Hybrid EV and BEV Owners: A Comparative Analysis of Household Demographics, Travel Behavior, and Energy Use

May 2023

A Research Report from the National Center for Sustainable Transportation

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16. Abstract
Electric Vehicles (EVs) significantly reduce energy consumption and emissions from on-road operations and help create more sustainable transportation environment by reducing emissions from the entire well-to-wheel energy cycle. Differences between hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery electric vehicles (BEV) users is an important element in understanding potential impacts on travel demand and vehicle adoption, the fact that these vehicles may be adopted into households that undertake very different vehicle activities and energy usage patterns has not been a primary focus in the literature. This study differentiates between HEV, PHEV, and BEV users across three factors: owner household socio-demographic attributes, household daily travel patterns, and household energy usage profiles. The analyses examine factors that appear to influence users' preferences towards specific EV types and how the selection of different EV types potentially relates to household socio-demographics and daily travel patterns. The 2019 Puget Sound Regional Council travel survey data set serves as the main analytical dataset. Influential factors identified as significant through statistical approaches are employed as variables for developing a two-phase choice model for determining potential EV-purchasing households and their choice of specific EV type. As EVs continue to capture increasing market share over time, these research findings and the resulting vehicle type choice model are expected to significantly improve future travel demand model development, allowing activity-based travel demand models to assign specific vehicles to specific households and then to individual trips in planning scenario analysis.

17. Key Words
hybrid electric vehicles (HEVs); battery electric vehicles (BEVs); data mining and statistical learning; EV purchase and use decisions; household demographics; travel patterns and household energy usage; household travel surveys

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EXECUTIVE SUMMARY

This report summarizes the NCST research conducting comprehensive comparison analysis towards hybrid-EV-owners and pure-BEV-owners regarding their household socio-demographic attributes, household daily travel patterns, and household energy usage profiles. The research team used the 2017-2019 Puget Sound Regional Council travel survey data set to differentiate between hybrid EV users and pure BEV users, examining factors that influence users' preferences towards specific EV types and how the selection of different EV types potentially relates to household socio-demographics and daily travel patterns. Specific research tasks included:

- Data collection and data processing: Household, person, vehicle, and trip information were pre-processed and recoded to obtain the all EV-households information which will be used in comparison analysis, model construction, and future applications.
- Differentiation in hybrid-EV-owners and pure-EV-owners household demographics and daily travel patterns: Attributes regarding household-level and personal-level demographics, travel patterns and transportation energy use are compared through statistical tests to identify variable significance.
- Visualization of influential variables by grouped distribution heatmaps and 3d-barplot: Grouped heatmaps were plotted for household- and person-level demographics between owner groups of the two EV types. 3d-barplots were plotted for two-factor combined effects of variables to reflect the intercorrelation between different features.
- Tests of statistical significance for influential variables: Household-level and person-level demographics across owner groups for the two EV types were conducted to support the findings of the visualization comparisons.
- Differentiation in hybrid-EV-owners and pure-EV-owners household energy usage profile: Energy consumption of trips by different EV groups were quantified through minute-by-minute trip data using MOVES-Matrix and Autonomie tools.
- Vehicle type model choice development and application: A two-phase choice model was developed with influential factors identified as significant through statistical approaches employed as input variables for determining potential EV-purchasing households and their choice of specific EV types under 15% and 30% market penetration rate assumption, resampling methods were adopted for imbalanced groups.
- Calculation of average probability for purchasing HEVs/PHEVs or BEVs by specific demographic household groups: The average probabilities of household groups with the

largest differences identified during comparison analysis were explored by running the choice model 100 times per comparison.

With the use of open-source travel survey data, specifically household-level demographics and trip-level attributes, and the application of statistical-learning theory methods, this research was able to quantitatively compare and visualize the differences between different EV-type owners, which might be a research question that was ignored before, which is the fact that these vehicles may be adopted into households that undertake very different vehicle activities and energy usage patterns. Research findings also point out that the biggest differences between different EV-type owners still lie in household size, together with collateral features such as household vehicle ownership and number of workers. Households with more household members and middle-aged members that are fully employed with substantial income were found to be the main owners of BEVs, while HEV-ownership was found in a wider distribution across demographic factors. This finding was further evidenced by the differences in modeling results for the average probabilities of purchasing hybrid EVs vs. pure BEVs, where the difference in purchasing potential could hit a gap of over 70%. Modeling of vehicle type selection by potential EV buyers could further assist policymakers and stakeholders in policymaking targeting continuous EV promotion.

Introduction

In 2018, transportation accounted for about 28% of total energy use in United States and approximately 69% of total petroleum consumption *(1)*. In July 2020, the U.S. House of Representatives passed H.R. 2, the *Moving Forward Act* for vehicle-grid integration *(2)*. With further agreement on final legislation, further promotion of alternative fueled vehicle (AFV) technologies to reduce energy use and dependence on petroleum resources is believed to be forthcoming.

Electric Vehicles (EVs) either use electricity as their only energy source, resulting in near zero on-road emissions, or to enhance overall vehicle efficiency in conjunction with traditional internal combustion engines through power flow control *(3).* These EVs help reduce transportation energy consumption and emissions and support the development of a more sustainable transportation environment. EVs can be divided into two broad categories by considering the number of motive powertrains used within the vehicle: two-powertrain hybrid electric vehicles and single-powertrain (batteries and electric motor) battery electric vehicles. The hybrid types includes both serial and parallel hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs), while the all-electric type includes both battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). PHEVs are distinguished by their larger battery packs compared to HEVs, and PHEVs can be plugged-in or recharged from the electric grid *(4)*.

In recent years, many research studies have been conducted to assess consumer adoption of alternative fueled vehicles, especially within the range of HEVs and BEVs *(6-17)*. These studies provided professionals and stakeholders with some insights into which factors may influence people's purchase and adoption of EVs. However, most existing studies have not attempted to differentiate between a customers' choice of the HEV type and BEV type. Hence, different types of EVs may be adopted by households that have very different demographics and energy usage profiles for daily travel. Customer groups for the purchase of more affordable hybrid EVs and luxury pure BEVs are likely to vary significantly, as well as how the individuals drive their vehicles. As such, there may be a distinction in the pairing of household socio-demographic attributes and household daily travel patterns with respect to vehicle choice.

Studies of differences in households purchase and use decisions across different EV types are important to automakers, helping them assess different customer group needs and preferences and target marketing/promotion. Policymakers also benefit from assessments of EV adoption across demographic groups, as they can improve the design of EV-related policies, such as incentive and rebates programs, and explore potential equity issues that lie within these policies (18). Moreover, distinguishing between different EV owner groups also allows researchers and planning agencies to refine travel demand models to assign specific vehicles to specific households and predict trips by EVs and conventional vehicles. Understanding household vehicle adoption (ownership and on-road use) has an impact on the built-in environment and will play a significant role in the efficient deployment of EV charging infrastructure. Finally, properly allocating EVs to on-road travel will help analysts avoid overestimating benefits with respect to energy consumption and on-road emissions when conducting scenario analysis and modeling work related to EV shifts.

In this paper, the researchers conducted a comparative analysis of household and person demographics, travel behavior, and energy use of different EV type owners to examine: 1) differences in the household demographics between hybrid electric vehicle (HEV) owners and pure battery electric vehicle (BEV) owners and potential factors influencing households' choice of the type of EVs; 2) differences between different types of EV-owned households daily travel patterns and any influential trip attributes and geographic attributes associated with these differences; 3) differences between the transportation energy consumption between HEV-households and BEV-households and any potential underlying relationships between daily trip pattern and energy usage profiles; and, 4) whether the location of public charging infrastructure may have influenced household-level EV type purchase choice or household daily travel patterns. A choice model was then developed to predict future potential EV-purchasing household purchase and use decisions with respect to specific EV type (HEVs vs. BEVs) given the household's demographic data, household travel patterns, and household historical energy usage profile.

The main data source used in this research is the 2017-2019 Regional Travel Survey data, collected by the Puget Sound Regional Council (PSRC). This travel survey collected household-level and person-level demographic information and monitored trip activities from residents throughout the Puget Sound four-county region from April to June of 2019 *(5)*. The final datasets contained subsets of household, person, vehicle, travel day, and trip information. A subset of the travel data collected by rMoves® also contains GPS information with specific trip locations and trip times with approximately 30 second resolution.

The next section of this paper provides a literature review of previous EV purchasing studies and comparison between different EV types. The paper then presents the comprehensive comparative analysis of different EV type owner groups, including household demographics, travel patterns and energy usage characteristics. Next, the paper elaborates on the choice model development and result discussions under different EV market penetration rate assumptions. The final section of the paper provides conclusions and recommendations.

Literature Review

Factors Influencing Household Purchase and Adoption of EVs

Previous researchers have examined factors influencing customers' purchase and adoption of EVs from several different viewpoints. Sierzchula et al. *(6)* studied how different financial incentives and socio-economic factors could influence the adoption of EVs and concluded that EV purchase cost remains the biggest barrier for most people, and that financial incentives and charging infrastructure availability are statistically significant factors associated with EV purchases. Javid and Nejat claimed that socio-demographic attributes like income and highest attainment of education were also influential in household EV adoption from their study of EV-households *(7)*. Morton, et al. conducted a geographical analysis of EV early market demand, identifying spatial clustering of EV-households' residences, which further relates to households' characteristics *(8)*. Other researchers have adopted survey-based methods to examine how household opinions influence EV purchasing decisions *(9)*, with results showing that pro-environmental consumers were much more likely to purchase and use EVs. These factors were also correlated with education level.

Studies of how financial incentives affect households' purchase of EVs, studies confirmed that government incentives did show a positive and significant effect on the market share of HEVs *(10, 11)*, where state-level PHEV incentives also significantly promote PHEV sales and the states with the largest PHEV incentives had the largest PHEV sales share *(12)*. But differences were spotted by Vergis and Chen's research in which they concluded that although incentives were correlated with HEVs/PHEVs market share, they were not for the BEV market share *(13)*. Other researchers have conducted a review of 211 studies on the adoption of the electric vehicles, categorizing and discussing relative importance of demographic, situational, contextual, and psychological factors and finding that regression analysis was the most used method *(14)*.

Comparisons between Different Types of EVs

Other EV-related studies focus on the potential influence of EV characteristics (technologies, features, limitations, and challenges in their deployment) on EV adoption and replacement of conventional vehicles *(see for example 4, 15)*. Other studies have focused on the cost comparison of FCEVs and BEVs for both manufacturing and refueling costs, with results showing that BEVs were more favorable in terms of cost, energy efficiency, weight, and volume than FCEVs, at least at present *(17)*. Other studied have assessed and compared the economic and environmental impacts of conventional, hybrid, electric and hydrogen fuel cell vehicles and concluded that electric cars with on-board electricity generation offered significant advantages in terms of both efficiency and ecological impact *(17)*. Fewer studies have explored what factors influenced customers' choice of specific EVs and what were the differences between different EV type owners. Axsen and Kurani *(19)* distributed web-based games to 508 San Diego households to assess consumer interest in various electric-driving vehicle designs and found that PHEVs are most popular, followed by HEVs and conventional vehicles. The study also claimed that the choice of electric-driving was associated with intelligence, responsibility, and environmental awareness. Another study explored the potential reasons for EV discontinuance in California, finding that around 20% PHEV owners and 18% BEV owners discontinued their use and that the reason for discontinuance was not, in general, related to vehicle range but rather with dissatisfaction with convenience of charging, not having level 2 charger at home, low total household vehicle ownership, and not being male *(20)*.

Despite the above studies on customer EV purchase and adoption and comparison of EV types, it remains unclear how "different" the HEV owners and the BEV owners are regarding their demographics, travel patterns, and energy usage profiles. This study focused on a comparative analysis of these factors across different EV ownership groups. Through further development of a two-phase choice model, the study will provide an innovative method to predict potential EV-purchasing households and their choice of the specific EV type.

Comparative Analysis of HEV and BEV Owners

A comparative analysis was conducted between HEV and BEV owners with respect to the household and person-level demographics, EV-adopted trip travel patterns and energy usage profiles. The data used in this paper are from the 2017-2019 Puget Sound Regional (PSRC) Travel Survey, which was the second wave of a planned three-wave, six-year data collection effort. It collected household-level and person-level demographic information and travel activity from residents within the Puget Sound four-county region *(5)*. Data cleaning, pre-processing, merging, and recoding were required to extract the EV-owned households' information. Table 1 summarizes the travel survey results (household, person, vehicle, and trip data). The sections that follow present visualizations of electric vehicle type selection with respect to household-level and person-level household demographics, trip attributes, and energy consumption, accompanied by statistical significance tests including t-test and chi-square tests to further strengthen the comparison of the visualized results (with significance level set as 0.1). Specifically, t-tests were adopted for numerical and ordered input variables while chi-square tests were adopted for categorical input variables.

Table 1. Summary Statistics of PSRC Travel Survey

	Total Households	EV Households	BEV Households	HEV/PHEV Households
Number of Households	6,319	545	100	445
Number of People	11,940	1,239	252	987
Number of Vehicles	8,087	953	209	744
Number of Trips	70,890	9,553	2,586	6,967
Number of HEVs/PHEVs/BEVS	/	583	110	473
Number of EV-used trips	/	5,695	1,456	4,239

Comparative Analysis of Household-Level Demographics

Commonly used household demographic characteristics, as well as some custom categories designed for the Puget Sound region were selected for comparison. Table 2 below presents the variable name, variable meaning, variable type, and the response values for the selected household-level demographics used in these analyses.

