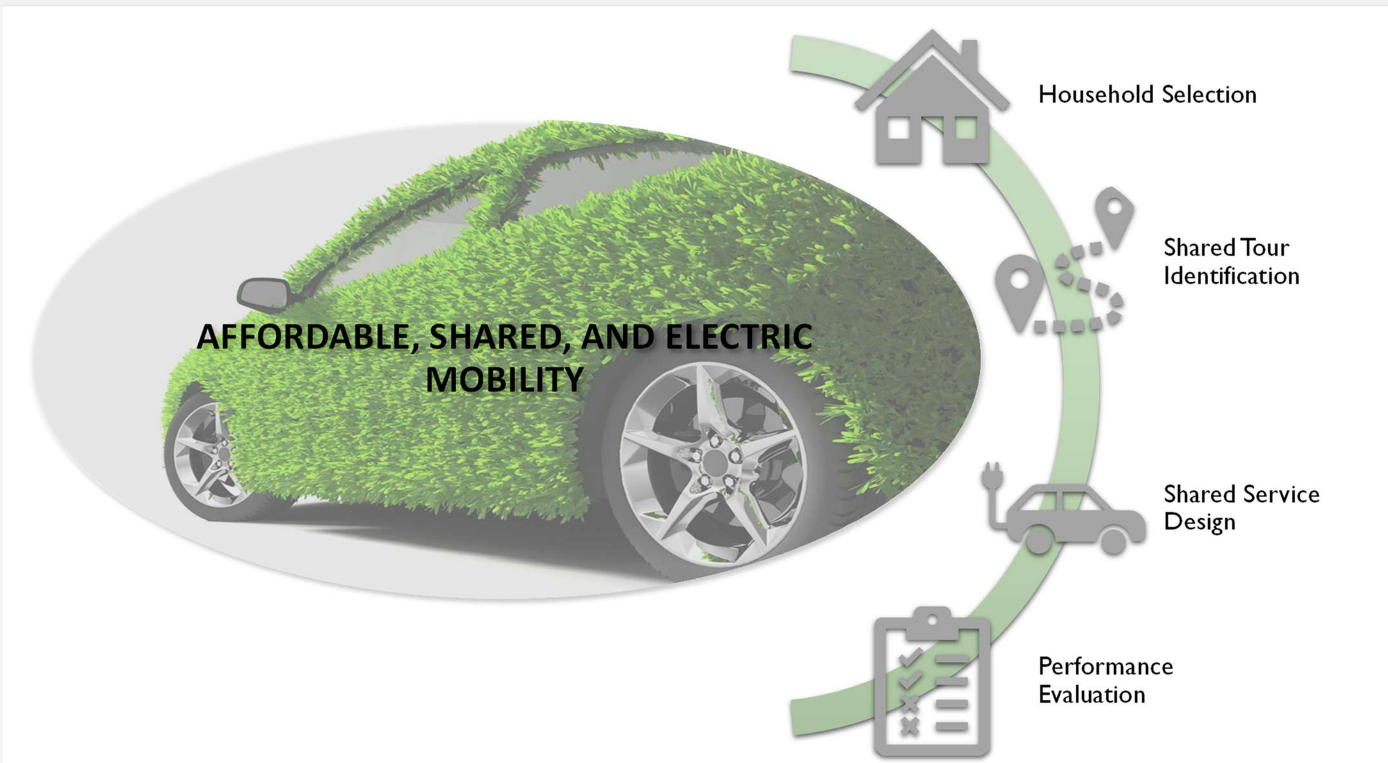
FEASIBILITY ANALYSIS AND INFRASTRUCTURE REQUIREMENTS OF AFFORDABLE, SHARED, AND ELECTRIC MOBILITY



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16. Abstract

Many low- and medium-income households are disproportionately affected by high traffic congestion and increased vehicle emissions. Electric vehicles (EVs) produce less emissions compared to diesel vehicles; however, they are still unaffordable for these households despite EV incentives and credits. More effective strategies are needed to help low- and medium-income communities get access to cleaner transportation options such as EVs and lower potential health impacts. Shared EV service is one way to help combat these issues. Creating a car sharing service with EVs in these areas can benefit these communities by reducing a greater amount of emissions, bridging the existing equity gap, increasing mobility for some users, and reducing vehicle ownership and user transportation expenses. Therefore, the major objective of this project is to assess the feasibility of these services in terms of operation and recognize the potential service areas within a metropolitan. The approach used for this study is as follows: identifying the households and zones for potential shared EV service use, evaluating passenger car tours for car sharing and ride matching services, designing a two-way EV sharing service, and evaluating its performance. The current case study in the Houston-Galveston area showed a potential for initializing a fleet of 20 shared EVs within six zones with high demand in terms of passenger miles. Such a service can accommodate more than 24,000 passenger miles and save 3 tons of CO_2 per day. The current study can be used for exploring shared EV service designs as well as their cost and impact assessment.

