Environmental Science and Pollution Research (2024) 31:16735–16745
https://doi.org/10.1007/s11356-024-32337-7

RESEARCH ARTICLE

Barriers to adoption of electric vehicles in Texas

Apurva Pamidimukkala[1] · Sharareh Kermanshachi[2] · Jay Michael Rosenberger[2] · Greg Hladik[3]

Received: 14 September 2023 / Accepted: 31 January 2024 / Published online: 7 February 2024

Abstract

Sustainable mobility options such as electric vehicles (EVs) have the potential to improve the quality of life for Americans as well as those in other countries, as they can enhance the quality of the air we breathe, while reducing greenhouse gas emissions, fossil fuel consumption, and the adverse impacts of global warming. Despite their many benefits, however, the demand for EVs remains low. Therefore, this study aims to identify the barriers that affect the widespread EV adoption in the United States. Seventeen barriers were identified from the literature, and a questionnaire survey was designed and distributed to potential consumers of EVs. The survey yielded 733 responses, and various statistical tests like cluster analysis and chi-squared tests were performed. The results revealed that the high purchase price of the vehicle, high battery replacement cost, and the lack of public infrastructures for charging them were the primary concerns. The results also revealed that middle-aged men with high education and income are more enthusiastic about adopting EVs. The results presented in this study indicate a range of developments that different stakeholders could implement. To surmount the economic barriers to EV adoption, policymakers should strengthen incentives countrywide, and automakers should introduce more affordable EVs to the market. To overcome the challenges associated with charging, it is necessary to make investments in rapid charging infrastructure along the primary toll routes.

Keywords Electric vehicle · Consumer adoption · Barriers · Cluster analysis · Ranking · Sociodemographics

Introduction

The transportation sector contributes significantly to emissions and air pollution. In addition, it utilizes roughly one-fourth of the global fossil fuel supply, the majority of which is used for road transportation (Gnann et al. 2018; Moeletsi 2021; Khan et al. 2023; Pamidimukkala et al. 2024). The 2020 International Energy Agency (IEA) report states that the transportation sector causes 24% of direct CO_2 emissions from fuel combustion. According to projections, this number will increase by up to 70% by 2050, assuming business as usual (IEA 2020). The statistical data presented herein underscores the importance of developing a technological solution to mitigate CO_2 emissions released by automobiles (Adnan et al. 2018).

The adoption of electric vehicles (EVs) holds significant promise for fostering positive environmental and societal changes. One key benefit is the substantial reduction in greenhouse gas emissions and air pollution, leading to an enhancement in air quality and public health (Pamidimukkala et al. 2023a). This shift away from traditional fossil fuels not only improves local air conditions but also plays a crucial role in mitigating global climate change (Ghosh 2020). Additionally, embracing EVs contributes to energy independence by decreasing reliance on imported oil, thereby promoting greater energy security. The growth of the EV industry not only fosters innovation but also creates

Responsible Editor: Baojing Gu

✉ Sharareh Kermanshachi
sharareh.kermanshachi@uta.edu

Apurva Pamidimukkala
apurva.pamidimukkala@mavs.uta.edu

Jay Michael Rosenberger
jrosenbe@uta.edu

Greg Hladik
hladik@uta.edu

1 Department of Civil Engineering, University of Texas at Arlington, Arlington, TX 76019, USA

2 Industrial Manufacturing and Systems Engineering, University of Texas at Arlington (UTA), Arlington, TX 76019, USA

3 Auxiliary Services, University of Texas at Arlington, Arlington, TX 76019, USA

job opportunities in manufacturing, technology, and related sectors. Furthermore, the quieter operation of electric vehicles compared to traditional one's aids in reducing noise pollution in urban areas (Zhou et al. 2020). The transition to EVs also presents an opportunity for governments to generate tax revenues, potentially supporting resource redistribution and funding public services. The increased demand for EVs can drive investment in charging infrastructure, not only creating job opportunities but also enhancing overall transportation networks. Moreover, the reduced air pollution from traditional vehicles can lead to lower healthcare costs associated with respiratory and cardiovascular diseases (Sanguesa et al. 2021).