Table 2. Variables for Household-Level Demographics

Variable	Definition	Variable Type	Values
Household-Level Socio-demographic Attributes			
HHSIZE	Count of household members	Discrete numerical variable	1 – 9
VEHICLE_COUNT	Count of household vehicles	Discrete numerical variable	0 – 10
NUMCHILREN	Number of children within the household	Discrete numerical variable	0 – 6
NUMWORKERS	Number of workers within the household	Discrete numerical variable	1 – 6
LIFECYCLE	Household lifecycle	Categorical variable	1: Household size being 1, householder aged under 35 2: Household size being 1, householder aged 35-64 3: Household size being 1, householder aged 65+ 4: Household size larger than 1, householder aged under 35 5: Household size larger than 1, householder aged 35-64 6: Household size larger than 1, householder aged 65+ 7: Household includes children under 5 8: Other
HHINCOME_DETAILED	Household gross annual income	Categorical variable	1: Less than $24,999 2: $25,000 to $49,999 3: $50,000 to $74,999 4: $75,000 to $99,999 5: $100,000 to $149,999 6: $150,000 to $199,999 7: $200,000 to $249,999 8: Other
EDUC_HIGH	Highest educational attainment within the household	Categorical variable	1: Less than high school 2: High school graduate 3: Associates degree 4: Some college 5: Vocational/technical training 6: Bachelor’s degree 7: Graduate/post-graduate degree 8: Other
CAR_SHARE	Household joined a car share program or not	Categorical variable (dummy)	1: Yes 0: No

Variable	Definition	Variable Type	Values
RENT_OWN	Household residence owned or not	Categorical variable (dummy)	1: Yes 0: No
Built Environment Attributes			
FINAL_HOME_RGCNUM	Household residence located within regional growth center or not	Categorical variable (dummy)	1: Yes 0: No
FINAL_HOME_UVNUM	Household residence located within urban village or not	Categorical variable (dummy)	1: Yes 0: No

Figure 1-Figure 11 present grouped heatmaps for household-level demographics comparison between the owner groups of the two EV types. Table 3 and Table 4 summarize the t-test and chi-square test results across household-level demographics. The biggest observed differences seen in Figure 1 occurred between single and mid-sized (four-person) households with single-person households preferring HEVs while larger four-person households tend to prefer BEVs over hybrid EVs. The combined vehicle ownership observations seen in Figure 2 lead to the conclusion that single-person households with one vehicle available currently tend to choose the hybrid type, with multi-person households with more than one vehicle available have a higher probability of purchasing BEVs.

Table 3. Summary Statistics for T-Test Results on Household-level Demographics

Variable Name	Test Statistics	P Value
Hhsize	2.7296	0.0065
vehicle_count	4.7308	0
Numchildren	2.0531	0.0405
Numworkers	1.0698	0.2852
hhincome_detailed	3.5059	0.0005

Table 4. Summary Statistics for Chi-Square Test Results on Household-level Demographics

Variable Name	Test Statistics	P Value
lifecycle	8.8056	0.2669
car_share	4.3638	0.0367
rent_own	7.515	0.0061
final_home_rgcnum	0.0355	0.8505
final_home_uvnum	2.8137	0.0935

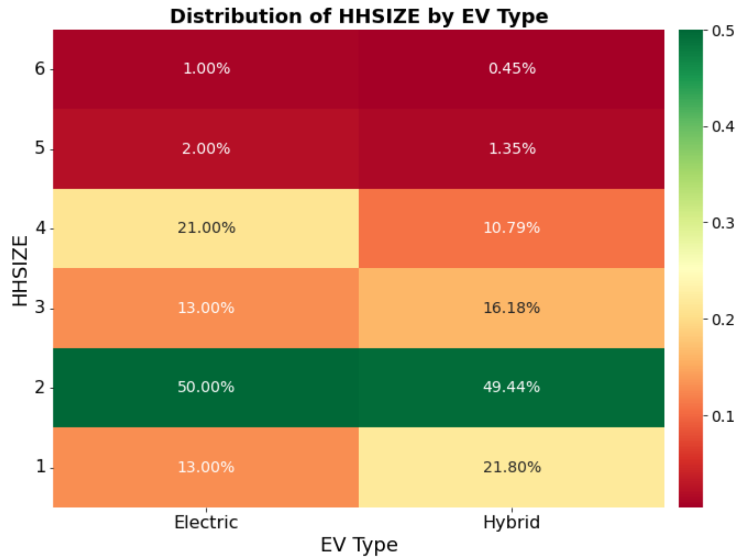

Figure 1. Household Size Distribution

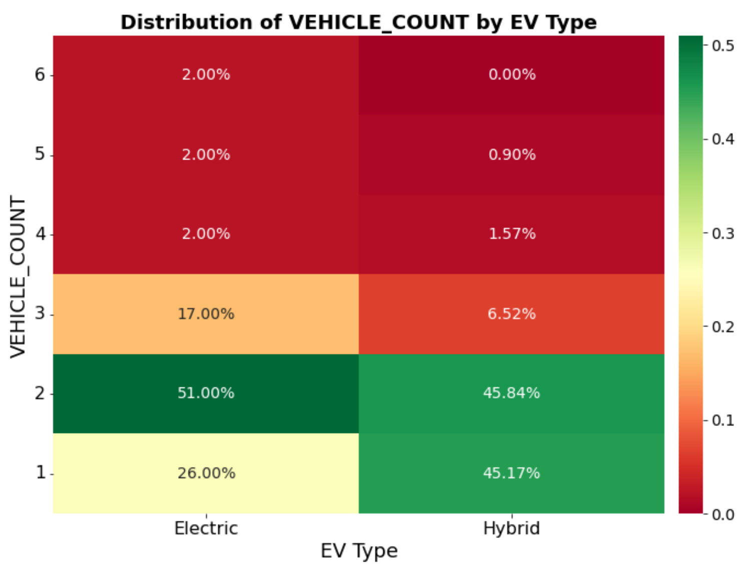

Figure 2. Vehicle Count Distribution

The number of children and workers within the household also affect households' choice of specific EV types. Differences observed in households' children number in Figure 3 correspond to what was found in household size, households without children tend to choose the hybrid type, and households with more than one child (middle-sized family) tend to own a BEV. Regarding number of workers within the household, seen in Figure 4, households with no workers tend to have a larger proportion of hybrid-types, while household with workers tend to own more BEVs. Further statistical tests led to the finding that the number of children appears to have a statistically significant impact on vehicle type selection, whereas the number of workers does not really appear to be significant for these data.

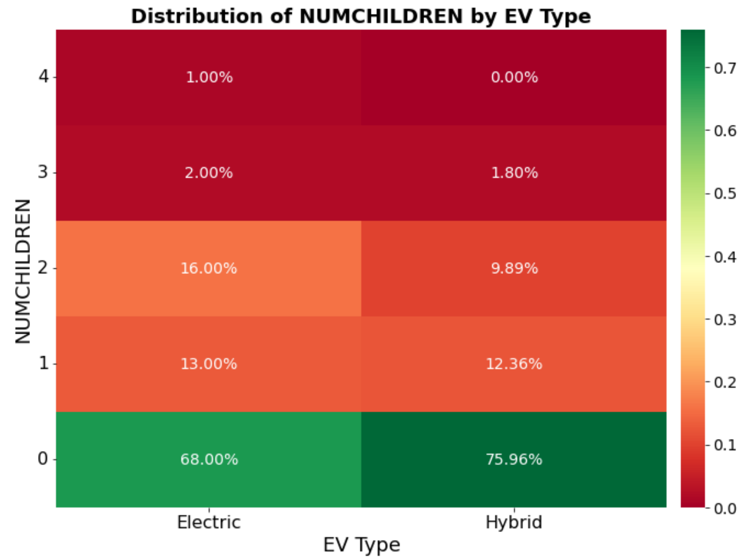

Figure 3. Number of Children Distribution

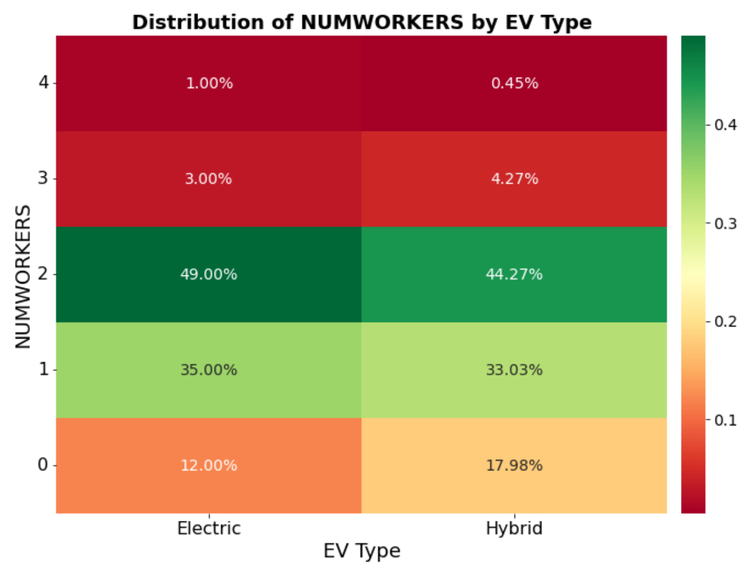

Figure 4. Number of Workers Distribution

The biggest differences observed in household lifecycle lie in middle-sized, middle-aged families (household size larger than 1 and household member in middle age), younger households (householder under age 35) have a relatively larger proportion of the hybrid type while middle-sized households (householder age ranging from 35 to 64) have a larger proportion of BEVs, seen in Figure 5. However, the corresponding chi-square test does not indicate a statistically significant impact on the vehicle type selection regarding different lifecycles. Household income of $150,000 could serve as another threshold as households with family income higher than $150,000 tend to prefer BEVs over HEVs/PHEVs, while households with family income lower than $150,000 would be more likely to purchase a hybrid-type EV, as seen in Figure 6. The corresponding t-test also shows the significance of household income on vehicle type selection.

Relatively small differences were observed considering the highest education attainment within the household, seen in Figure 7, EV owners were mostly concentrated in households with at least a bachelor's degree, regardless of EV types.

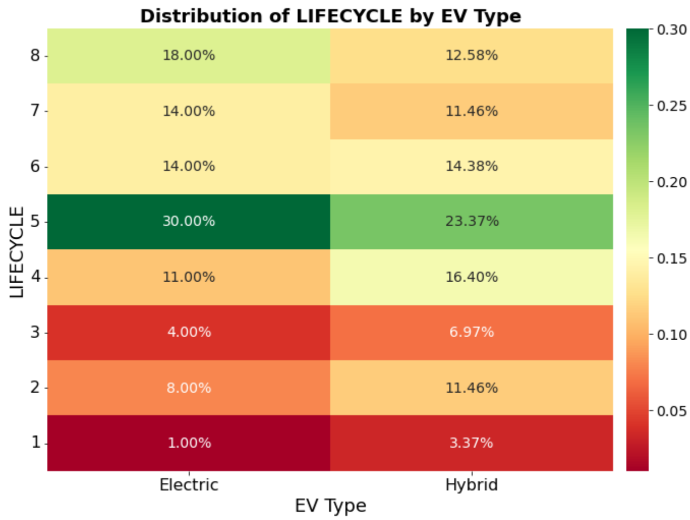

Figure 5. Household Lifecycle Distribution

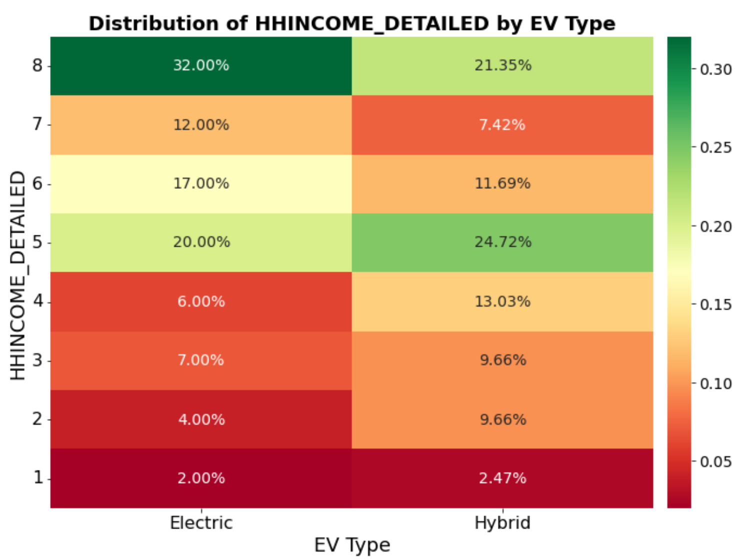

Figure 6. Household Income Distribution

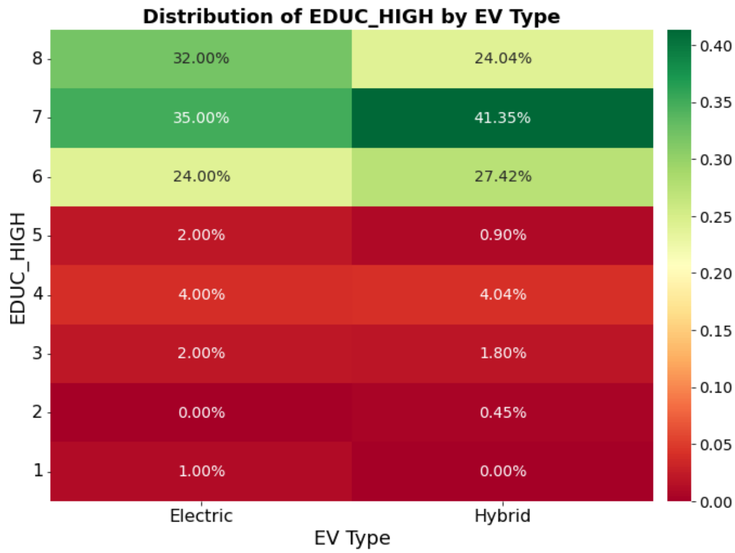

Figure 7. Highest Education Level Distribution

Similar findings were noted in whether households join the car share program or not, and whether the residence is owned or rented (Figure 8). Households with BEVs have a lower probability of joining the vehicle share program and have a higher probability of owning their residences, seen in Figure 9. The chi-square tests also confirmed the significance of these two factors.