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Executive Summary

Many low- and medium-income households are disproportionately affected by high traffic congestion and increased vehicle emissions. Electric vehicles (EVs) produce less emissions compared to diesel vehicles, however, they are still unaffordable for these households despite EV incentives and credits. More effective strategies are needed to help low- and medium-income communities get access to cleaner transportation options such as EVs and lower potential health impacts. Shared EV service is one way to help combat these issues. Creating a carsharing service with EVs in these areas can benefit these communities by reducing a greater amount of emissions, helping bridge the existing equity gap, increasing mobility for some users, and reducing vehicle ownership and user transportation expenses. Therefore, the major objective of this project is to assess the feasibility of these services in terms of operation and recognize the potential service areas within a metropolitan. The approach used for this study is as follows: identifying the households and zones for potential shared EV service use, evaluating passenger car tours for carsharing and ride matching services, designing a two-way EV sharing service, and evaluating its performance. The current case study in the Houston-Galveston area showed a potential for initializing a fleet of 20 shared EVs within six zones with high demand in terms of passenger miles. Such a service can accommodate more than 24,000 passenger miles and save 3 tons of CO_2 per day. The current study can be used for exploring shared EV service designs as well as their cost and impact assessment.

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Introduction

The minority and low-income households are on average more likely to live near a high volume road or in an area with higher traffic density in the United States, hence they are disproportionally affected by vehicle emissions and bear elevated health risks [1, 2]. It is urgent to provide clean transportation alternatives to those households to mitigate the adverse health impacts on their communities. Electric vehicles (EVs) can reduce operation costs [3], energy consumption, and environmental impacts [4]. From a socio-economic perspective, EV consumers are less vulnerable to fuel prices. However, the adoption of EVs remains slow in low-income and minority households, which raises significant equity issues as the incentives for alternative vehicle purchases have been disproportionately allocated to high-income households [5]. The equity issues of EVs are becoming a major concern of EV adoption, and immediate solutions are needed to provide EV access to households with lower income.

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CARTEEH is a Tier 1 University Transportation Center, funded by the U.S. Department of Transportation's Office of the Secretary for Research and Technology.

Currently, consumers can apply for federal and state tax credits to lower the financial hurdle while purchasing EVs. However, 90 percent of the federal tax credits for EVs go to households with incomes over $75,000, and EVs still appear unaffordable for low- to middle-income households even after incentives [6]. The lack of charging infrastructure accessible to those neighborhoods has also fueled the inequitable distribution of EVs [2]. EVs need to be both financially and operationally accessible to substantially reach more users. Shared mobility has been recognized as a viable way to reduce transportation expenses, bridge the equity gap, and reduce vehicle ownership through previous practices [7]. Shared mobility enables the shared use of a motor vehicle, bicycle, or other transportation mode among users, and may reduce individuals' spending by saving the cost of vehicle ownership. By electrifying the shared mobility service, the cost-saving can be expanded by further reducing vehicle operating costs and providing sustainable transportation services to middle- and low- income households. In early adoption states such as California, an EV car-share program is demonstrated as a useful service for many of the low-income households [8].

Previous Practice of Shared EV

To identify the potential opportunities and challenges of a shared EV program, existing or ceased shared EV programs are reviewed and summarized in this section. There are many other electric car-share programs across the United States. Some helpful data worth looking into for these programs include fleet size, if the service is primarily aimed towards low-income areas, number of participants, success level, user costs, and more. These numbers for each program examined can be seen in **Table 1**.

Table 1. Comparison of Shared Electric Vehicle Services in the United States.

Service Name	Location	Service Provider	Fleet Size	User Costs	User Demographics	Operation Status	References
BlueLA	Los Angeles, CA	Shared-Use Mobility Center (SUMC) and the City of Los Angeles	100 vehicles, 200 charging points	Standard—$5/month and $0.20/driving minute; Low-income—$1/month and $0.15/driving minute	Found in low-income communities; nearly 2,000 members after 1 year	In operation	[9–11]
City CarShare	San Francisco, CA	City CarShare and Getaround (after 2016)	200 vehicles	Varies greatly	20,000 active users; found in low-income communities	In operation	[12]
Buffalo CarShare	Buffalo, NY	Buffalo CarShare	19 cars, trucks, and vans	Unknown	Over half of its customers in the low-income range	Ceased	[11, 13]
WaiveCar	Santa Monica, CA	WaiveCar	20 vehicles	First 2 hours free, $5.99/hour after this	Unknown	In operation	[14, 15]
Envoy	Multiple U.S. cities	Envoy	Unknown	Varies greatly	Some locations found in low-income communities	In operation	[16]
BlueIndy	Indianapolis, IN	BlueIndy	250 vehicles, 92 charging stations	$9.99/month and $4/20 minutes and $0.20/additional minute	11,000 users over four years; discounts to 18–25-year-olds	Ceased	[17, 18]
Miocar Inc.	San Joaquin Valley, CA	Miocar Inc.	27 vehicles	$4/hour or $35/day; 150 miles included then $0.35/mile	Most have a household income under $50,000; median household income $37,500	In operation	[19, 20]

As seen in Table 1, some of these electric car-sharing companies have ceased their operations. This includes the companies Buffalo CarShare and BlueIndy. Buffalo CarShare was doing quite well and had steady growth from 2009–2015 [8]. However, in 2015, Philadelphia Insurance ended their insurance coverage with Buffalo CarShare due to New York's insurance law on personal injury protection. This law required the insurance carrier to pay for the medical bills of those injured in a crash, and no other insurance carrier was willing to offer them coverage because of this. For this cost-benefit analysis, an emphasis on insurance is of high importance because the lack of an insurance company willing to take on a car-sharing program can sink the entire idea into the ground. However, other companies such as BlueIndy were just overall not economically viable and ceased operations for this reason [17]. This goes to show that there is a chance that not enough ridership or profit is possible with this sort of investment and that all financial profit ranges must be considered.

