Evolve:

Charging You Into the Future

Ramisa Fariha

Ryan Mai

Daabir Momin

Yobel Polestico

SEEA - Evolve Houston

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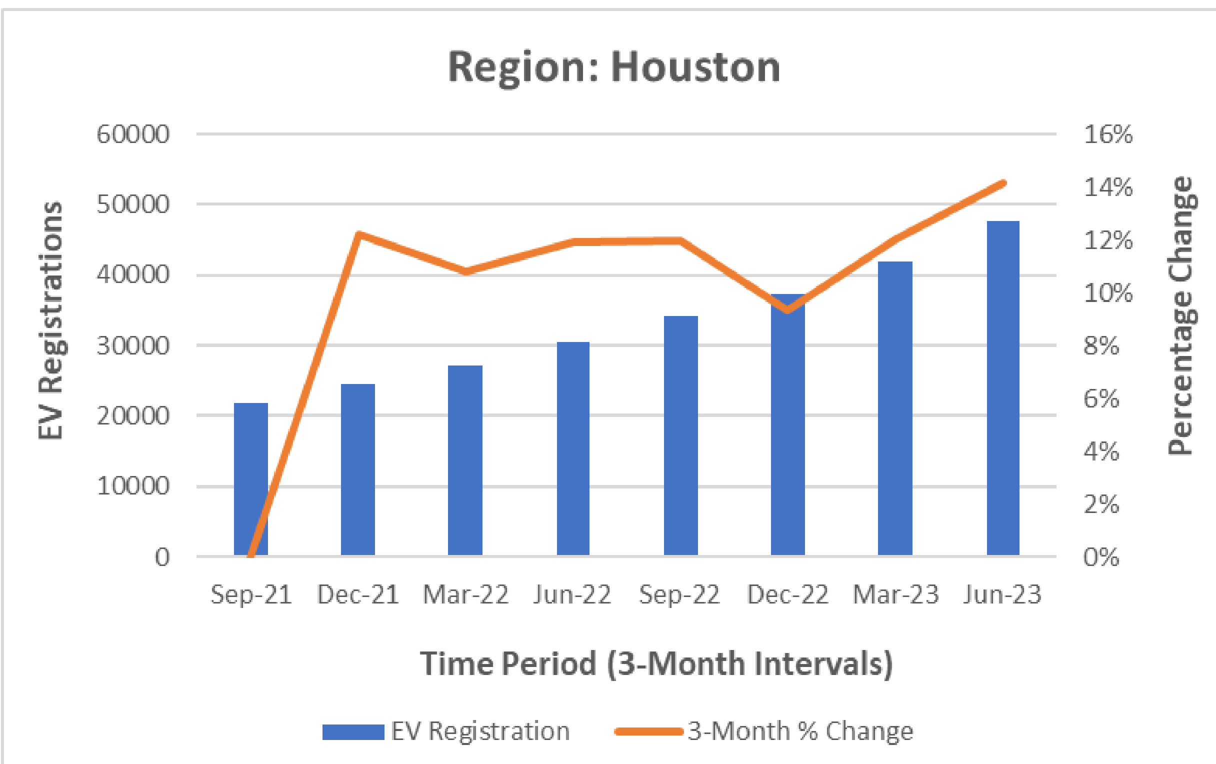
Introduction

Evolve Houston is a nonprofit organization whose goal is to improve the air quality of the Houston area through greater adoption of electric vehicles (EVs). In the view of Evolve Houston, motivated firms are willing to direct their investment in more sustainable and green solutions regarding transportation, though these firms' concerns about efficient resource allocation are apparent. This is when Evolve Houston can step in and make recommendations to efficiently redirect such investments. Thus, Evolve Houston desires to examine and determine the significance of distinct factors that could greatly influence the adoption of EVs. Our team's goal is to identify and quantify the importance of different factors affecting the adoption of EVs. Our approach is to perform an econometric analysis using data on EVs as a percentage of all cars to serve as a proxy for EV adoption. We then incorporate data on certain factors, such as the count of gas stations and multi-family housing by ZIP code, run a linear regression, and produce suggestions toward Evolve Houston's goal.