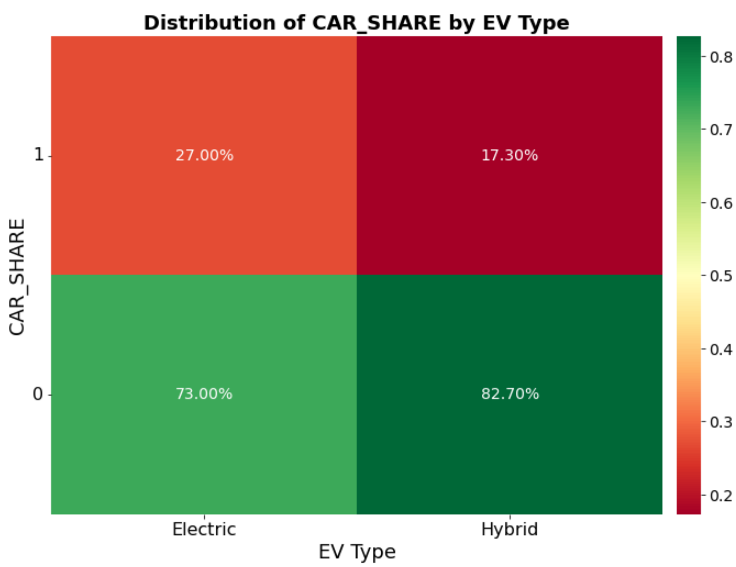

Figure 8. Car Share Program Status Distribution

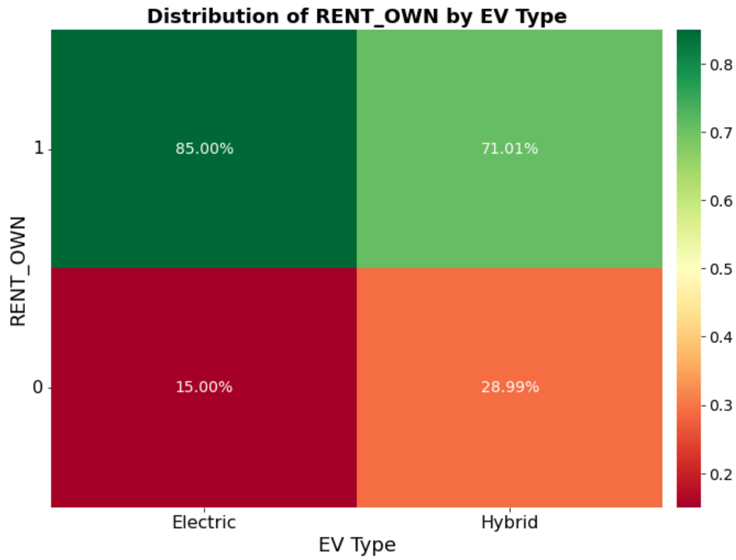

Figure 9. Household Residence Status Distribution

A comparison on households' residences geographical environments, seen in Figure 10 and Figure 11, shows that HEV owners and BEV owners do not display a significant difference in whether the residence is in regional growth center or not, which is further strengthened by the corresponding chi-square test, but a higher proportion of hybrid-type EV owners live within the urban areas than do BEV owners (also indicated by chi-square test results).

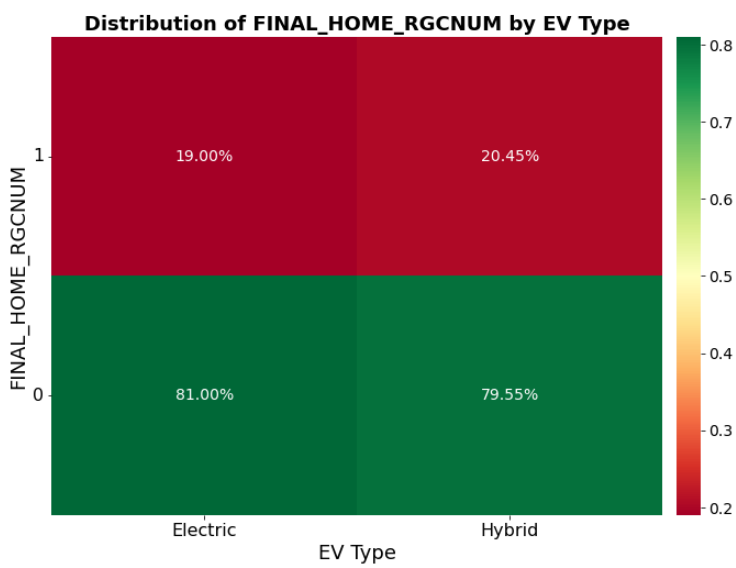

Figure 10. Regional Growth Center Status Distribution

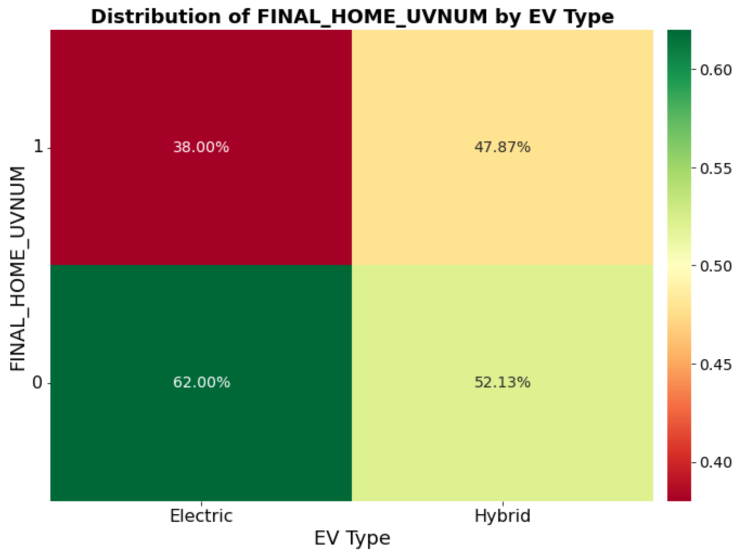

Figure 11. Urban Village Status Distribution

The literature acknowledges a great deal of intercorrelation among various household demographic factors (e.g., household size and vehicle ownership and number of workers within the household). Correlation among potential independent household-level demographic variables were calculated and visualized through heatmap in Figure 12 below, which presents results of high correlation between household size and number of children, household size and highest education attainment within the household, number of children and highest education attainment within the household, household size and number of workers within the household, as well as household size and vehicle ownership. High correlation leads to the need for comparison between different EV type owner groups regarding multiple factors. Figure 13-Figure 19 use 3-D bar plots to present the two-factor combined effects of variables on the choice of specific EV type (reflecting the intercorrelation of different features). The left side of each plot displays the distribution for pure BEVs and the right side displays the distribution for hybrid EVs. Each plot’s X-axis and Y-axis reflects the specific value for one factor and the Z-axis displays the specific count number for the cross-tabbed population.

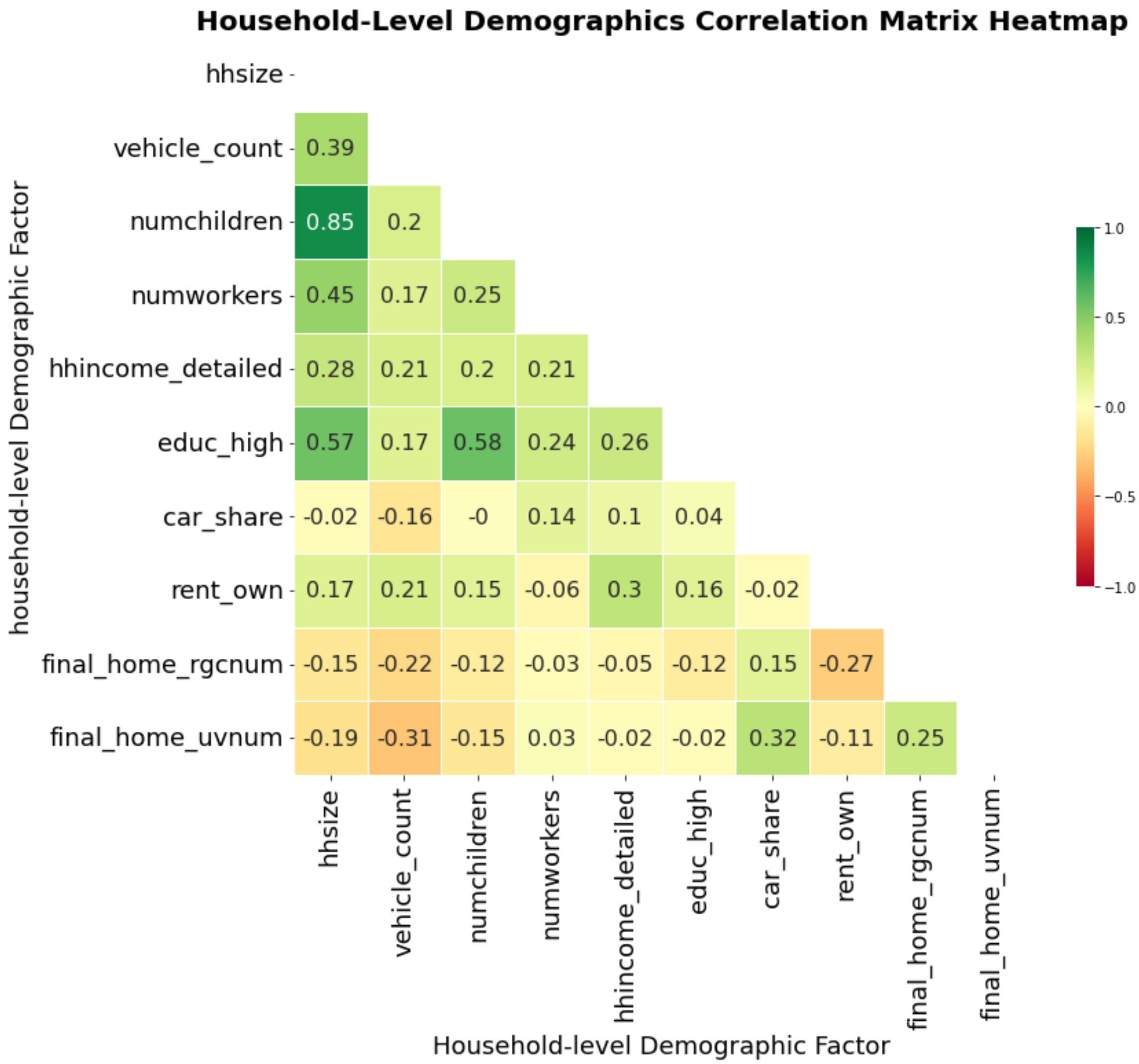

Figure 12. Correlation Heatmap of Household-Level Demographics

Figure 13 points that the main differences observed lie in small-sized households with one vehicle and middle-sized households with more than one vehicle.

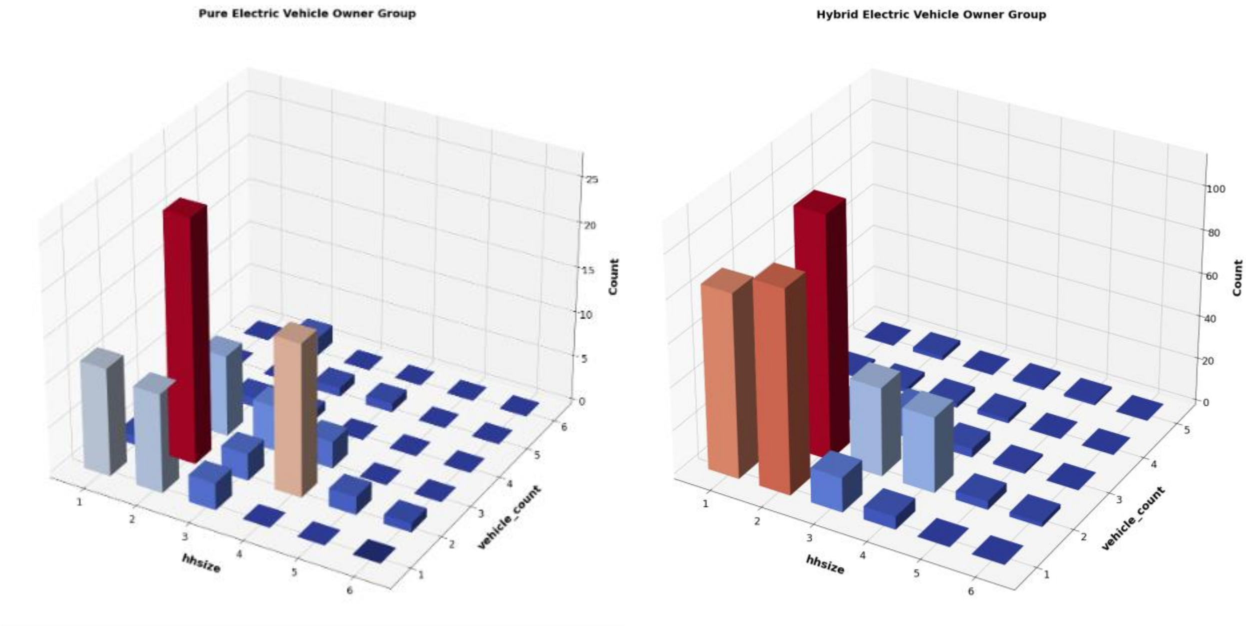

Figure 13. Joint Effect of Household Size and Vehicle Count

Figure 14 shows that households with household size larger than one and household member aging from 35-64 are found to be the major owners of both EV types, which also corresponds to the findings between household size and vehicle count.