Other electric car-sharing companies included in this analysis are also experiencing financial difficulties even though they are still operational at this time. As mentioned above in the existing cost analysis tools section, City CarShare was bought out in 2016 by a company named Getaround, and they have experienced financial losses due to car theft that has made it difficult to continue operations. They had around 20 of their vehicles disappearing each month [21]. On the other hand, WaiveCar has a large demand for their services [14]. However, they have an insufficient fleet size to meet their demand, but they are not financially able to increase their fleet size. There is a difficult balance between offering an affordable service to low-income communities and being able to profit enough to grow the company if demand begins to increase.

However, many of these companies offering services in low-income areas and neighborhoods are still operational and have benefited many customers and improved air quality. BlueLA, City CarShare, Envoy, and Miocar Inc. are among some of these companies. BlueLA offers competitive pricing to low-income users by giving them a much cheaper monthly and per minute fee compared to the rest of their customers. During their first 10 months of operation, they had 8,253 total trips and 158,546 total vehicle miles traveled [22]. Around 47 percent of customers during that 10-month period were low income. Through BlueLA, it is estimated that 260 metric tons of greenhouse emissions have been reduced in that 10-month span as well. Miocar is another company that has been examined closely. During a 10-month period, they had an average of 4,249 vehicle miles per month [20]. In a survey, 59 percent of customers said that they would not have been able to travel to their primary destination without the availability of Miocar, which suggests the significance of such a service to local communities.

There are many examples of successful and unsuccessful electric vehicle car share programs. Case studies have revealed lessons learned from these programs and several key factors to success [22]. The first key to success is building a strong partnership. The second is fine-tuning the project's goal with stakeholders' interests. The third is financial sustainability, which is one of the main components of a cost-benefit analysis. The last key to success is marketing and advertising to ensure that any potential program created gains users and targets the demographics it needs to achieve its goals.

Research Goals

The primary objective of this study is to assess the feasibility of providing shared EV service to middle- and low-income households that live in multi-unit communities, using Houston, Texas, as a case study. Specifically, this study answered the following feasibility questions during shared EV service planning:

- Where the service is needed: based on regional travel patterns and transportation mode choice, the potential for middle- and low-income households to use shared mobility services will be identified. Neighborhoods with higher density land use, more shared destinations, availability for building and accessibility to charging stations, access to transit, and access to the internet may have a better chance of providing such shared mobility service.

- How the service should be designed: the EV sharing service needs to be designed to balance affordability and service quality. The potential subsidies need to be estimated to fill the gap between the service provided and the service that can be afforded.
- The potential benefits attributed to EV sharing service: by modeling the operation of shared EV services among selected areas, the economic, environmental, and social benefits of such services were demonstrated for evaluating the effectiveness of the proposed plan.

Methodology

The feasibility of electric car-sharing services will be demonstrated using a case study of Houston, Texas, with daily travel information collected from the regional travel demand model. In this study, the model results from the Houston-Galveston Area Council Activity-Based Model (ABM), which served as the primary data source for analytical work [23]. The major benefits of the ABM compared to the traditional four-step model include its ability to closely model the traveler decisions at the individual level, generate results at high spatial/temporal resolution, and provide better forecasts of future travel patterns [24]. The synthetic population data (socio-demographic attributes of households and persons), daily travel patterns, and traffic conditions were generated from the 2017 model runs.

To develop a feasible plan for EV car sharing, four major tasks were performed to identify the demand and design of the service. The overall workflow of the feasibility analysis is illustrated in **Figure 1**, followed by the objectives of each task.

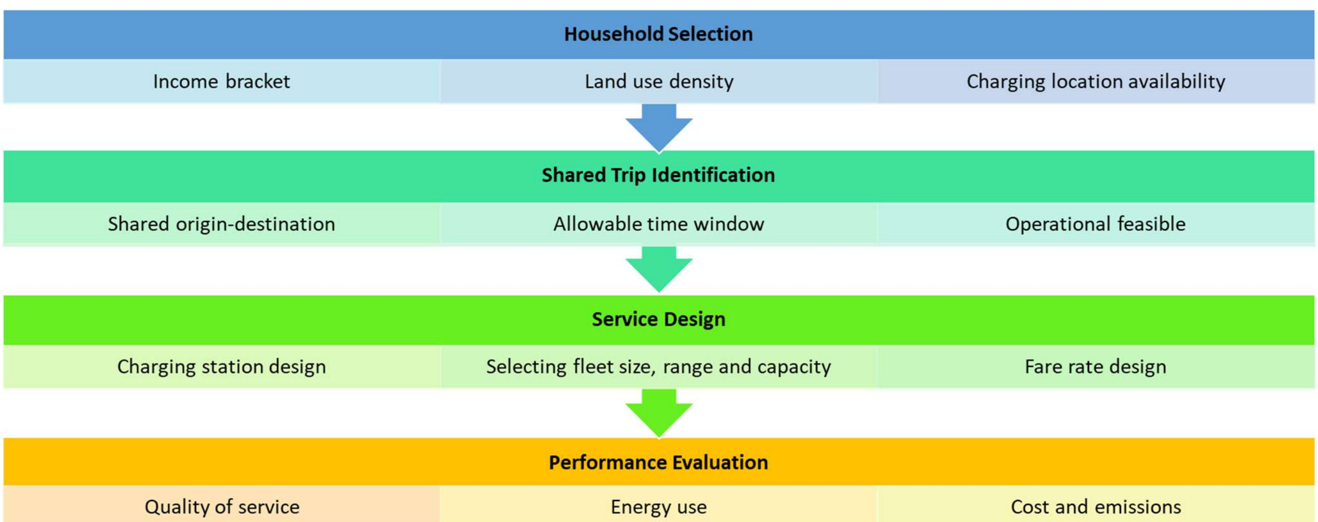

Figure 1. Proposed Shared EV Feasibility Analysis Workflow.