Background

The Houston region is becoming one of the fastest growing markets for EVs in the United States, as EV registrations in the Houston region have more than doubled within the last two years (DFW Clean Cities Organization and North Central Texas Council of Governments 2023).



Source: DFW Clean Cities Coalition

The recent exponential growth in EV demand in the Houston region makes it necessary for EV infrastructure to accommodate such growth. Although the Houston region is making significant strides in providing EV charging stations to areas with high EV adoption, especially in urbanized areas, there is still a significant amount of areas within the Houston region that lack sufficient EV infrastructure (DFW Clean Cities Organization and North Central Texas Council of Governments 2023). Many of these areas within the Houston region that have lower amounts of EV infrastructure tend to have lower EV adoption. Furthermore, there also exist areas in the Houston region that do have higher EV adoption but have surprisingly fewer EV infrastructures than expected. These observations serve as intriguing, but vital takeaways in analyzing the current state of EV adoption in the Houston region. To help achieve Evolve's mission of attaining equitable EV adoption in the Houston region, our project explores the correlations that could not only help explain the reasons for the current status of EV adoption in Houston, but could also help further bolster EV adoption in Houston.

This project's main area of interest is Greater Houston, an area divided by nearly 300 ZIP codes. There are approximately 48,800 EVs registered within this area, which amounts to 24.07 percent of the EVs in Texas (DFW Clean Cities Organization and North Central Texas Council of Governments 2023). While the state of Texas ranks relatively favorably in terms of EV registrations, the Houston area itself lags behind other major metro areas. This is seen when compared to other metro areas like Seattle or Dallas, as the Houston area is described to be behind in "EV friendliness," indicating more effort needs to be taken in this regard (Mericas 2023). This all suggests that the Houston area is a prime target for analysis and recommendation for EV adoption.

When it comes to EV adoption, it is important to review the potential factors involved. According to Kumar and Alok (2020), EV adoption factors lie in various categories, all with varying levels of relevance or effects. For this project, we look at socio-demographic variables and antecedents, with the latter being described as barriers or motivators to EV adoption. The key factors that our team considers are the ratio of electricity and gas prices, the number of gas stations, the number of charging stations, multi-family housing, commute time, blue-collar workers, and service stations.

Intuition would hold that the price of gas would be relevant in predicting the adoption of EVs in a given area. Yet, literature holds that there may be limitations to this, as Sierzchula et al. (2014) find that the price of gasoline did not play as relevant of a factor as originally thought. In fact, Sierzchula et al. (2014) hold that the price of gasoline is statistically insignificant. The authors posit that the volatility of gasoline pricing may provide some explanation for this result. Given this, we have decided to use a ratio of electricity and gasoline pricing to capture their effects on EV adoption by ZIP code. We aim to find and compare these estimators with the findings by Sierzchula et al. (2014). In addition to this, we utilize the absolute count of gas stations in a given zip code to capture their respective effects on EV adoption.

The number of charging stations is a factor that makes intuitive sense, with literature supporting its relevance. For instance, Sierzchula et al. (2014) note the importance of charging infrastructure when discussing EV adoption. From the idea referenced by Sierzchula et al. (2014), our team has decided to also analyze the effect of charging stations on EV adoption in Greater Houston in our modeling.

One curious factor to note is multi-family housing. From our discussions with Evolve Houston, multi-family housing is thought to be a factor that would be negatively associated with EV adoption. The reasoning underlying this is that multi-family housing tends to have less suitable conditions for an EV charging station when compared to single-family housing. For instance, a single-family home can house a charging station in the garage, while multi-family housing may have limitations in this regard. Multi-family housing is thus a plausible factor to include in the model.

Another important factor to note is commute time. Despite factors relating to commuting being key to evaluating the adoption of vehicles, few studies have analyzed how commuting time affects EV adoption in the United States. The study conducted by Coffman et al. (2023) is one of these few studies, as the paper is focused on factors affecting EV adoption in Hawaii. When observing the effect of commute times on EV adoption in Hawaii, Coffman et al. (2023) discovered that longer (40+ minutes) commute times for drivers are negatively associated with the number of EVs registered in ZIP codes in Hawaii. With the idea of commuting time first conducted by Coffman et al. (2023), our study will also observe the association and effect that commuting time has on EV adoption in Greater Houston.