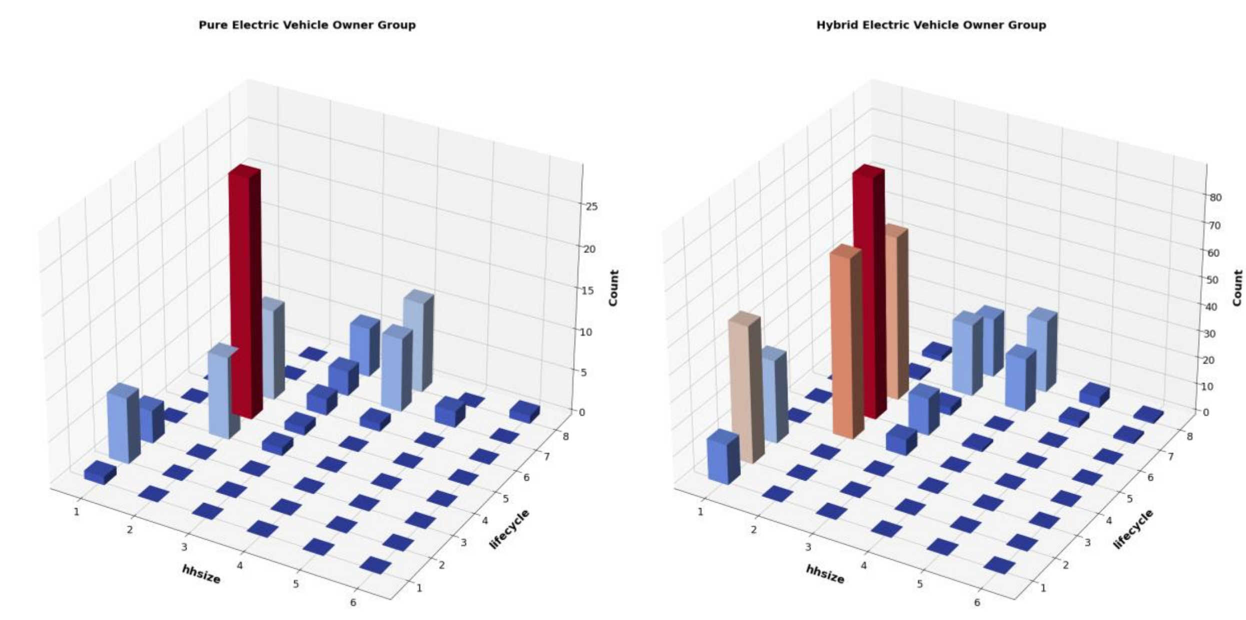

Figure 14. Joint Effect of Household Size and Lifecycle

Figure 15 further strengths the conclusion that EV owners are concentrated in relatively high-income households, and the main differences lie in middle-sized household with average to above-average income. Overall, HEVs tend to be purchased at greater rates than BEVs by relatively low-income households.

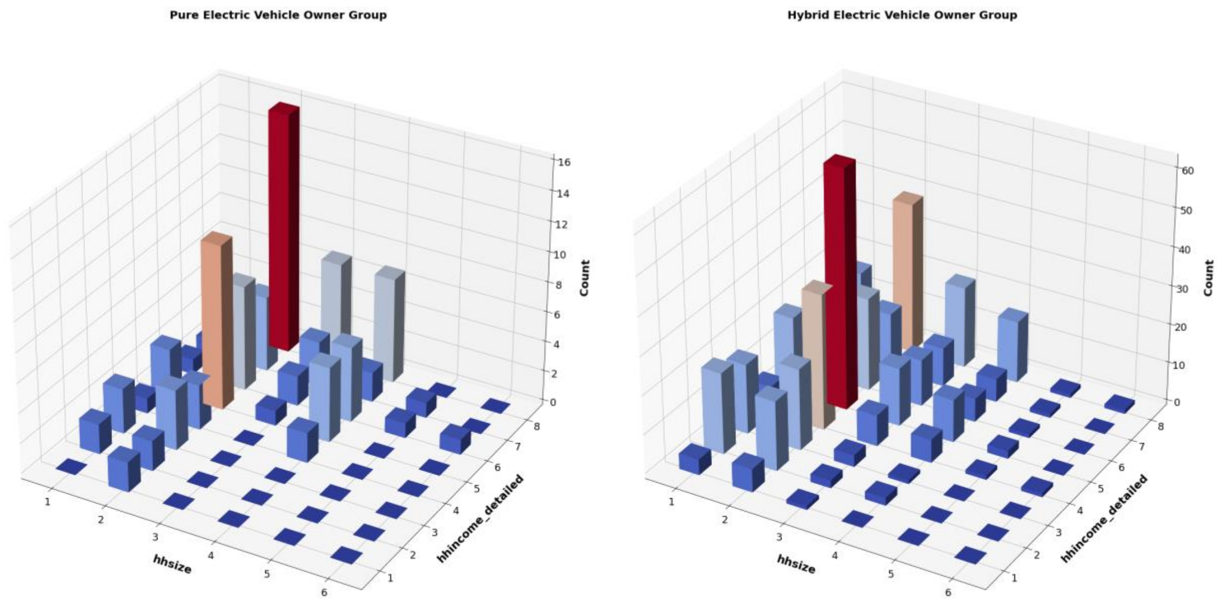

Figure 15. Joint Effect of Household Size and Household Income Level

Figure 16 shows very little difference between different EV type owner groups, with the two-people households with at least bachelor's degree attained being most owners. The only significant differences lie in middle-sized households with high level of education attained.

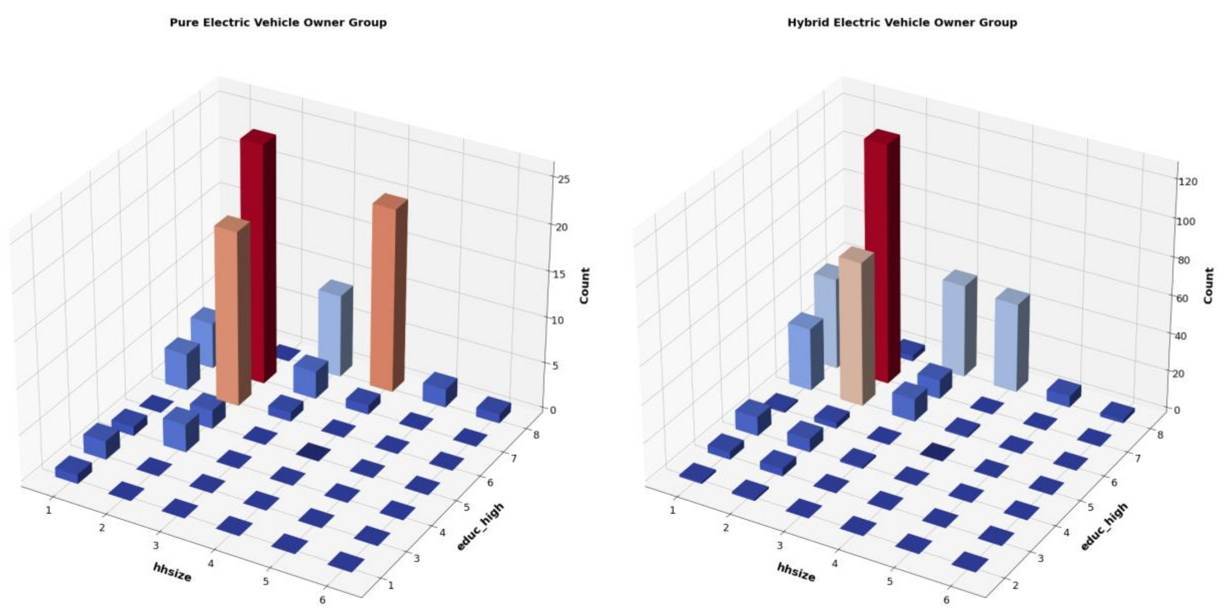

Figure 16. Joint Effect of Household Size and Highest Education Level

Figure 17 shows main differences between different EV type owners lie in households with above-average income and two vehicles, BEV owners are more concentrated towards high-income groups, while hybrid-type EV owners are more evenly distributed across average-income and above-average-income households.

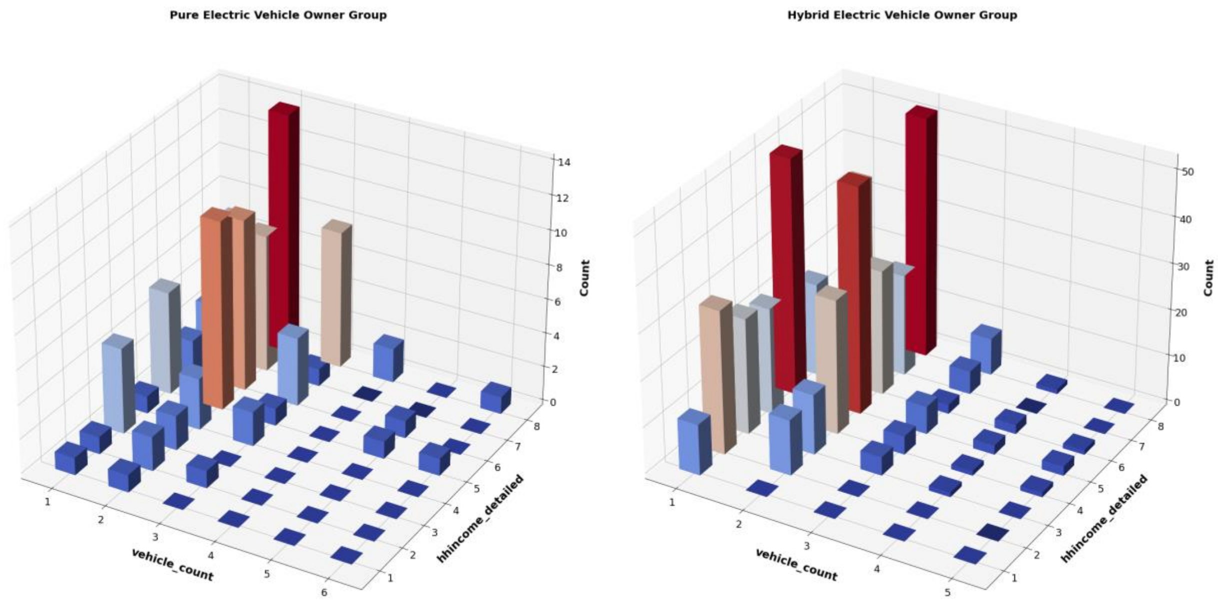

Figure 17. Joint Effect of Vehicle Count and Household Income Level

Figure 18 further reinforces the conclusion that the biggest differences spotted between hybrid-type EV-households and BEV-households lie in households with above-average income, household size larger than one, and household members of middle age.

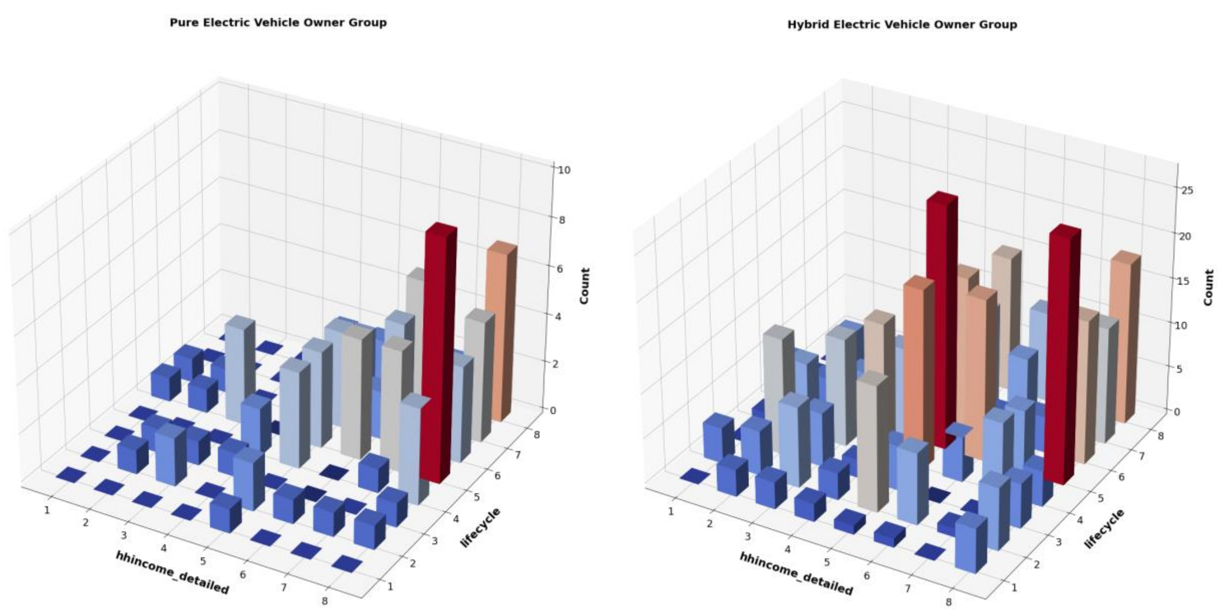

Figure 18. Joint Effect of Household Income Level and Lifecycle

Figure 19 shows that no matter what specific EV type owner group, the majority of these vehicles are owned by households with one to two workers and with relatively high education level attained, with BEVs also linked to households with a higher proportion of workers.

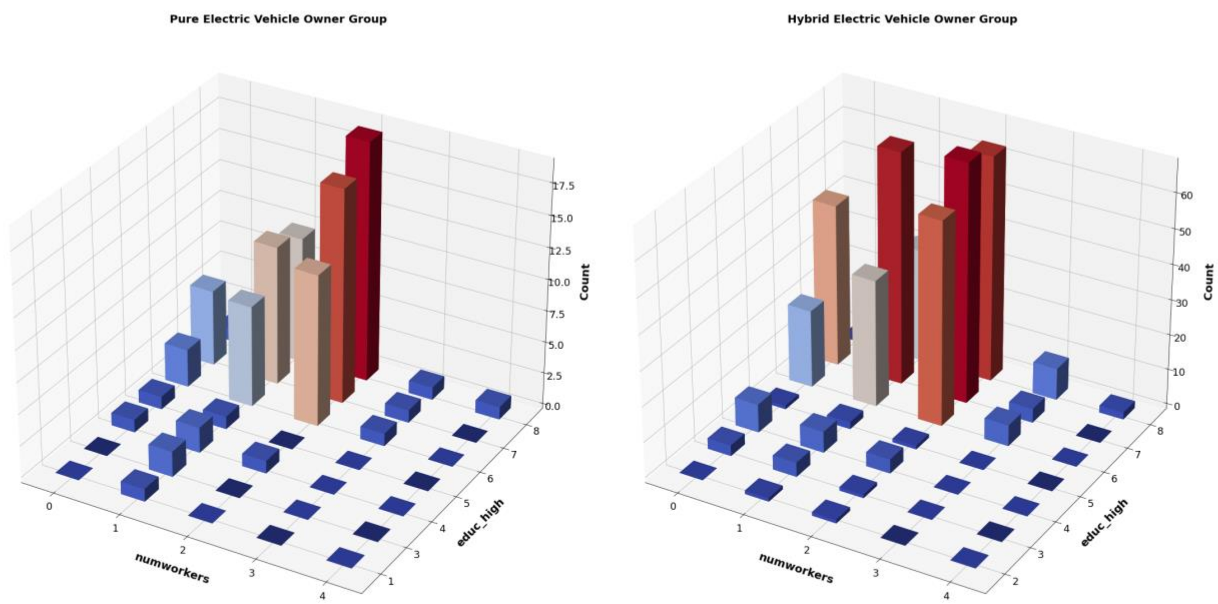

Figure 19. Joint Effect of Number of Workers and Highest Education Level

Comparative Analysis of Person-Level Demographics

With Person ID and Vehicle ID information available, household specific vehicles were able to be matched to specific household members. Specific EV users were also compared across different EV types regarding person-level demographic features as listed in Table 5.