Task 1—Household Selection: The goal of this task is to identify the households living in the metropolitan Houston area that meet the following criteria: (1) fall into middle- and low-income bracket and (2) live in areas that can potentially be served by shared EVs. Therefore, this task selected candidate households to achieve shared EV services. The service areas were also defined to cover the common destinations of those households and within typical EV range. In this task, around six service areas were selected, and the potential customers within the areas were identified for service design.

The following data sources from the Houston ABM were used to select the qualified households:

- **Traffic analysis zone (TAZ) data:** This dataset provided zonal-level land use, household density, and travel frequency information, which are critical to determine if the shared EV services can be provided. The zones with high potential for providing shared EV services were selected in this step.
- **Synthetic household data**: The synthetic household data from ABM are representative of the demographic characteristics across the region. The households with home location within the selected TAZs were selected, and middle- and low-income households were identified.

In this task, the high potential zones for providing the service and potential households that can subscribe to this service were provided as output. Those attributes were key indicators of service accessibility under the sustainability and accessibility goals.

Task 2—Shared Trip Selection: In this task, potential daily travel activities that can be served using EV car-sharing services were identified from selected households. The trajectory of shared EV to serve those trips, as well as the charging window, were generated for service design.

There are generally two types of travel that can be served by a shared vehicle: (a) household travels that share the same itinerary and time window and (b) household travels that are not overlapped with other travel and can be performed independently. In this task, the daily travel pattern from the Houston ABM model were used to develop the shared ride schedule. The following steps were performed to select the shared trips.

- **Initial trip screening:** Selecting the travel data from selected households that originated from service zones. Among those travel patterns, potential shared trips were identified by pair itineraries with the same origin, destination, and time window. The shared trips can also be identified by selecting itineraries that were operated at entirely different time slot with no overlapping with other travels. The number of passengers was identified after matching shared trips to estimate total passenger miles that can be electrified.
- **Shared EV scheduling**: Assuming all the shared trips can be served using shared EV unless the single itinerary exceeded the typical EV range, the trips were chained within a day to develop the shared EV schedule. The number of EVs was determined by the number of unique trip chains. The time gaps between trips were potential time windows for recharging.

Task 3—Shared EV Service Design: The major objective of this task was to develop a practical plan combining evidences from the data and professional opinions. In this task, the shared EV service plan was designed by combining evidence from the data and inputs from stakeholders. The service plan was developed based on the service demand revealed in Task 2, including fleet size, vehicle type, charging requirement, fare structure, and engineering review for maximizing utilization. The following preliminary steps were performed.

- **Service prototyping using Task 2 results**: Using the trip data, EV schedule, and charging window from Task 2, the vehicle needs and charging need were determined, and the initial service plan was formulated. The initial plan included proposed fleet size, vehicle type, minimum charging requirement, and cost estimation of the service.
- **Finalizing shared EV service design**: Combining the evidences from the travel data and engineering review for service locations, the final service design was developed for selected areas and households. The remaining concerns not covered by the current plan were also documented for future improvement and development.

Task 4—Shared EV Performance Evaluation: In this task, the performance of the proposed shared EV service was evaluated using the optimization method. By maximizing the electric vehicle miles traveled (VMT) within service areas, energy use and emissions were estimated for evaluating the performance of shared EV service.

The following analyses were performed in this task:

- **Optimizing the shared EV operation**: An optimization algorithm was designed to maximize the fraction of electric VMT using proposed shared EV services. For the unsatisfied trip, it assumed to be performed using conventional-fueled private vehicles.
- **Impact analysis using The Transportation Energy & Mobility Pathway Options (TEMPO)**: The optimization results from the previous step were used to establish the transportation scenario with shared EV service. The service quality, energy use, emissions, and cost impacts of shared EV service at the regional level were assessed using the TEMPO platform [25].
- **Results summary and visualization**: The final cost-benefits of the shared EV service were summarized using the output from previous steps.

Results and Discussion

This section details the findings of each task in the method.

Task 1—Household Selection

The obtained 2017 Houston-Galveston ABM consists of 5,217 TAZs, 2,441,155 households, 6,795,858 people, 7,861,971 tours, and 15,975,244 individual trips. Figure 2 maps the land use in the Houston-Galveston area, showing the spatial locations of each area type and a denser urban and central business district in the center, with a wider suburban and rural area around. Figure 3 and Figure 4 show the distribution of household annual income both regionally and spatially. Almost 36 percent of the households in the region have an annual income lower than $40,000, making them low- or medium-income households. The spatial spread of these households shows some substantial part of them living in the central business district and urban area, as well as rural land use. Higher income households are within the suburban and rural areas.