In addition to commute time, our team also considered the factors of blue-collar workers. Albeit more of a minority group in the Greater Houston population (Houston Public Health Data Portal 2023), blue-collar workers still play an essential role in the Greater Houston workforce. Furthermore, blue-collar roles, such as electricians (Dreibelbis 2022) and construction workers (ABC 2022), are crucial to the development and maintenance of EV infrastructures in Greater Houston. Our team includes the variable Blue-Collar Workers to observe whether blue-collar workers in Greater Houston are more or less likely to adopt EVs.

Vehicle services and repair stations are essential to vehicle maintenance. EVs are no exception. However, traditional gasoline vehicle maintenance and repairs are much different from EV maintenance, and general automotive repair shops are specialized to maintain and repair gasoline vehicles more often than EVs (VehicleServicePros.com 2023). In addition, many general automotive repair shops lack the financial resources, knowledge, and/or tools and equipment to invest in EV repairs (VehicleServicePros.com 2023). Because of these reasons, there exists an infrastructure barrier when it comes to EV adoption. Our team decided to include the variable Service Stations into our model to observe whether the effect of this infrastructure barrier on EV adoption exists in Greater Houston.

Methodology

The project is conducted using a linear-log regression model based on zip codes in the Greater Houston area. The dependent variable is the percentage of all vehicles that are EVs, found with car registration data from Evolve Houston. For the socioeconomic variables, our team has data for income, population density, and unemployment by using the American Community Surveys (ACS). Houston State of Health, a collaborative project for demographic information in the city of Houston, serves as our source for data on blue-collar workers.

We collected data on gas stations and auto service stations from Sage Data, which serves as a publisher of data from numerous government and private organizations. The data in this case is sourced from the US Census Bureau, where we could find an absolute count of gas stations and auto service stations at the ZIP code level. This is done by referencing the North American Industry Classification System to find the number of businesses registered as *Gasoline Stations* and *General Automotive Repair*. Regarding data for charging stations, we noticed that data for charging stations collected by Evolve was incomplete, as some ZIP codes simply lacked data in this area. Our team approached this issue by including a 5-mile radius to the outer regions of each ZIP code using data from the Alternative Fuels Data Center of the US Department of Energy. This method helps capture charging stations within the ZIP code level as well as of agglomeration economies, which better explains EV adoption within each ZIP code in relation to charging stations. Similarly, there was a challenge in gathering multi-family housing data, since the census data available tended to merge multi-family housing and single-family together. As a result, we found data from Zillow and Apartments.com, which gives counts on multi-family housing by zip code.

A ratio of electricity and gas pricing for each zip code is also added to the model, with the former being measured in average cents per kilowatt hour, and the latter being measured in average price per gallon. Data for electricity pricing is sourced from Texas Electricity Ratings, while data for gas pricing is sourced from GasBuddy, a technology company that provides crowd-sourced information on gas prices. BestPlaces, which is a website that has various metrics on the quality of life for a given area, serves as our source for commute time, which is measured in minutes.

The econometric model used is specified below, where the dependent variable Y represents the percentage of vehicles that are classified as EVs. The variables of X_1 to X_{10} represent income, population density, unemployment, gas stations, charging stations, electricity/gas price ratio, multi-family housing, commute time, blue-collar workers, and service stations respectively. For this project, we hypothesize that income and charging stations are positively associated with the adoption of EVs. Conversely, we hypothesize that gas stations, service stations, multi-family housing, and the ratio of electricity-to-gas pricing are negatively associated with the adoption of EVs.

$$Y = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + \beta_7 X_{7i} + \beta_8 X_{8i} + \beta_9 X_{9i} + \beta_{10} X_{10i} + \mu_i$$

Results

The results from the regression confirm our hypothesis for income and charging stations, as both income and charging stations are significant at the one percent level and positively associated with EV adoption. A one percent increase in income brings about a 0.0079 percentage point increase in EVs as a percentage of all cars in Greater Houston. When it comes to charging stations, a one percent increase in the former positively changes EVs as a percentage of all cars in Greater Houston by .0022 percentage points. Given the nature or background of these variables, these results make intuitive sense. However, curious to note is that gas stations and the ratio of electricity-to-gas pricing had no statistical significance at all. This suggests that the presence of gas stations or even the prices of electricity and gas may not play as relevant a part in EV adoption as one may think. These results are consistent with the findings of Sierzchula et al. (2014).