Table 5. Variables for Person-Level Demographics

Variable	Definition	Variable Type	Values
Person-level Socio-demographic Attributes			
AGE	Household member age	Categorical variable	1: 16 - 17 years 2: 18 - 24 years 3: 25 - 34 years 4: 35 - 44 years 5: 45 - 54 years 6: 55 - 64 years 7: 65 - 74 years 8: 75 - 84 years 9: 85 or years older
GENDER	Household member gender	Categorical variable	1: Female 2: Male 3: Another 4: Prefer not to answer
EMPLOYMENT	Household member employment type	Categorical variable	1: Employed full time 2: Employed part time 3: Unpaid volunteer or intern 4: Self-employed 5: Homemaker 6: Retired 7: Not currently employed 8: Missing: skip logic
EDUCATION	Household member education attainment	Categorical variable	1: Less than high school 2: High school graduate 3: Associates degree 4: Some college 5: Vocational/technical training 6: Bachelor degree 7: Graduate/post-graduate degree 8: Other
RACE_CATEGORY	Household member race	Categorical variable	1: White only 2: Hispanic 3: Asian 4: African American 5: Child 6: Other 7: Missing

Figure 20-Figure 24 present the grouped heatmaps for each feature. Table 6 and Table 7 show the summary statistics for the corresponding t-test and chi-square test results for person-level demographic factors. Interestingly (but not surprisingly), none of the t-tests or chi-square tests show a statistical significance of any of the person-level input variables. Generally speaking, the vehicle purchasing decision may be more of a household-level decision than a person-level decision (considering that vehicles within a household may be shared by different members and

used for different trips). For age distribution, people from 35 to 54 years old display the largest differences in their choice between HEVs and BEVs. Regarding gender, women seem to prefer the hybrid type over the pure BEV type, while men take a slightly higher proportion in BEV owners (Figure 21).

Table 6. Summary Statistics for T-Test Results on Person-level Demographics

Variable Name	Test Statistics	P Value
age	-0.4523	0.6512
education	-1.3665	0.1722

Table 7. Summary Statistics for Chi-Square Test Results on Person-level Demographics

Variable Name	Test Statistics	P Value
gender	1.7954	0.1803
ifemployedfulltime	0.344	0.5575
ifselfemployed	1.603	0.2055
ifretired	2.6759	0.1019

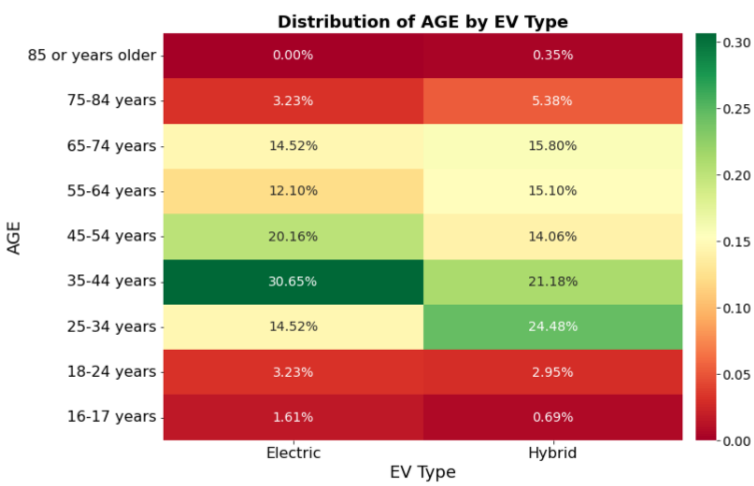

Figure 20. Age Distribution

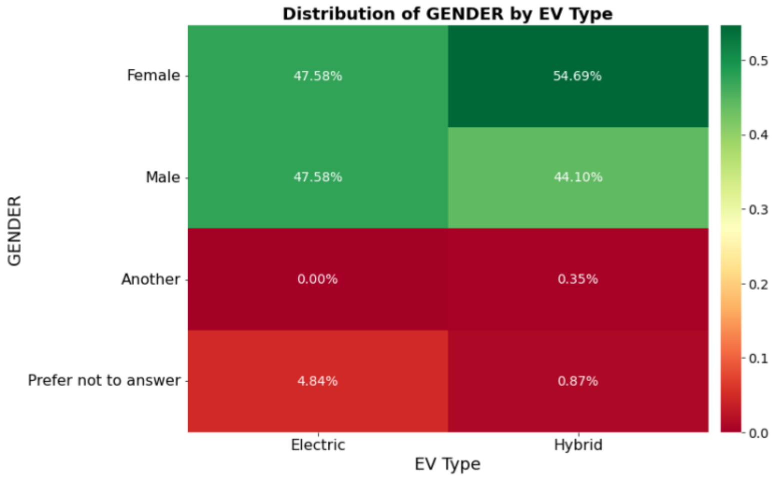

Figure 21. Gender Distribution

Regarding employment type, the biggest differences spotted between different EV type owners lie within household members employed full time (more BEVs) and household members retired (more HEVs), seen in Figure 22. However, regarding specific person-level education level, no big difference was found between different EV type owner groups, as seen in Figure 23.

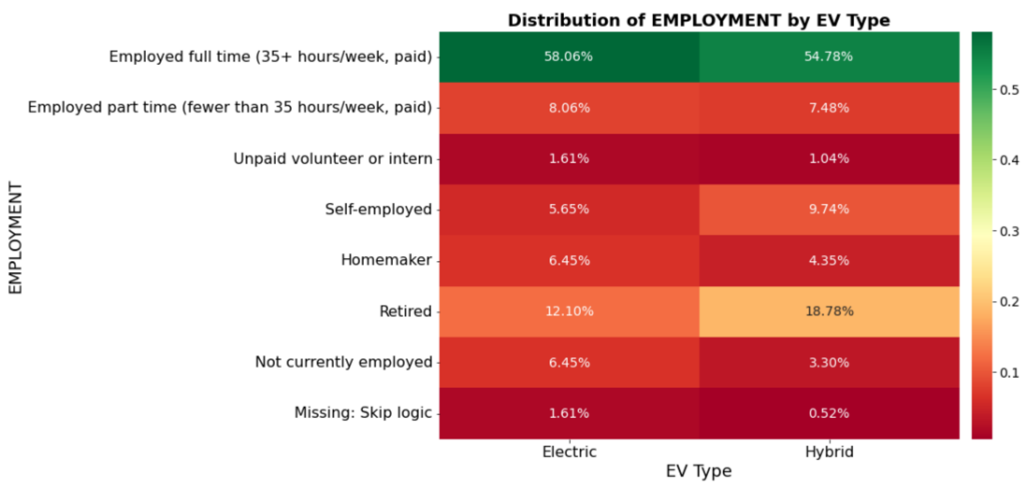

Figure 22. Employment Type Distribution

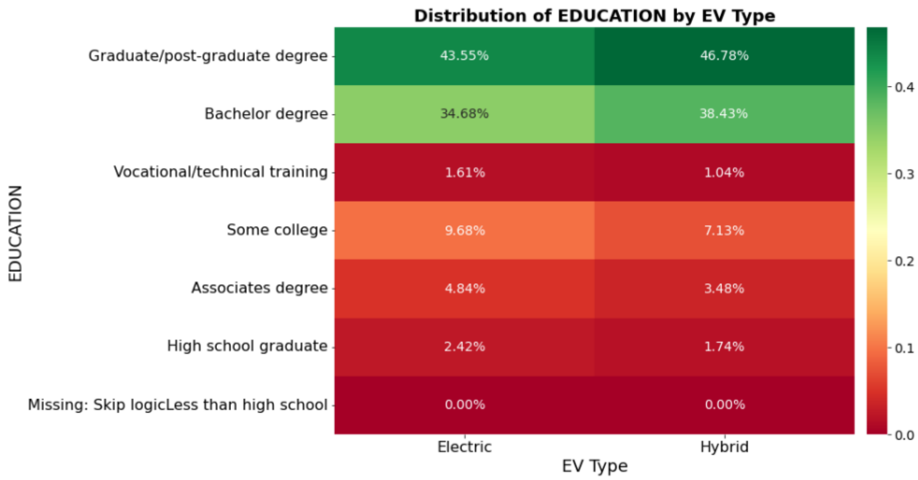

Figure 23. Education Level Distribution

A comparison of the race and ethnicity between different EV type owner groups, seen in Figure 24, indicates that household member's race did not display a great difference between different EV type groups.

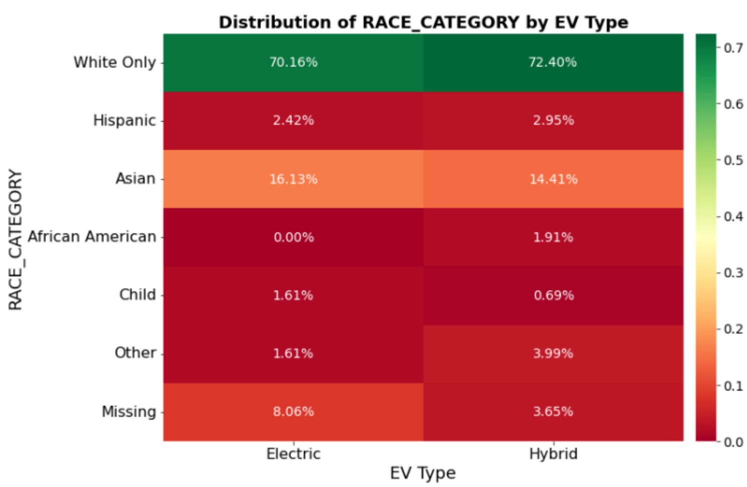

Figure 24. Race Distribution

Correlation was also calculated towards person-level demographics as visualized in Figure 25 below. The gender feature was transformed into a dummy variable with female being 1 and male being 0, and the employment feature was transformed into three dummy variables to represent the three categories displaying the most distinctive differences spotted. To no surprise, results indicated a relatively high correlation between age and the employment type.

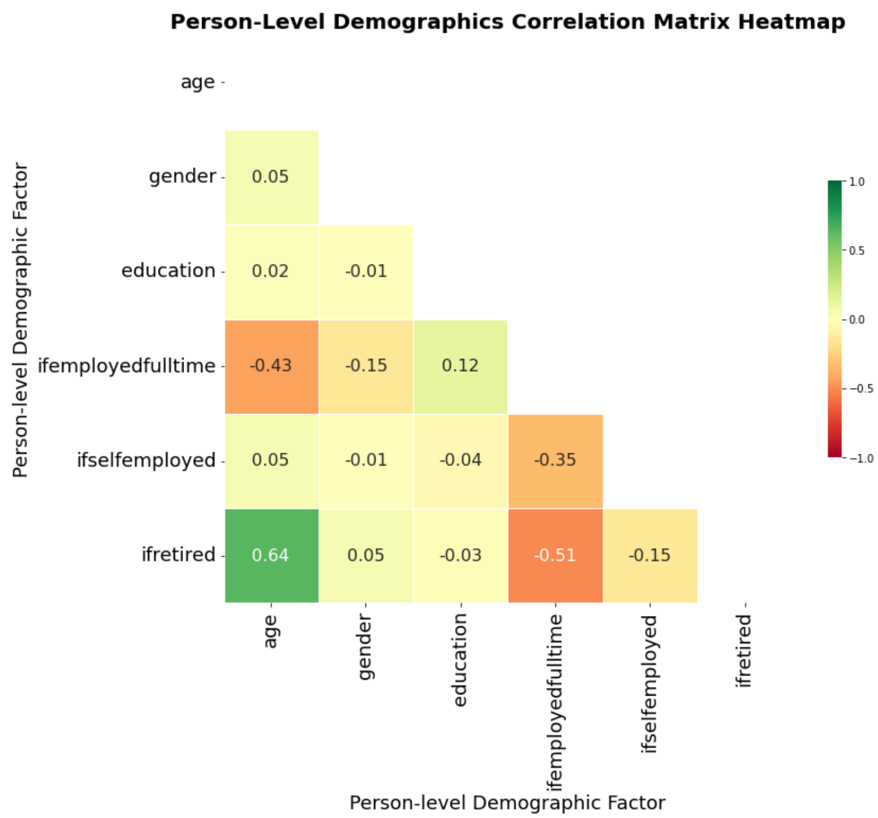

Figure 25. Correlation Heatmap of Person-Level Demographics

Further visualization of multi-factor relationship provided us with more insights into HEV/PHEV-drivers and BEV-drivers with ‘Prefer not to answer’ and ‘Missing skip logic’ answers removed. Figure 26 shows that middle-aged male drivers prefer BEVs, while young to middle-aged female drivers tend to choose HEVs.