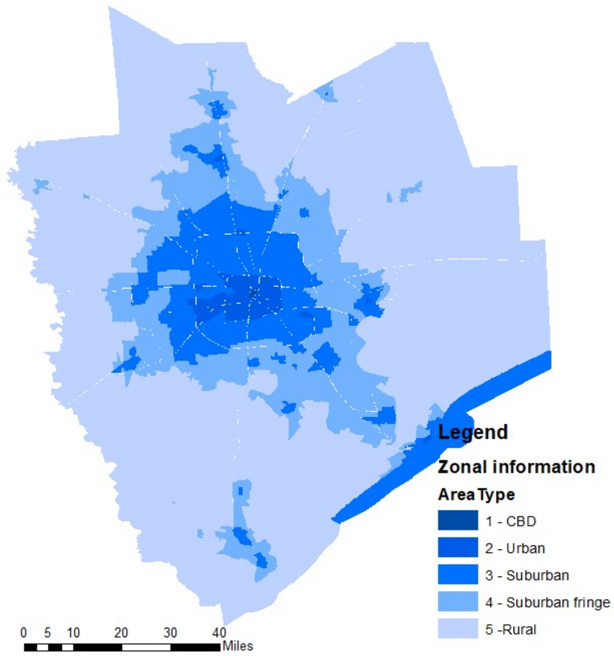

Figure 2. Houston-Galveston Land Use.

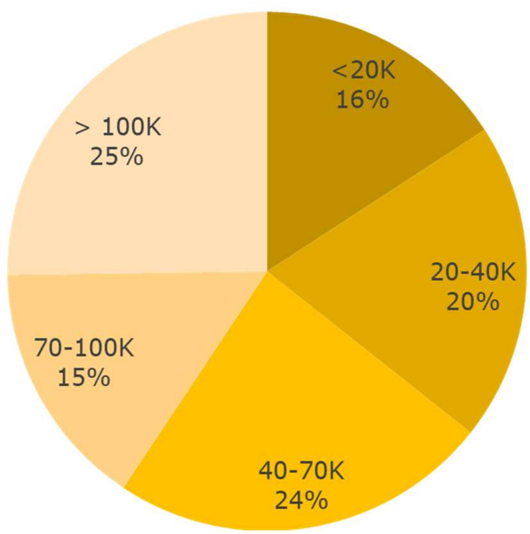

Figure 3. 2017 Household Annual Income in Houston-Galveston Area.

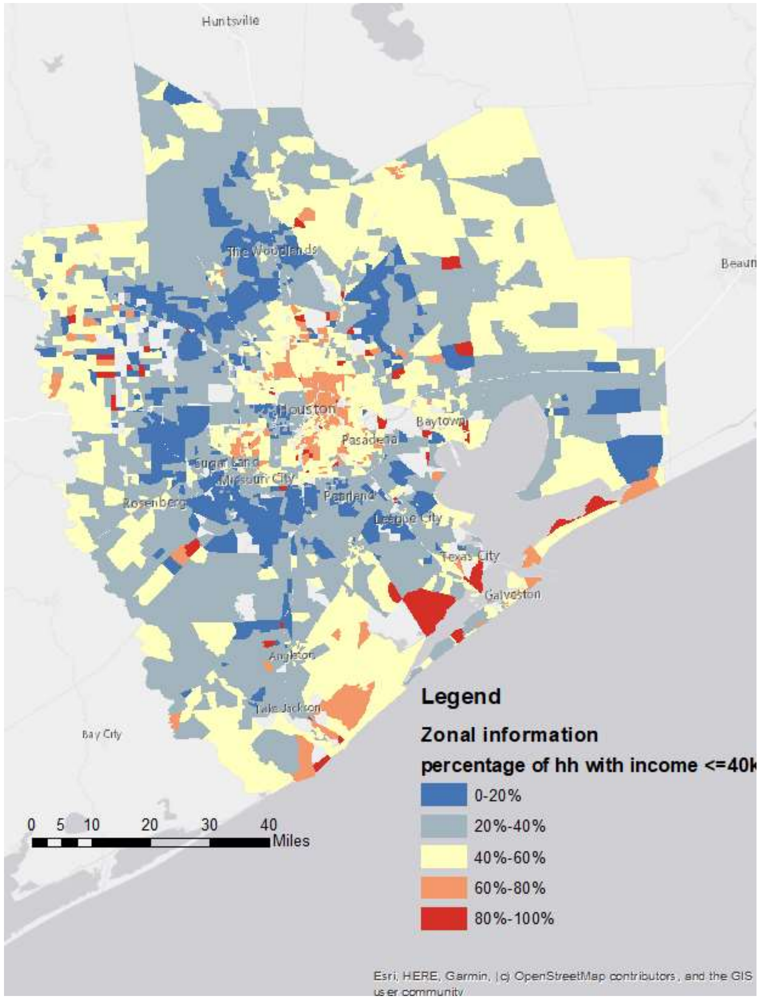

Figure 4. Spatial Distribution of Low- and Medium-Income Households.

Based on the spatial distribution of land use and annual household income, a set of criteria was defined for household selection. The study proposed to focus on households within the urban or central business district area with low- or medium-income (annual household income < $40,000). Using the household selection criteria, the TAZs with more than 50 low- or medium-income households and within the urban or central business district were identified for further shared EV service depot locations.