However, the widespread adoption of EVs is not without its challenges and potential negative consequences. One significant barrier is the high upfront cost of purchasing an electric vehicle, which can limit its widespread adoption, particularly among certain consumer groups (Noel et al. 2020). The production and disposal of batteries, integral to EVs, raise environmental concerns, encompassing issues such as resource extraction, energy-intensive manufacturing, and recycling challenges (Ramesan et al. 2022; Pamidimukkala et al. 2023b). Another challenge is the phenomenon of "range anxiety," where concerns about the limited driving range of EVs and the availability of charging infrastructure may deter potential buyers (Singh et al. 2020). The transition to EVs poses challenges for traditional automakers, potentially leading to job losses in traditional automotive manufacturing. Moreover, the decline in demand for traditional vehicles may impact the oil and gas industry, causing economic challenges in regions dependent on these sectors. Uneven development of charging infrastructure could hinder the widespread adoption of EVs, especially in rural or less-developed areas (Stockkamp et al. 2021). Additionally, a large-scale transition to EVs may strain electricity grids, necessitating upgrades to accommodate increased demand for charging. Lastly, while EVs have a lower operational carbon footprint, the overall environmental impact depends on factors such as the energy sources used for electricity generation and battery production, highlighting the need for a comprehensive approach to sustainability in the EV transition. Utilizing renewable energy sources like hydro, wind, solar PV, and solar thermal for power generation would enhance the environmentally friendly nature of EVs (Barman et al. 2023).

In 2019, global electric vehicle (EV) sales surged by 16%, sparking heightened interest in the automotive sector. Notably, Europe experienced an impressive 80% growth in EV sales, while Canada saw a substantial 43% increase. In contrast, sales in China and the United States remained steady. Other nations, including Norway with a 39.5% growth and the UK with a 1.94% increase, actively embraced the trend by purchasing more electric vehicles. This surge continued, with EV sales reaching a remarkable 6.6 million in 2021, marking a twofold increase from the previous year's figures (Rietmann and Lieven 2019). The global market share of electrified auto sales also saw a substantial rise in 2021, reaching nearly 10%, a fourfold increase compared to the market share recorded in 2019. As highlighted by Patyal et al. (2021), the worldwide count of electric vehicles reached approximately 16.5 million, signifying a threefold increase from 2018.

Despite the recent increase in the share of EVs in the United States, the country still confronts difficulties in its efforts to encourage extensive EV adoption. Several studies attribute the massive adoption of electric vehicles to consumers' perceptions (Egbue and Long 2012; She et al. 2017; Singh et al. 2020). Hence, comprehending the consumer perception of EVs and identifying the barriers impeding their purchase is of utmost significance. Although an increasing amount of research has highlighted several barriers to the adoption of EVs, the current debate on the subject is not very helpful in gaining a better understanding and conceptualizing these barriers and in providing useful policy measures to increase the adoption of electric vehicles (Berkeley et al. 2018). In the United States, most scientific studies focus on the outcomes of extensive trials conducted in major urban areas with strong policy incentives that tend to attract drivers who are already inclined towards adopting sustainable technologies (Archsmith et al. 2022; Gehrke and Reardon 2022). Several additional studies investigate the effectiveness of vehicles powered by alternative fuels in a setting characterized by distinct traffic conditions and mileage requirements compared to United States (She et al. 2017; Berkeley et al. 2018; Kongklaew et al. 2021). Therefore, this study aims to address the above research gaps through a survey questionnaire developed and distributed to conventional vehicle drivers in Texas. The study involved a three-step process, which included (1) the ranking of barriers and subsequent comparison of results with prior research, (2) the identification of homogenous groups of respondents through cluster analysis, and (3) the comparison of socioeconomic groups of respondents through the use of a chi-squared test.

The study offers multiple significant contributions. Initially, it utilizes worldwide literature to combine and summarize the several barriers to EV adoption that have been recognized. Furthermore, a comprehensive survey of conventional vehicle drivers yields a distinct dataset that gives evidence of the significance of these barriers, and cluster analysis identifies the homogeneous respondent group with respect to each identified barrier. Furthermore, the chi-squared test enables us to compare the demographics of the respondents. The outcomes of this research can guide policymakers in crafting efficient energy and transportation policies and guide those responsible for designing EVs that fit the needs and demands of potential consumers.