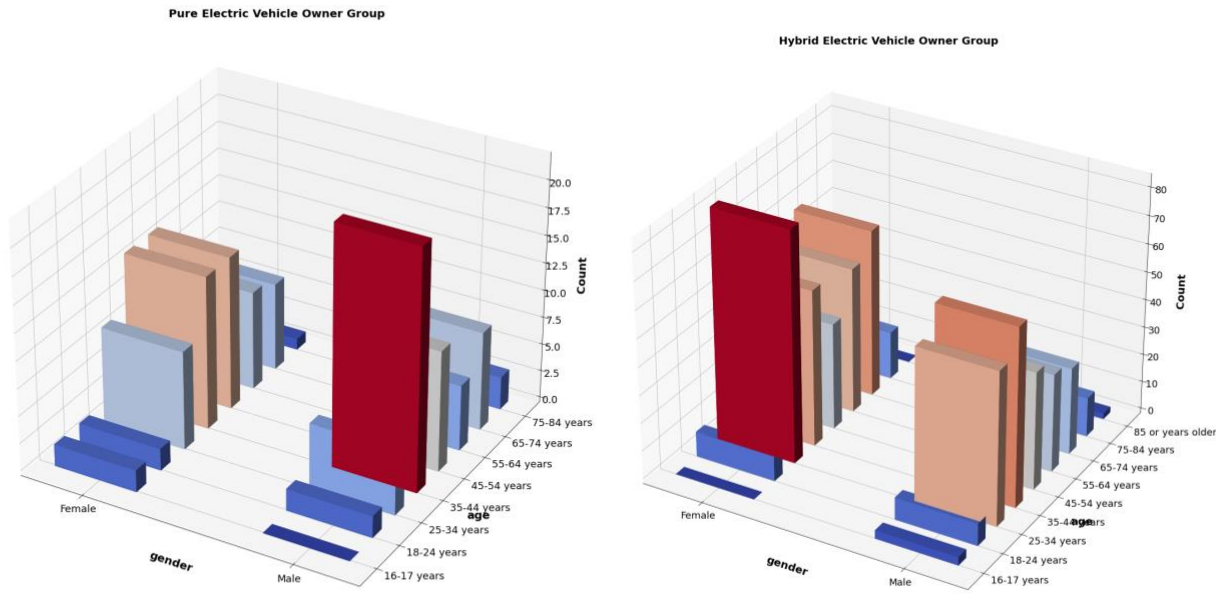

Figure 26. Joint Effect of Gender and Age

Figure 27 shows that most EV-drivers lie in young to middle-aged full- employed workers, and the main difference spotted between HEV owners and BEV owners lie in different age categories, overall, the age group of HEV/PHEV owners are relatively younger than are BEV owners.

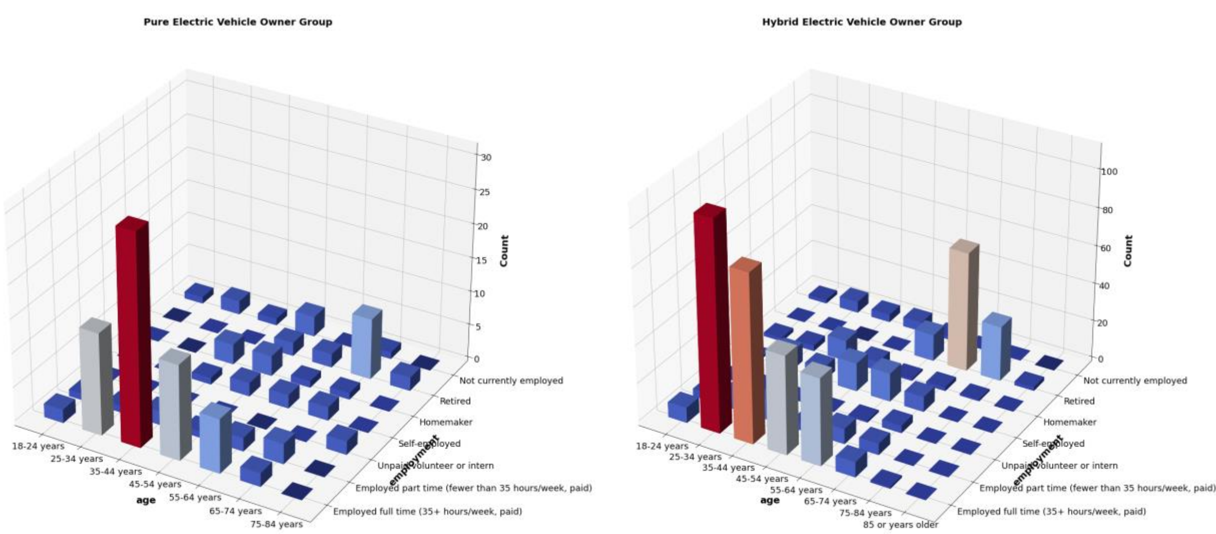

Figure 27. Joint Effect of Age and Employment Type

Figure 28 displays the main group for driving EVs regarding age and education, people with bachelor's degrees and aged from 25 through 34 are main drivers for HEVs/PHEVs, while people with graduate or higher degrees and aged from 35 through 44 tend to own more BEVs.

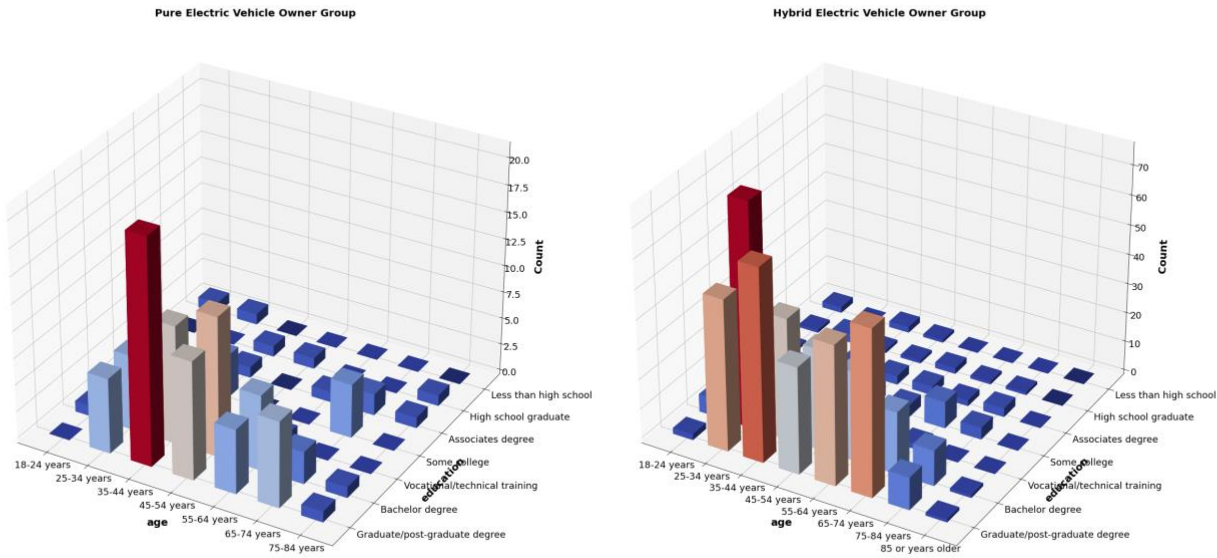

Figure 28. Joint Effect of Age and Education Level

Figure 29 finds that the main differences for different EV types chosen regarding gender and employment type lies in full-time female workers (who tend to prefer HEVs over BEVs) and unemployed females.

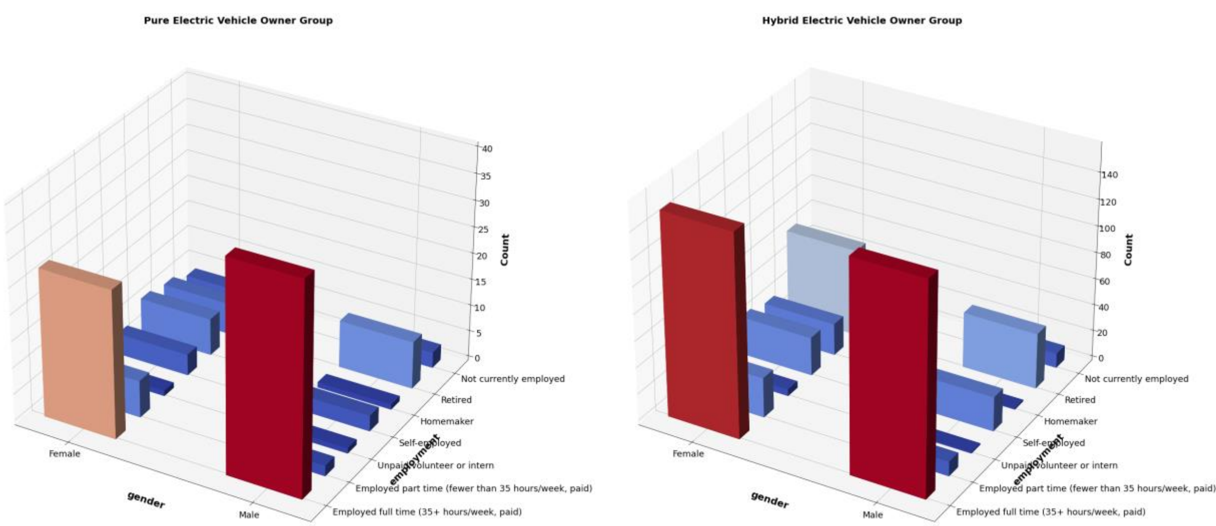

Figure 29. Joint Effect of Gender and Employment Type

Figure 30 shows that the main differences lie in hybrid-type EV owners regarding gender, while male and female drivers with at least bachelor's degree are evenly distributed within BEV owners, female drivers with at least bachelor's degree tend to choose HEV/PHEVs over BEVs.

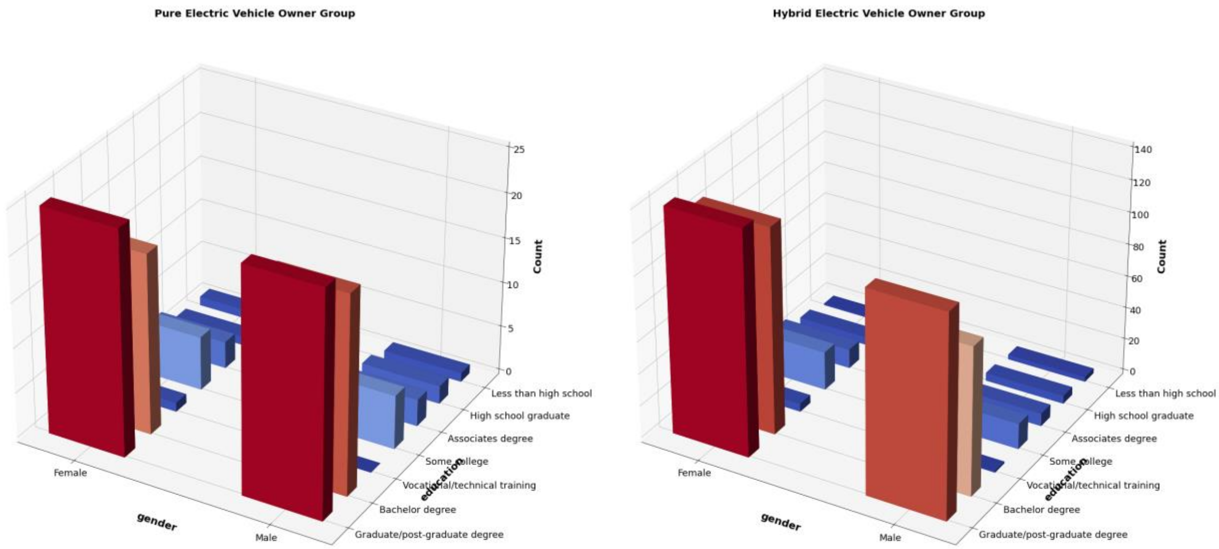

Figure 30. Joint Effect of Gender and Education Level

Comparative Analysis of Household Travel Patterns

As acknowledged in the literature, the biggest difference between HEVs and BEVs is their cruise range, as BEVs are only powered by battery packs without internal combustion engines, which will run out of energy before an equivalent size HEVs. Moreover, HEVs may operate differently under highway driving and local road driving. Existing EV operations studies point to the conclusion that different travel patterns, trip characteristics, and vehicle on-road operations could potentially influence households' purchasing decisions of specific vehicle type *(21, 22)*. For example, households driving long-range distances on a frequent basis might have a higher preference for more fuel-saving vehicles, but they could also have the concern that a BEV might run out of electricity during their travel day. Therefore, four trip-related attributes contained in the travel survey trip records were selected for comparison between HEVs/PHEVs-adopted trips and BEVs-adopted trips with extreme values removed, as listed in Table 8 below.

Table 8. Variables for Trip-Related Attributes

Variable	Definition	Variable Type	Values
Trip-Related Attributes			
REPORTED_DURATION	Reported trip duration in minutes	Continuous numerical variable	1 - 24
TRIP_PATH_DISTANCE	Google-estimated (rSurvey) or detected (rMove™) trip distance in miles	Continuous numerical variable	0.04 - 10
SPEED_MPH	Trip speed in miles per hour	Continuous numerical variable	0.5 - 57.5
TRAVELERS_TOTAL	Number of total travelers on trip (including self)	Discrete numerical variable	1 - 8

Figure 31-Figure 34 display the grouped histogram of selected trip-related attributes. Figure 31 shows the distribution of trip duration made by HEVs and BEVs. No distinctive difference in trip duration was spotted between these two EV types.

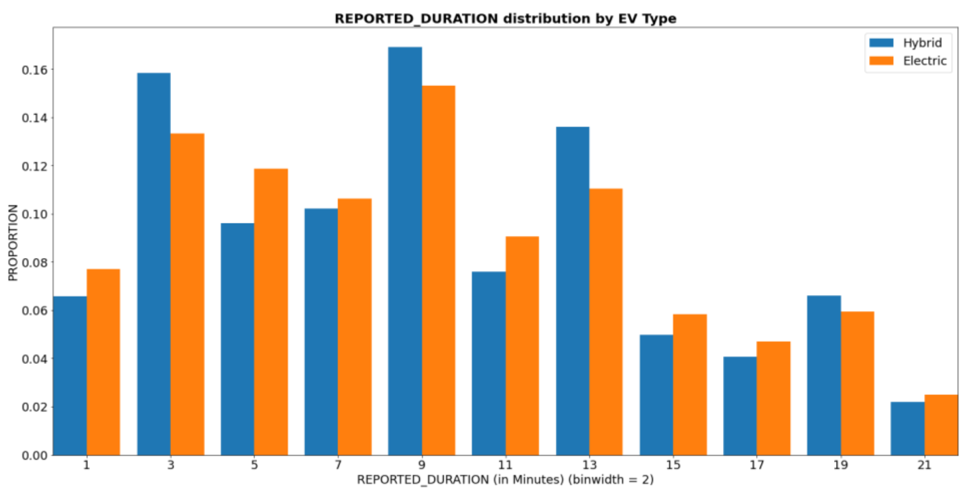

Figure 31. Distribution of EV-Trip Reported Duration

Trip path distance distributions were also similar for HEVs/PHEVs and BEVs , as seen in Figure 32. Because most of the trips recorded in the travel survey were under 10-miles range, battery pack capacity for BEVs is not a problem for these trips, which further reflects the fact that actual on-road trip range is not a main concern when purchasing EVs.