Researchers selected 531 TAZs with 183,895 low- or medium-income households, which is 20 percent of low- or medium-income households and 7.5 percent of all households within the region. Figure 5 shows the selected target zones for electrifying feasible tours and placing shared EV service.

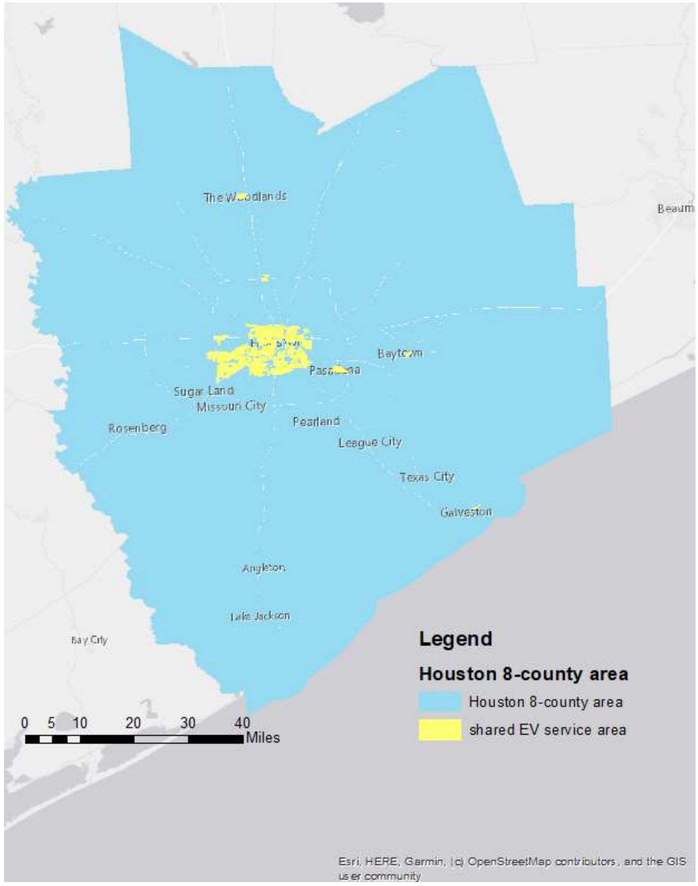

Figure 5. Selected Shared EV Service Zones.

Currently 1,007 charging stations are being operated in the Houston-Galveston area, among which 299 stations are free and 171 stations have fast charging technology [26]. Also, spatial distribution of these stations shows more than 60 charging stations in the selected target zones.

Task 2—Shared Trip Selection

The study extracted all tours with home locations within selected TAZs from the Houston-Galveston ABM dataset. **Table 2** lists the total count of tours for different travel modes. The researchers propose to replace the unclean travel modes with clean and sustainable EV technologies. Therefore, personal car tours (drive alone, ride share 2+ or 3+) are selected for service design. These modes account for 339,143 tours, which is 88 percent of the total tours originating from selected TAZs.

Table 2. Tour Distribution Based on Mode.

Tour Mode	Count	Percentage
Drive Alone	185,748	48%
Rideshare 2+	104,297	27%
Rideshare 3+	49,098	13%
Walk to Transit	20,909	5%
Drive to Transit	16,545	4%
Bike	9,155	2%
Walk	2,110	1%
Total	**387,862**	**100%**

Figure 6 shows the distribution of tour battery energy consumption. As it is shown, almost all tours need an operable battery energy consumption, meaning less than battery capacity (= 200 kWh). Then the tours with battery energy consumption more than 200 kWh were removed and 330,117 tours for shared EV scheduling were kept.

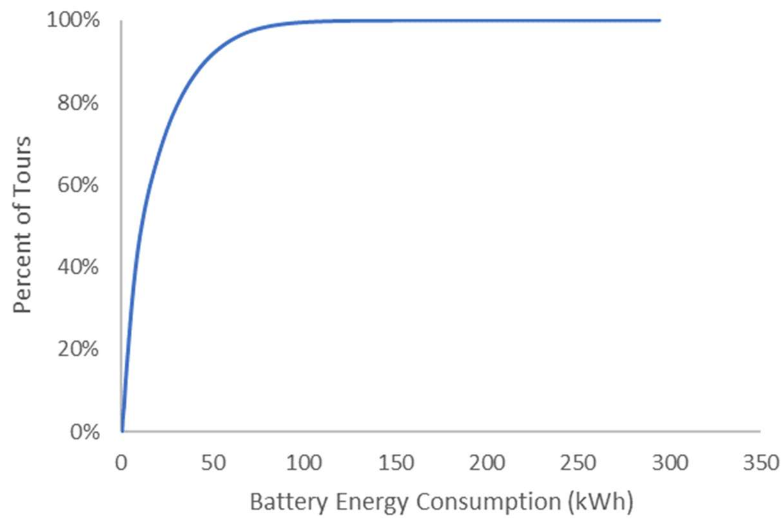

Figure 6. Cumulative Distribution of Battery Energy Consumption.