In our analysis, we found that a one percentage point increase in multi-family housing units decreases EVs as a percentage of all cars in Greater Houston by nearly .0001 percentage point. While multi-family housing is negatively associated with EV adoption, it does not hold statistical significance in our analysis. The multi-family housing result was peculiar, as one would think that the prevalence of multi-family housing in the Greater Houston area would play more of a role in EV adoption. The multi-family housing result suggests that more research may be necessary in this regard.

Commute time is found to be statistically significant at the 10% level and negatively associated with EV adoption. More specifically, we found that a one percent increase in the minutes in commute time decreases EVs as a percentage of all cars in Greater Houston by .0057 percentage points. Similar results are found with blue-collar workers, as the variable for blue-collar workers is also statistically significant at the 10% level and negatively associated with EV adoption. Our team found that a one percentage point increase in blue-collar workers decreases EVs as a percentage of all cars in Greater Houston by 0.0128 percentage points. The results pertaining to commute time may allude to the idea of Houstonians with longer commute times opting away from EVs as the main form of transportation. In addition, our results indicate the idea that blue-collar workers in Greater Houston are also not too keen on adopting EVs as the main form of transportation.

Similar to the variables for blue-collar workers and commute time, our team found the variable for service stations to also be statistically significant at the 10% level. We also found that the result for our Service Stations variable supports our hypothesis that service stations are negatively associated with EV adoption in Greater Houston. We found that a one percentage point increase in service stations decreases EVs as a percentage of all cars in Greater Houston by 0.0012 percentage points.

Discussion

The first point of interest within our study is the minimal effect, on EV adoption, of gas stations in our target area. As per our study, the powerful effect of charging stations lies with both new and used EV registrations. Regarding logistical efforts in sustaining EV adoption in the Greater Houston region, our analysis suggests that full prioritization of EV charging stations infrastructures would provide a much more significant impact on EV adoption in the Greater Houston area rather than sole focus on the effects of gas stations on EV adoption in the Greater Houston area.

One important observation regarding EV adoption in the United States is that regions with lower populations tend to have lower EV adoption. This is especially evident in rural areas, as rural areas generally have lower populations than urban areas and tend to have less charging infrastructures than their urban counterparts (EESI 2021). Regarding Greater Houston, our analysis suggests that population density may not have a significant effect on EV Adoption in Greater Houston as originally thought. However, our study did support the significance of EV charging stations on EV adoption in Greater Houston. If Evolve Houston seeks to expand EV demand into the rural areas of Greater Houston, our analysis suggests focusing more on EV infrastructure needs rather than just population density itself.

Our team found the results produced for the Blue-Collar Workers variable to be very intriguing, as our analysis displayed a statistical significance in the negative association between the blue-collar workforce and EV adoption in Greater Houston. We hypothesize that the result produced for the variable Blue-Collar Workers in our model could be due to a few major reasons. Regarding driving patterns of blue-collar workers, there exists a positive correlation between blue-collar workers and the distance traveled to work (Lin et al. 2012). In addition, some blue-collar workers may also require heavier-duty vehicles due to the physical circumstances of the blue collar job. Given the blue-collar workers' preferences for vehicles, both personal and/or labor, blue-collar workers would tend to demand more for gasoline cars and/or trucks than EVs. Additionally, from the results produced for the Commute Time variable in our study, our team also discovered that Houstonians that tend to have longer commute/drive time to work may not prefer EVs as a primary means of transportation. Overall, our team believes that the current limitations in driving ranges of EVs (Barkenbus 2020) and limitations in specifications for EV models-like size, weight, and HVAC energy requirements (Goodall and Robartes 2023)-inhibit a potential substitution effect in the vehicle demand of both the blue-collar workers and workers with longer commute time in Greater Houston. But with the exponential progression in the development of EV models, like affordable longer-range batteries (Nykvist, Sprei, and Nilsson 2019), many vehicle manufacturers like Tesla, GM, and Ford are taking on the challenge to manufacture EVs that may solve the issue of lack of substitution in vehicle models (Ulrich 2020) in the future, and thus could potentially improve EV adoption among the blue-collar population and among workers with longer commute time in Greater Houston.