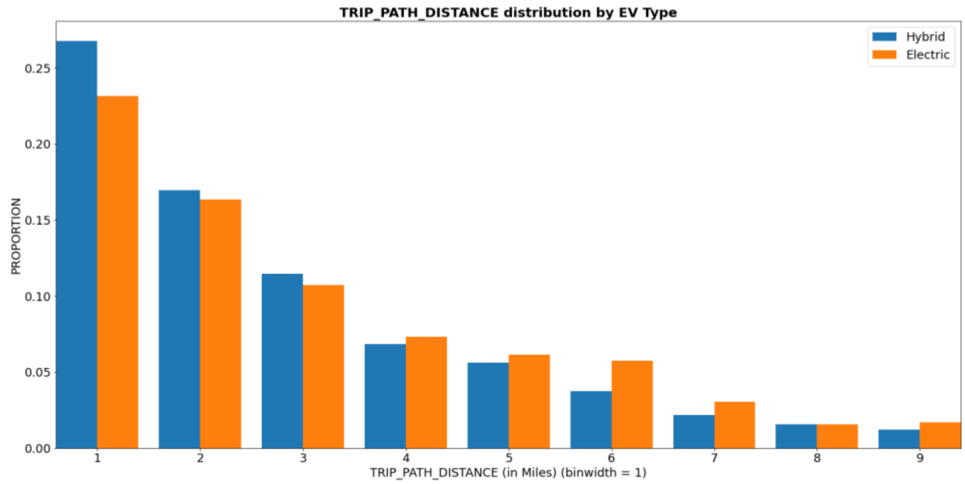

Figure 32. Distribution of EV-Trip Path Distance

Looking deeper into the average trip speed made by hybrid-type and BEVs, it was found that a higher proportion lies in high average speed by BEVs-adopted trips, seen in Figure 33.

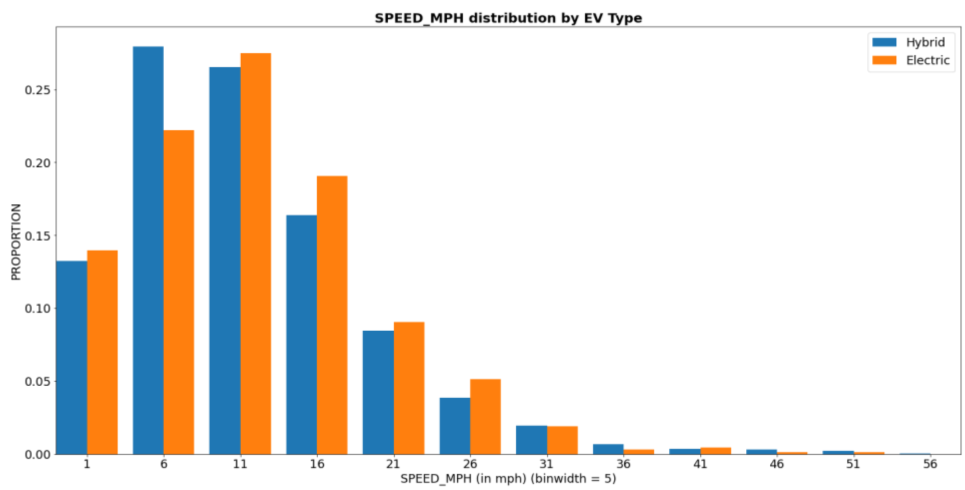

Figure 33. Distribution of EV-Trip Average Speed

Final exploration on total number of travelers in the car indicates that a relatively higher proportion of BEVs-adopted trips have only one driver inside the car, which could correspond to the household size characteristics of these households (Figure 34).

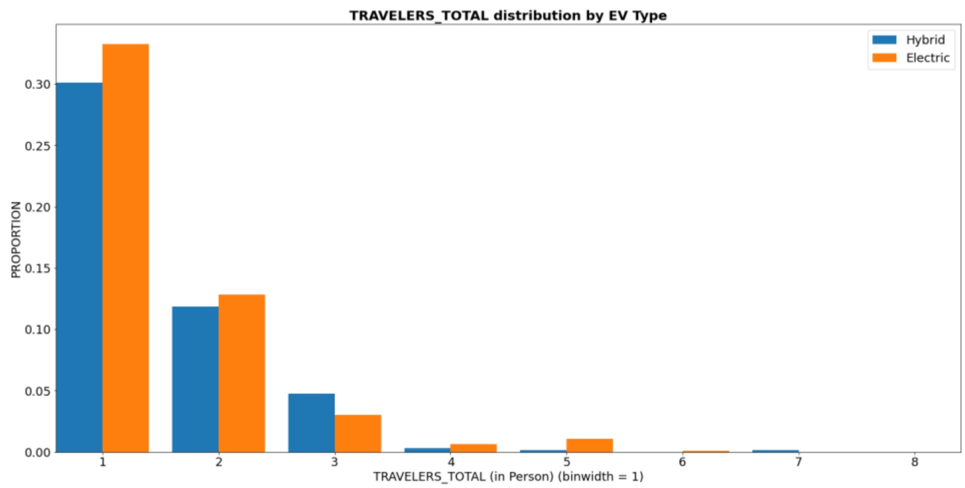

Figure 34. Distribution of EV-Trip Total Number of Travelers

Comparative Analysis of Household Energy Consumption

Another big difference between HEVs and BEVs is their energy use and emission, as HEVs/PHEVs have two powertrains, consume gasoline/diesel, and therefore emit pollutants during on-road operation, while BEVs depend only on electricity (where pollutants are emitted at the power generation source) and do not contribute to on-road emissions. The energy consumption of HEVs/PHEVs-adopted trips and BEVs-adopted trips were calculated and compared using an EV modeling tool *(23)*, which was developed via a full-vehicle simulation modeling approach (Autonomie) for various EV types and then mapped to the USEPA MOVES modeling approach for on-road vehicle operating conditions. The calculation of trip energy consumption was conducted through the fuel rate and electricity rate extracted from the tool (BEVs have a zero fuel rate naturally) and the average speed and miles traveled information extracted from the travel survey trip records, as well as the specific vehicle make and model information extracted from the travel survey vehicle data, with the assumption that the initial state of charge being 0.9, and average speeds higher than 50 mph are associated with highway activity and lower than 50 mph are associated with arterial and local road activity. The comparison between specific EV type groups was conducted through four metrics: average energy consumption per trip, average mileage per trip, total energy consumption per day and total mileage per day.

A comparison of the average mileage per trip, seen in Figure 35, shows generally a lower mileage traveled by BEVs than HEVs/PHEVs. Moreover, while the average mileage of BEVs-adopted trips was concentrated towards relatively short trip distances (less than 20 miles), the average mileage of HEVs/PHEVs-adopted trips within some households can reach much higher values (25-50 miles).

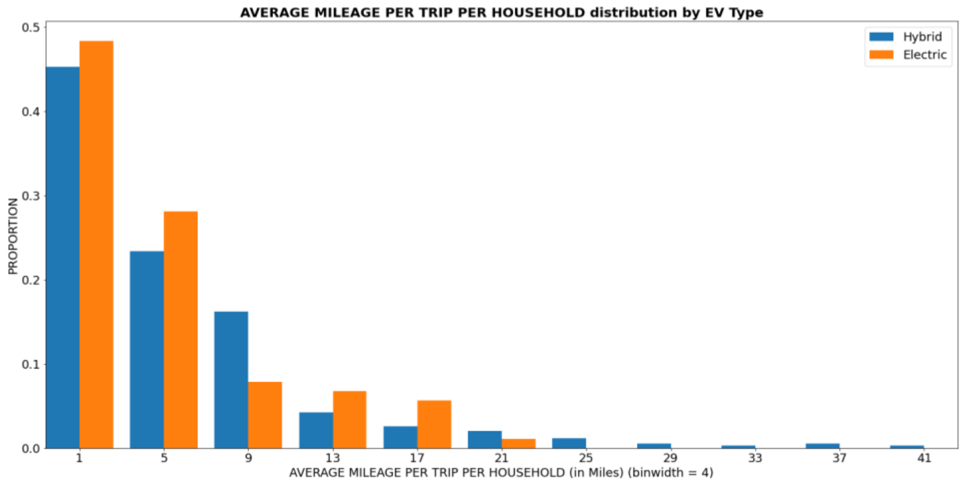

Figure 35. Distribution of Average Mileage per EV-Trip

The comparison of average energy consumption per EV-adopted trips, seen in Figure 36, displays the trend that BEVs-adopted trips generally consumed less energy than HEVs/PHEVs-adopted trips, taking a much larger proportion in the range of 0-10 MJ per trip uses.

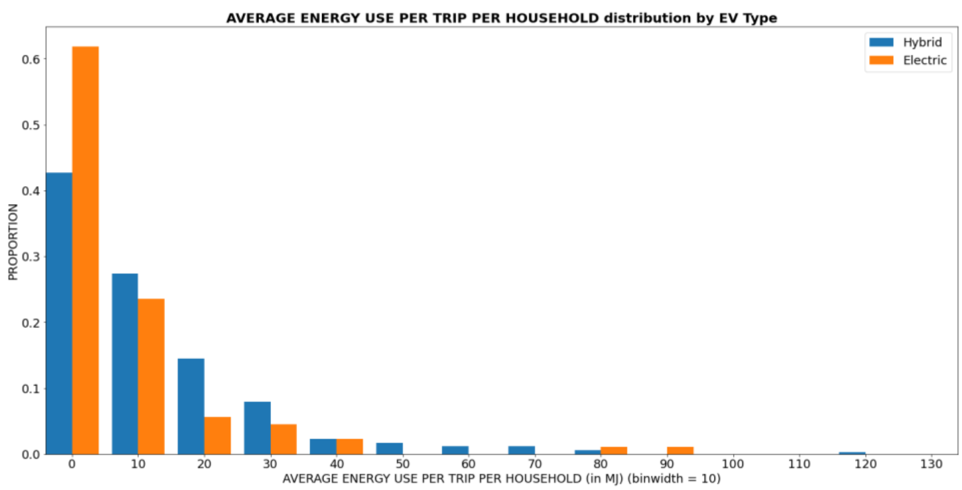

Figure 36. Distribution of Average Energy Usage per EV-Trip

A further comparison on the sum of energy use and mileage traveled per day are shown in Figure 37 and Figure 38. While the previous table reported shorter trips per BEV, total household mileage within these households tends to be larger than that of HEV households. This likely correlates with total vehicle ownership within the household, with some combination of more vehicles available to make trips and more trips per vehicle per day.

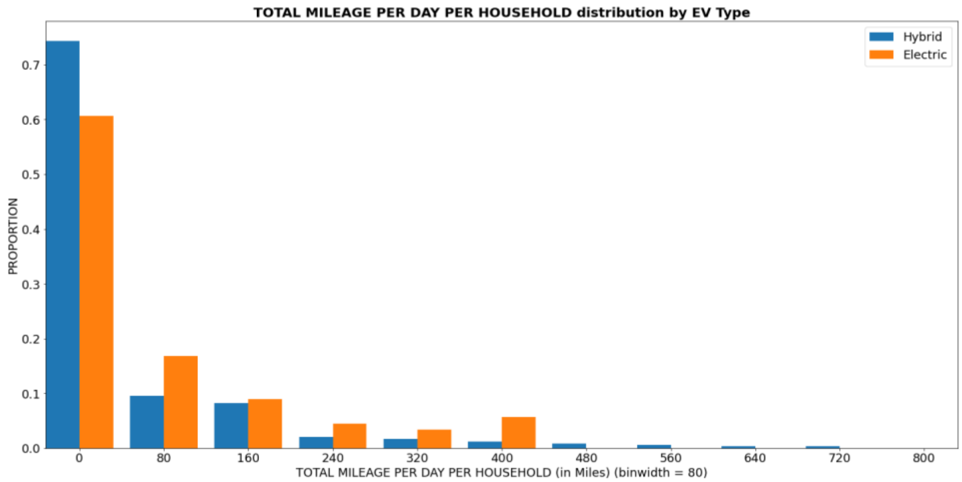

Figure 37. Distribution of Total Mileage per Day per Household

While the total mileage traveled per day of BEVs-households are found to be generally higher than HRVs/PHEVs-households, the comparison of total energy usage per day still shows that the total energy consumption of BEVs-adopted trips are relatively lower than HEVs/PHEVs-adopted trips, given the efficiency of BEVs.

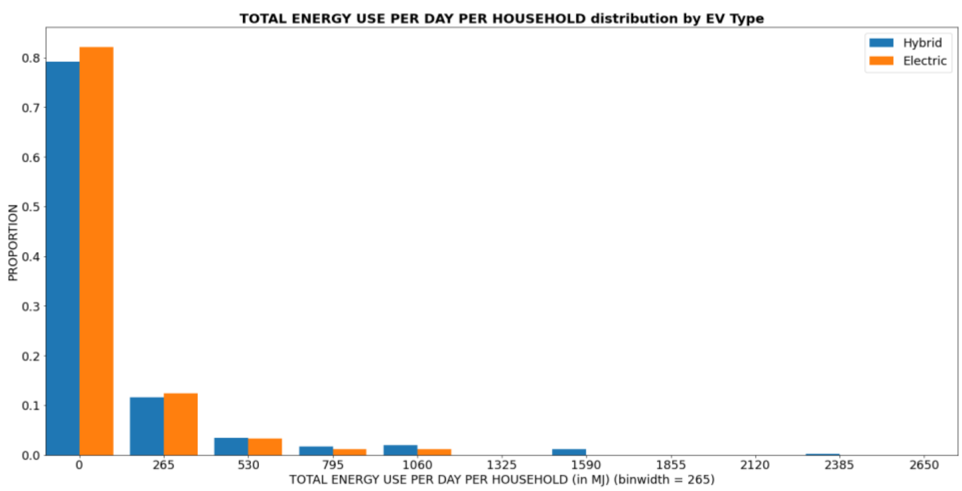

Figure 38. Distribution of Total Energy Usage per Day per Household

Comparative Analysis of Public EV Charging Station Availability

In addition to the features identified in the PSRC travel data, the literature indicated that EV charging station availability was expected to influence customers' choice of purchasing EVs *(6,7)*. Therefore, availability of public EV charging stations at household residences, trip origins, and trip destinations were checked using the AFDC EV charging station location data *(24)* and location census tract information, and then compared between hybrid-type EV owners and BEV owners.