Next, tours were matched based on tour origin and path, and tour arrival and departure time at each location, and were assigned to EV based on the current number of passengers in the vehicle and EV capacity (one driver and four passengers). Also, the maximum time interval an individual may accept to leave earlier was assumed to be less than 30 minutes. Finally, the matched tours were sequenced and chained using dynamic programming and considering charging feasibility to estimate the number of EVs needed in total and in each zone (**Algorithm 1**). The study showed that at least 98,870 EVs are needed to accommodate all passenger car tours in the low- and medium-income households. A zonal study to prioritize zones with higher demand for shared EVs is discussed in the next section.

Algorithm 1. Tour Sequencing

- Objective: Maximizing EV passenger miles
- Input: List of matched tours with tour origin, start time, end time, energy consumption
- Output: List of tour sequences
- Method: Dynamic programming for each origin zone
- Optimization Algorithm:

  C = Battery Capacity
  r = Charging Rate
  s_i = Start Time of Interval i
  f_i = End Time of Interval i
  v_i = Energy Consumption of Interval i
  pm_i = Passenger miles of Interval i
  PreviousIntervalLinking():
  1) Sort intervals by their end time
  2) Set $p_i = 0$ for all intervals i
  3) Set $b_i = C - v_i$ for all intervals i
  4) For all intervals i

a) For all intervals $j < i$

i) Set $rest = s_i - f_j$

ii) If $rest \geq 0.5$ & $b_j + rest * r \geq v_i$

(1) Set $p_i = j$

(2) Set $b_i = \min(C, b_j + rest * r) - v_i$

(3) Break

ForwardIntervalScheduling():

1) Set $m_i = -1$ for all intervals i

2) For all intervals i

a) If $i = 1$: Then $m_1 = pm_1$

Else if $p_i = 0$: $m_i = \max(pm_i, m_{i-1})$

Else: $m_i = \max(pm_i + m_{p_i}, m_{i-1})$

3) Set m as the set of m_i for all intervals i

BackTrackSolution(m,i):

1) If $i > 0$

a) If $pm_i + m_{p_i} > m_{i-1}$

i) Output i

ii) $\text{BacktrackSolution}(\text{m}, p_i)$

b) Else

i) $\text{BacktrackSolution}(\text{m}, i-1)$

Task 3—Shared EV Service Design

The proposed shared EV service was designed to be a two-way service and not allowed to pick up along the tour. Also, the following assumptions were made for the purpose of tour assignment without the loss of generality and based on available EV and charging technologies:

- Charging availability at the time of tour end either at depot or public charging station.
- Charging rate (level 2, 7.2 kW).
- EV range (200 miles, 60 kWh).
- Fixed fleet size (20, 100, 200).

The main goal of the study is to provide low- and middle-income households with affordable and clean transportation. So, the shared EV program needs to be maximized in utility to meet both the goal of the program and be cost optimal. Maximizing EV passenger miles based on the ranking may assign some EVs to the neighbor zones and/or spread EVs among many zones, causing an inefficient investment in the parking and charging infrastructure. Therefore, the current study proposed a zone-based distribution of EVs using the total passenger miles (or required number of EVs) at each zone. The researchers selected six service areas, as located in **Figure 7.**

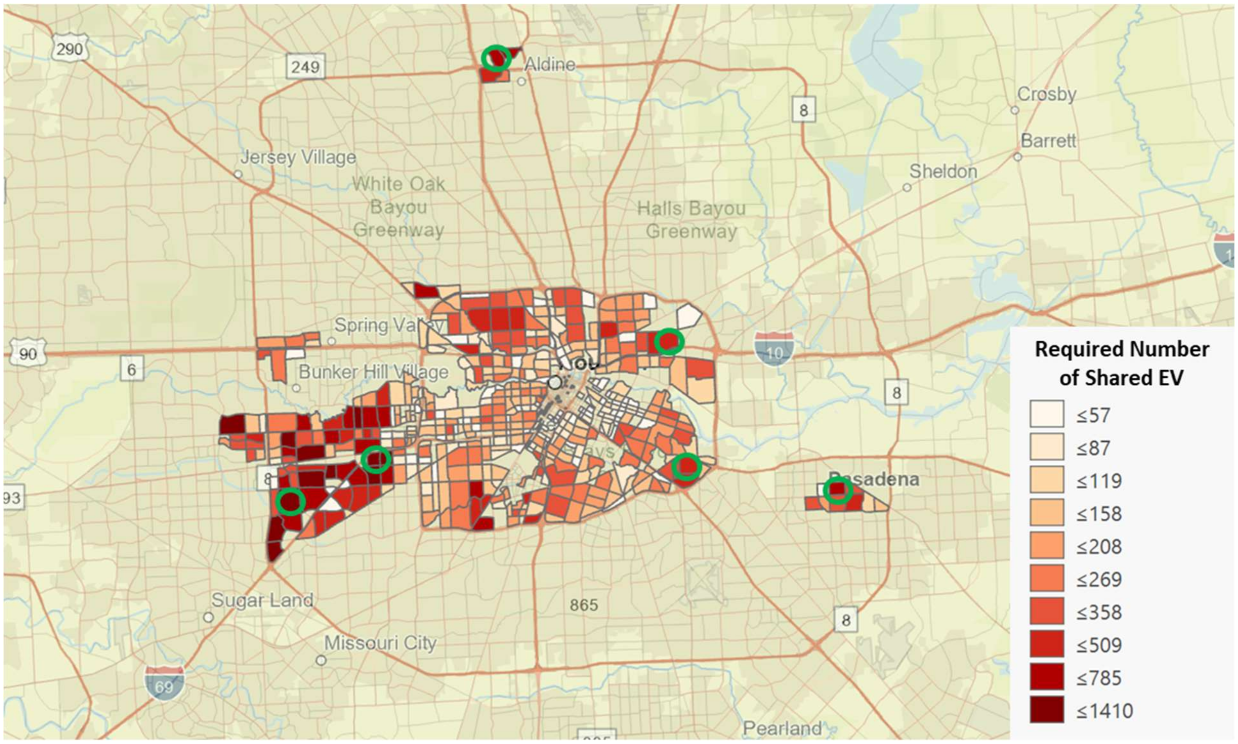

Figure 7. Selected Shared EV Service Zones.