Literature review

Technological barrier

As demonstrated in Table 1, range limitation is one of the technological barriers to EV adoption. For an electric vehicle to operate, the batteries must be charged, and the battery's storage capacity determines the vehicle's range (Berkeley et al. 2018). Individuals whose daily routines necessitate extensive travel are less inclined to embrace EVs (Li et al. 2017). Literature reveals that respondents in numerous studies are concerned about lengthy charging durations (Adhikari et al. 2020). Charging was hampered by high charge times and a dearth of public charging stations, differences that were especially noticeable when comparing EVs and ICE vehicles (Noel et al. 2020).

Charged batteries power electric vehicles. The average warranty for an EV battery, which has been enhanced in recent years, now lasts between 8 and 10 years (Haddadian et al. 2015). After this period, the user is responsible for battery replacement. Additionally, the batteries are prone to excessive charging, which is problematic for EV drivers (Noel et al. 2020). The limited battery life necessitates frequent battery replacements, a significant barrier for EV drivers.

EVs are recent technological advancements compared to traditional vehicles, and potential users often express apprehension regarding their safety and efficacy, increasing their reluctance to use EVs (Xue et al. 2014; She et al. 2017). Furthermore, users' perception of EVs is affected by their lack of reliability, while the expansion of EV deployment is significantly impeded by system instability. Thus, the insufficiency of evidence about reliability can be considered another technical barrier.

In addition, the fewer EV models pose a hindrance to widespread EV adoption. A wider range of vehicle models has the potential to attract a more diverse market segment (Linzenich et al. 2019). Thus, the limited availability of EV models presents an additional obstacle in restricting user options (Kongklaew et al. 2021). The electric vehicle manufacturing sector is accountable for conducting research, carrying out development activities, and producing electric vehicles. Nevertheless, EV production is typically limited (Xue et al. 2014).

Environmental barrier

Despite the numerous environmental benefits that EVs provide, there exists a divergent viewpoint with regard to the environmental benefits they offer, as evidenced by the studies conducted by (Liu et al. 2020; Ramesan et al. 2022). Furthermore, a number of studies have identified concerns among some consumers questioning the environmental protection capabilities of EVs. This phenomenon is attributed to the significant pollution generated during battery and electricity production and inadequate recycling infrastructure to dispose of old batteries (Ali and Naushad 2022; Stockkamp et al. 2021).

Table 1 List of EV adoption barriers

Category	#	Barrier	References
Technological barrier	B1	Limited driving range	(Berkeley et al. 2018; Singh et al. 2020)
	B2	Longer recharge durations	(Adhikari et al. 2020; Li et al. 2017)
	B3	Limited battery life	(Noel et al. 2020)
	B4	Poor safety	(She et al. 2017)
	B5	Doubts about reliability	(Adhikari et al. 2020)
	B6	Fewer EV models	(Kongklaew et al. 2021)
Environmental barrier	B7	Problems of battery disposal	(Berkeley et al. 2018)
	B8	Environmental impact of battery manufacturing	(Giansoldati et al. 2020)
Economic barrier	B9	High acquisition cost	(Noel et al. 2020)
	B10	Lower resale value	(Lim et al. 2015)
	B11	High electricity costs for charging	(Kim et al. 2018)
	B12	High battery replacement cost	(Kongklaew et al. 2021)
	B13	Cost of adapting a residential electrical infrastructure	(Patt et al. 2019)
Infrastructure barrier	B14	Insufficient public charging stations	(Kongklaew et al. 2021)
	B15	Unreliable charging electricity grid performance	(Illmann and Kluge 2020)
	B16	Inadequate repair and maintenance services	(Giansoldati et al. 2020)
	B17	Charging problem in the absence of a garage	(Kumar and Alok 2020)