Out of 545 EV-households, only 13 households' tracts have EV charging stations, as shown in Figure 39. Almost no difference (1% vs 2.7%) was observed between different EV type owner groups but is worth further exploration to see whether these households are high-density apartment-dwellers.

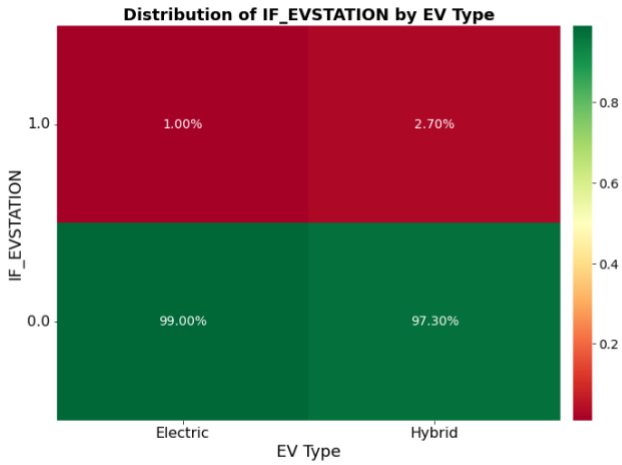

Figure 39. EV Station Availability Distribution (Household Residences)

Like the findings regarding household residence locations, no difference was found in public EV charging station availability in trip origins and destinations, as shown in Figure 40. Out of 5,695 EV-adopted trips, only 221 trips' origin tracts have EV charging stations and only 224 trips' destination tracts have EV charging stations.

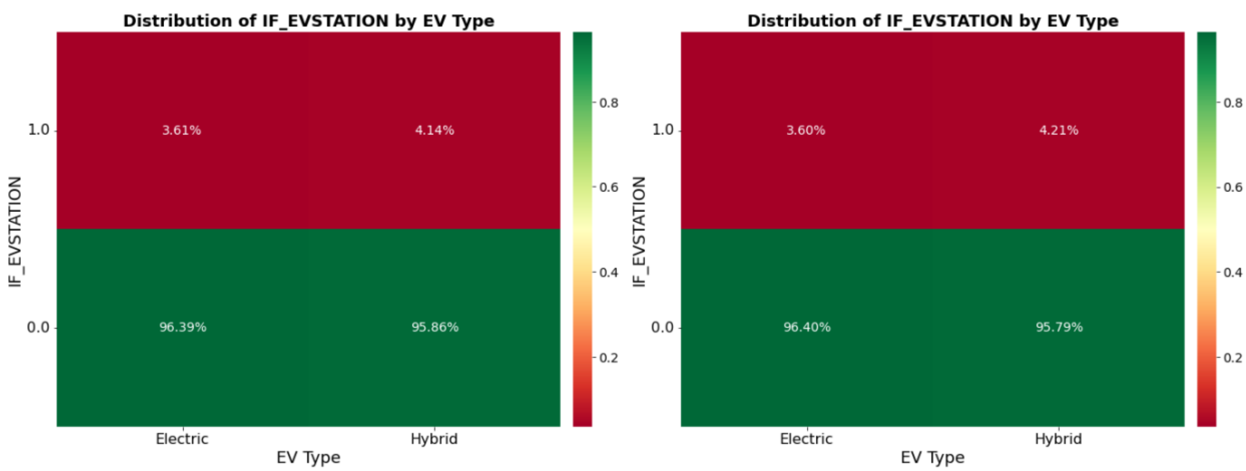

Figure 40. EV Station Availability Distribution (Trip Origins and Destinations)

The findings above regarding public EV charging station availability indicated that for households' choice towards specific EV types, the availability of public EV charging stations does not appear to be an influential factor yet. The fact that most census tracts of household residences, trip origins, and trip destinations have no public EV charging stations also reflected the fact that EV owners charge their vehicles at private locations (e.g., home charging).

Household EV Type Choice Model

With knowledge on what features could potentially influence households' choice between hybrid-type and pure BEVs regarding household demographics and trip-related attributes, a two-stage choice model was developed. The purpose of the first stage is to identify potential EV-purchasing households and the goal of the second stage is to predict their choice between HEVs and BEVs. The specific modeling process and methods adopted during the first stage is outlined in a related research paper *(25)*, which proposes a data-driven model to assess the potential of EV purchase and corresponding EV adoption to specific trips. This research makes use of the first modeling stage in that paper, which identifies the potential EV-purchasing households based on their similarity measure to current EV owners (weighted Euclidean distance calculations), as well as a kernel density probability estimation. The current EV market penetration rate in Puget Sound region as reflected in the PSRC travel survey data is around 8.5%. Two future EV market penetration rate assumptions were proposed for this study: 15% and 30% (a projected penetration rate estimated by Statista *(26)* for the year 2030). For predictions, 403 households were selected as targeted households to purchase an additional new EV or replace an old vehicle with a new EV for the 15% market penetration rate assumption, and 1,351 households were potential EV purchasers for the 30% rate assumption. Tree-based models were considered in this research for their potential to identify important variables affecting variability in ownership decisions (feature identification). A gradient-boosted decision tree model was built at the second stage, as a binary classification problem, to predict between the hybrid type class and pure type class. The proportion of HEVs/PHEVs-households and BEVs-households is around 4.5:1, which makes the training data an imbalanced set and requires some resampling effort. Random resampling method and Synthetic Minority Over-sampling Technique (SMOTE) were adopted to oversample the minority class to adjust the training set for better capturing the characteristics of BEV owners. Random resampling method simply duplicates examples from the minority class from the training set, but add no additional information to the model, while SMOTE is a type of data augmentation based on the synthetization of new examples from the existing examples by selecting examples that are close in the feature space, drawing a line between the examples in the feature space, and drawing a new sample at a point along that line *(27)*. Data pipelines were built for automating the process of tuning the hyperparameters and making predictions for households under different scenario assumptions.

Prediction results using either the random resampling method or SMOTE under the two future market penetration scenarios were shown in Table 9, from which conclusions could be drawn that the vast majority of the potential EV-purchasing households will choose the hybrid type, as HEVs/PHEVs are relatively less priced, thusly setting fewer obstacles for potential buyers, which also corresponds with the forecast by Frost and Sullivan that HEVs/PHEVs will account for the maximum market share of 89.6% in the EV market by 2025 *(28)*.

The researchers further explored the average probability of household groups with the largest differences identified in the comparative analysis above to purchase HEVs/PHEVs or BEVs by running the model 100 times per comparison (under the 30% market penetration rate). As indicated by current market penetration rates, more households across all demographic groups purchase HEVs/PHEVs than BEVs. However, the analyses do show differences in the BEV purchase decisions within and across demographic criteria using both the random resampling and SMOTE methods (Table 9). The first round compared single-person households with one vehicle available vs. multi-person households with more than one vehicle and confirmed that multi-person households with more than one vehicle have a much higher probability of purchasing BEVs. The difference observed between the random resampling method and SMOTE was due to the characteristics of these two methods as mentioned above, with SMOTE adding additional information to the model while random resampling does not, the large difference also reflected the fact that household size and vehicle ownership exert a large influence in vehicle purchasing decisions. The second round explored the influence of age range, with results showing that households with members in middle age rages have a much higher probability of choosing BEVs. The last comparison round examined the threshold of household income of $150,000, confirming that households with income larger than $150,000 are much more likely to purchase BEVs over HEVs than the other income groups. These findings not only further strengthen the findings observed in the comparative analysis, but also provide a statistical method to estimate the probability of a certain household group to choose between HEVs/PHEVs and BEVs.

Table 9. Predicted EV Type Under Future Market Penetration Scenarios

Method	Random Resampling	SMOTE
Predicted Number of Households to Purchase Specific Type of EVs		
Market Penetration Rate 15%		
HEVs/PHEVs	382	380
BEVs	21	23
Market Penetration Rate 30%		
HEVs/PHEVs	1,258	1,273
BEVs	93	78
Predicted Probability of Certain Households to Purchase Specific EV Types for 30% Market Penetration		
Single-person Households with One Vehicle		
HEVs/PHEVs	95.43%	61.76%
BEVs	4.57%	38.24%
Multi-people Households with More Than One Vehicle		
HEVs/PHEVs	80.73%	58.50%
BEVs	19.27%	41.50%
Multi-people Households with Member Age from 18-34		
HEVs/PHEVs	95.28%	92.34%
BEVs	4.72%	7.66%
Multi-people Households with Member Age from 35-64		
HEVs/PHEVs	81.54%	80.85%
BEVs	18.46%	19.15%

Method	Random Resampling	SMOTE
Households with Income Below $150,000		
HEVs/PHEVs	90.94%	91.29%
BEVs	9.06%	8.71%
Households with Income Above $150,000		
HEVs/PHEVs	81.66%	79.93%
BEVs	18.34%	20.07%

Conclusions

In this study, a comprehensive comparative analysis was conducted for households that own HEVs/PHEVs and BEVs with respect to household-level demographics, person-level demographics, trip-related attributes (including mileage traveled and trip average speed), and energy consumption characteristics, using data from the 2017-2019 PSRC travel survey as the case study. The purpose of the comparative analysis was to explore significant factors influencing potential EV-purchasing households' decisions of specific EV types and identify factors that may have been overlooked in previous studies given that different types of EVs (HEVs/PHEVs and BEVs) are adopted by widely different types of households and have very different energy usage profiles. The exploratory nature and findings of the research provide stakeholders, policymakers, and researchers with an enhanced understanding of household choices across specific types of EVs, which also helps link policymaking and EV marketing.

Features examined during the comparative analysis led to the development of a two-phase choice model to determine potential EV-purchasing households and their choice of the specific EV type. Prediction results under two future market penetration rate assumptions of 15% and 30% found that the vast majority of the potential buyers will choose the hybrid type, as they are relatively more affordable to most households and may alleviate range anxiety (which may not be a real issue given the daily mileage comparison of HEVs vs BEVs).

Comparison results indicate that the largest differences in HEV vs BEV selection still lie in household size, together with collateral features such as household vehicle ownership and number of workers. Households with more household members and middle-aged members that are fully employed with substantial income were found to be the main owners of BEVs, while HEV-ownership are found in a wider distribution across demographic factors. With respect to miles traveled by EV-adopted trips, no major difference was spotted between HEVs/PHEVs-adopted trips and BEVs-adopted trips, which led us to the conclusions that BEVs could generally serve for daily travel needs without concern for running out of battery charge. Moreover, current all-electric ranges in multi-vehicle households may not be a major concern in EVs purchases, and household range anxiety is likely to be even further diminished as larger BEVs with greater range continue to enter the market and become price-accessible to the general public. When combined with energy usage profiles, BEVs were found to be used for more frequent but shorter trips (likely due the higher uptake in more urbanized areas), and though total mileage traveled per day seemed to be generally higher, their energy consumption was still much lower than the HEVs/PHEVs. The research findings regarding the differentiation of hybrid and pure type EV users along with the choice model for specific EV type are expected to significantly enhance future travel demand model development, allowing activity-based travel demand models to assign specific vehicles to specific households and specific vehicles to trips in planning scenario analysis for future years, as well as assisting in the design and promotion of EV incentive and marketing programs for target populations, as EVs continue to capture increasing market shares over time.

While the findings of this study are important, the research is based entirely on relatively recent survey data. As electric vehicle technologies continue to evolve, the vehicle market will respond to significant vehicle technology breakthroughs, such as range and performance. Forthcoming changes in federal and state EV purchase incentives will also affect the market. Hence, the findings and patterns discovered through the research may not hold true over time, as changes in technology and economic incentives roll out. For example, the impact of range limitations on purchase decisions may be alleviated as battery size continues to grow (provided these vehicles are affordable). Larger families (household size) may also be incentivized to purchase larger-sized BEVs that become available in the market. Hence, it may not be appropriate to draw strong conclusions about future consumer preference based upon past revealed preference data in a rapidly changing market. This highlights the need for ongoing purchase and use data collection and future research designed to develop time-series models for the adoption of EVs over time, as factor importance across demographic groups continues to evolve.

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Data Summary

The main data used in this research is the Puget Sound Regional Council travel survey data 2017~2019, is obtained and extracted from online open resource Puget Sound Regional Council official website (www.psrc.org). The data contains highly granular data regarding household-level and person-level demographics, household vehicles and household trips. Necessary data cleaning, data processing and data recoding steps have been conducted for specific research purposes.

Products of Research

The data set used is the 2017-2019 Puget Sound Region Household Travel Survey data.

Data Format and Content

Data was obtained and downloaded in csv format, specifically for each file the content is listed below:

- 2017-2019-pr2-1-Household.csv: contains household level demographic information, 97 columns and 6,320 rows in total.
- 2017-2019-pr2-2-Person.csv: contains person level demographic information, 124 columns and 11,941 rows in total.
- 2017-2019-pr2-3-Vehicle.csv: contains household vehicle information, 11 columns and 8,088 rows in total.
- 2017-2019-pr2-4-Day.csv: contains trip day information, 69 columns and 30,883 rows in total.
- 2017-2019-pr2-5-Trip.csv: contains collected household trip information within one week, 121 columns and 124,517 rows in total.

Data Access and Sharing

The data is available at: https://household-travel-survey-psregcncl.hub.arcgis.com/

Reuse and Redistribution

The data is open sourced by Puget Sound Regional Council, further reuse and redistribution of the data should contact PSRC Program Manager Brian Lee at blee@psrc.org.