The minimum passenger miles covered by each of the EVs at the selected zones is between ~290–540 miles based on the fleet size. The maximum passenger miles is ~2,800 miles a day. **Table 3** shows that a fleet size of 20 EVs can electrify more than 24,000 miles a day with a maximum number of 6 EVs per zone. While increasing the number of EVs can increase the covered passenger miles, the EVs will be less utilized and cost efficient. On the other hand, motivating people to replace their travel mode can be challenging. Therefore, the researchers suggest to start with a lower number of EVs and expand it over time if the service meets utilization constraints. The next section compares these scenarios in terms of energy and emission impacts.

Table 3. Fleet Size Scenarios and Coverage.

Number of EVs	Passenger miles		Battery energy consumption per EV (kWh)		Max number of EVs per zone
	per EV	Total	per EV	Total	
20	1,211	24,220	193	3,862	6
100	571	57,100	100	10,019	20
200	444	88,800	79	15,837	40

Task 4—Shared EV Performance Evaluation

The three developed fleet size scenarios have different rates of energy and emission impacts. **Table 4** details the associated energy and emission impacts in total and per passenger miles regarding electrification of shared-car service.

Table 4. Energy and Emissions Savings for Fleet Size Scenarios

Fleet Size	Energy Saving (kWh)	CO_2 Saving (grams)	NO_x Saving (grams)	$PM_{2.5}$ Saving (grams)
20	9,330	3,413,489	1,352	35
100	25,240	9,123,897	3,553	92
200	40,180	14,495,426	5,627	146

Conclusions and Future Works

The researchers devised a method for planning shared EV services in a metropolitan area in a way that addresses sustainability goals within the low- and medium-income households. A set of criteria was developed for potential service area targets considering land use and spatial distribution of household annual incomes. Later, the researchers used ABM tours to identify the potential matchable tours for a two-way ridesharing during a typical day, and matched tours were split into EVs based on vehicle capacity. Then, tours were sequenced using a dynamic programming algorithm and considering charging feasibility at the depot. Final tasks devised a shared EV service plan and selected six zones with the highest passenger miles and spatially spread to place the shared EV services.

Findings showed that a fleet size of 20 can be spread within six zones in a way to accommodate a total of more than 24,000 passenger miles in day, leading to a daily energy savings of more than 9,000 kWh and daily CO_2 savings of more than 3 tons. Using a previously developed cost assessment, a fleet size of 20 EVs has a capital cost of $2 million at the program start and may cost between $7.7–$17 million over a 10-year lifetime [27]. On average, it can have a total net revenue of $15 million over a 10-year lifetime considering one charging station per zone.

The current study can be expanded into accessibility and equity issues around shared EV services. The final list of households that can be served by shared EVs can be further used to evaluate the impact of the shared EV services on increasing accessibility of EVs. The income distribution of shared EV users, compared to income distributions of EV owners, will be a key metric to assess the equity and accessibility impact of the shared EV service. Specifically, the composition of trips can be used to evaluate how shared EV services can help people gain access to jobs, health care, childcare, and education.

Outputs, Outcomes, and Impacts

The main output of this project is the shared EV feasibility assessment framework, with its four tasks for household selection, tour identification, shared EV design, and performance evaluation. The detailed steps made it possible to follow and implement on a case study in the Houston-Galveston area. Moreover, the study demonstrated a practical solution for deploying shared EV service in the Houston-Galveston area, and the solution can lead to major net revenue over 10 years. Furthermore, the framework can be extended to other issues around shared EV services including accessibility. The study can be based as a preliminary feasibility analysis framework for a shared EV service in Houston, Texas, an introduction of a possible solution to negative health impacts and equity issues for low- and medium-income communities, a drive for increased mobility for those that currently have no or very little mobility in those communities, and a method to provide education about EVs and their benefits to the region.

Research Outputs, Outcomes, and Impacts

Researchers are preparing a publication draft and EV assignment algorithm that will be included for a doctoral dissertation.

Technology Transfer Outputs, Outcomes, and Impacts

Researchers will upload a spatial distribution of used attributes as a dashboard in the CARTEEH Datahub.

Education and Workforce Development Outputs, Outcomes, and Impacts

Farinoush Sharifi is a PhD candidate in transportation engineering at Texas A&M University at the time of the project and is looking forward to using the EV assignment algorithm as a support for her final dissertation. This project was also a unique opportunity for her to gain insight into EV fleets and continue the work in her dissertation. Along with completing the tasks in the research plan, she benefited from reviewing previous work, learning the procedure to obtain datasets, collaborating with experts, and managing a project.

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