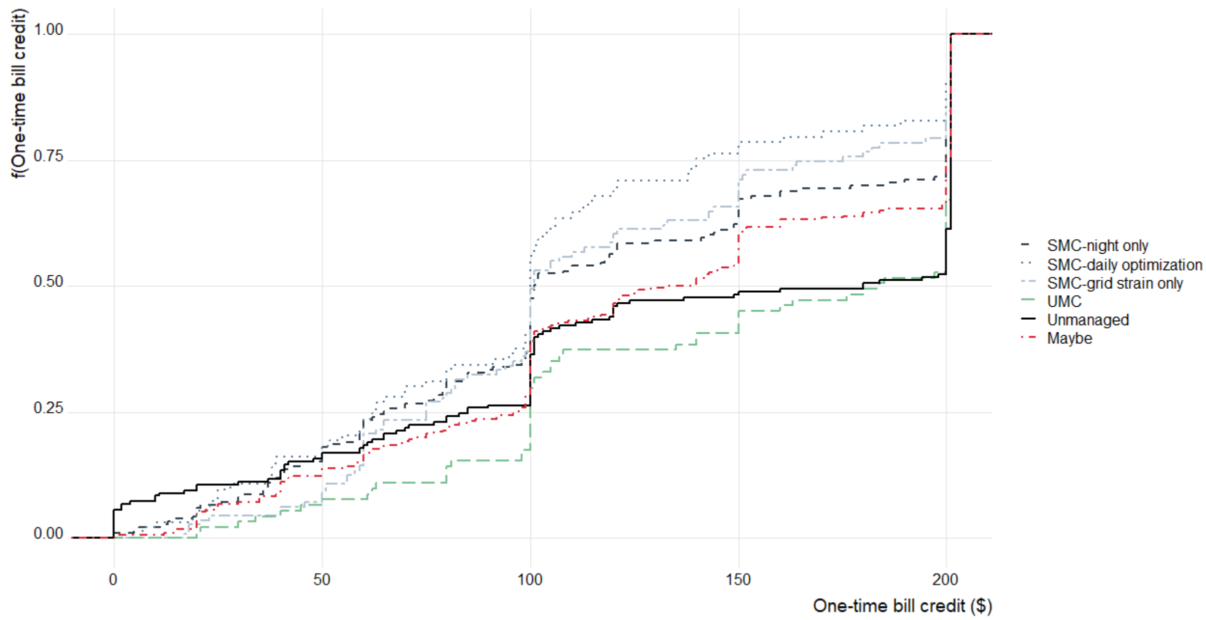


Fig. A.5: Empirical CDF plot of respondent's minimum one-time bill credit for participation in a future PEV smart charging program. Note: the survey censored data after $200.

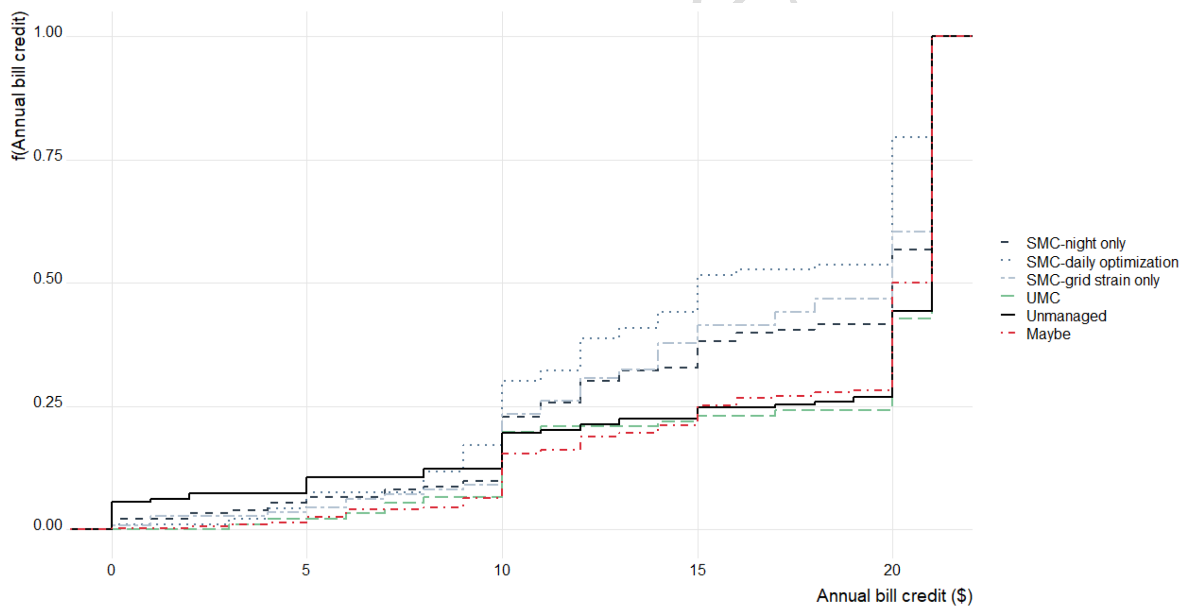


Fig. A.6: Empirical CDF plot of respondent's minimum annual bill credit for continued participation in a future PEV smart charging program. Note: the survey censored data after $20.

12.4 Auto-enrollment in SMC

Respondents were randomly assigned to the altruistic or pro-freedom text. Table A.2 shows the check that randomization did not bias the sample based on four key demographic attributes.

Table A.2: Randomization check for the WTP to leave an auto-enrolled SMC program.

	Altruistic text	Pro-freedom text
Gender		
Male	49.0%	46.5%
Non-Male	51.0%	53.5%
Highest Educational Attainment		
High school or less	35.3%	38.7%
Some college	31.4%	30.5%
Bachelor's degree	22.2%	19.8%
Master's degree or higher	11.1%	10.9%
Age		
18 to 24 years of age	16.6%	17.5%
25 to 34	22.0%	22.3%
35 to 44	18.5%	15.7%
45 to 54	16.3%	15.3%
55 to 64	16.1%	17.1%
65 years and over	10.5%	12.1%
Ethnicity		
White	76.7%	75.6%
Black	11.5%	12.3%
Asian	6.3%	7.5%
Other	5.4%	4.6%