The results yielded for the variable Service Stations supported our team's intuition that the relationship between service stations and EV adoption in Greater Houston is inversely related. To further increase EV adoption in Greater Houston, our team believes that Evolve should push for more recognition of the importance of service stations to EV adoption and financial investments in service stations among the public, businesses, and/or local and state governments. This would allow service stations in Greater Houston to allocate more time and resources toward maintaining EVs. This could also generate new service stations in Greater Houston that are dedicated to servicing EVs, which could also create more job opportunities in Greater Houston. Consequently, this could potentially create a positive association between service stations and EV adoption in Greater Houston in the long run.

Conclusion

In general, our team suggests that efforts in expanding EV adoption in Greater Houston should be more focused on strengthening accessible public EV infrastructure based on maintenance and utility. Although in our study we discovered that the factor of multi-family housing is less significant to EV adoption than originally thought, our team's analysis suggests that improvements in public EV infrastructure in Greater Houston, like charging stations and service stations, would contribute more to the provision of equitable distribution of EV adoption in Greater Houston. Our analysis also supports that factors relating to income still play a vital role in EV adoption and are still one of the major determinants of regional EV adoption. Finally, our team believes that advancements in EVs will facilitate Evolve's ability in promoting EV adoption in Greater Houston. This includes the ability to promote and provide outreach of EV adoption to specific demographics, which will be critical in achieving equitable EV adoption in Greater Houston. Regarding EV promotion, our analysis indicates that blue-collar workers and commuters should be focused more due to their transportation needs. However, we suggest more research on other specific or overlooked demographics in Greater Houston that tend to be less likely to adopt or prefer EVs, and more research on their reasons for issues with EV adoption.

One key issue that we have dealt with in our analysis is the limitation of databases for our potential explanatory variables. More specifically, our team has faced difficulty in finding ZIP code level data for some of our hypothesized independent variables, as databases typically do not consider ZIP codes as a primary categorization technique. The next best information found through databases is at the level of census tract and census blocks, though time and knowledge constraints have not allowed the conversion of this data to ZIP code level data. Such conversion would grant our team tremendous insight into the acquired data and expand our linear regression models.

Our team was able to observe how general demographic factors affect EV adoption in Greater Houston. In addition, our team was able to have the opportunity to observe explanatory variables that are not typically considered when analyzing EV adoption. However, our team believes further research is required regarding the expansion of EV adoption in Greater Houston. More specifically, we believe that more focus should be shifted to atypical explanatory variables regarding research on EV adoption in Greater Houston. We believe that more analysis on atypical explanatory variables and regression of these variables regarding EV adoption would provide greater insight to Evolve and faculty and help Evolve and faculty fully understand what impacts EV adoption in Greater Houston. Furthermore, taking this analysis further by implementing a time-series or panel-data modeling will help further the understanding of the effects of any new explanatory variables as well as the explanatory variables in our regression model.

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Appendix

Table of EV Regression Results

Variables	EVs
Income	0.788***
	(0.172)
Population Density	-0.0455
	(0.0550)
Unemployment	-0.0578
	(0.102)
Gas Stations	0.0763
	(0.0747)
Charging Stations	0.218***
	(0.0697)
Electricity/Gas Price Ratio	-0.161
	(0.463)
Multi-Family Housing	-0.00949
	(0.0649)
Commute	-0.570*
	(0.302)
Blue-Collar Workers	-1.276*
	(0.713)
Service Stations	-0.118*
	(0.0663)
Constant	-5.590**
	(2.254)
Observations	266
R-squared	0.310

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1