Economic barrier

Table 1 shows that the high acquisition cost of EVs is one of the economic barriers that hinder consumers from adopting them. The market price of EVs is high compared to conventional vehicles because of their higher production costs (Cherchi 2017; Anastasiadou and Gavanas 2022). According to Noel et al. (2020), the increased cost of PHEVs can be attributed to their dual operational complexity. Additionally, the lower resale value of EVs poses a concern to consumers. The resale values of current EVs are comparatively lesser than those of conventional vehicle alternatives because of absence of robust secondary resale market (Pamidimukkala et al. 2023c). According to previous research, the cost of the battery is a significant component of the overall cost of an EV (Stockkamp et al. 2021). As stated earlier, the lifespan of an EV battery is restricted to duration of 8 to 10 years, and the consumer is responsible for its replacement cost. Thus, it is a major barrier to EV adoption (Berkeley et al. 2018).

EVs are powered by electricity as opposed to conventional vehicles, which rely on gasoline or diesel. Considering that consumers are susceptible to the cost of fuel, a rise in electricity price leads to a decline in demand for EVs (Kim et al. 2018). The daily operational expenses of an EV are primarily influenced by the cost of electricity required for recharging. As shown in Table 1, the cost of electrical system adaptation is the last barrier in this category. Literature indicates that people renting their homes or apartments must negotiate with the building owner to install a charging unit. This also necessitates an extensive electrical infrastructure upgrade, which incurs additional costs (Patt et al. 2019).

Infrastructure barrier

As presented in Table 1, the extensive adoption of EVs relies on the presence of sufficient charging infrastructure. The scarcity of charging stations has been recognized as a barrier to widespread adoption of EVs (Kongklaew et al. 2021; Singh et al. 2020). Additionally, prospective EV drivers are hesitant to purchase the vehicle due to the inadequacy of charging stations. Moreover, the absence of a garage presents a difficulty for apartment dwellers who desire to charge their vehicles (Illmann and Kluge 2020).

Existing EV owners are dissatisfied due to the inadequate provision of support centers and facilities for EV repair and maintenance, in contrast to the availability of such services for conventional vehicles. Moreover, the processes associated with servicing and maintaining EVs can be complex, and there is a scarcity of skilled mechanics capable of addressing these matters (Giansoldati et al. 2020; Pamidimukkala et al. 2023d).

Method

To determine the potential consumers' perceptions of EVs, a survey was designed and conducted at the University of Texas at Arlington (UTA). The survey was reviewed and approved by UTA's Institutional Review Board (IRB) and distributed electronically in March 2023 to 10,000 students, faculty, and staff above 18 years of age with active parking permits, using the online application QuestionPro. The questionnaire comprised 27 questions, which were categorized into two sections and took around 7 min to finish. After sending two reminder emails, 733 complete responses were received that were used for further analysis.

According to data illustrated in Fig. 1, females comprised 52.9% of the responses, males 44.3%, those who identified as "Others" constituted 2.8%. Around 62% of the respondents possessed bachelor's degrees, rendering them more capable of differentiating the technological, financial, and environmental distinctions between conventional vehicles and EVs (She et al. 2017). Most of the respondents (52.2%) belonged to the age group of 35 years and older. A mere 17.6% of the participants belonged to households earning less than $35,000 annually, while 46.2% were from households with a median annual income ranging from $35,000 to $99,000. Most of the respondents had more than one vehicle, and 77% of participants are experienced drivers.

Results and discussion

Ranking of barriers

Figure 2 illustrates the scores of the identified barriers. The highest scoring barriers were the high acquisition price, inadequate availability of public charging stations, and expensive battery replacement costs, with an average score exceeding four. The highest-ranked factor was the substantial purchase price, which is consistent with the findings of most of the prior research (Berkeley et al. 2018; Noel et al. 2020). This highlights the importance of subsidies and the importance to reduce the purchase costs of EVs (Parker et al. 2021). In the present study, the inadequate provision of repair and maintenance services was identified as a more significant barrier compared to the research conducted by Noel et al. (2020). Additionally, cost of adapting a residential electrical infrastructure was ranked as a significant barrier.

In contrast to prior research (Kongklaew et al. 2021; Liu et al. 2021), our survey participants assigned a relatively

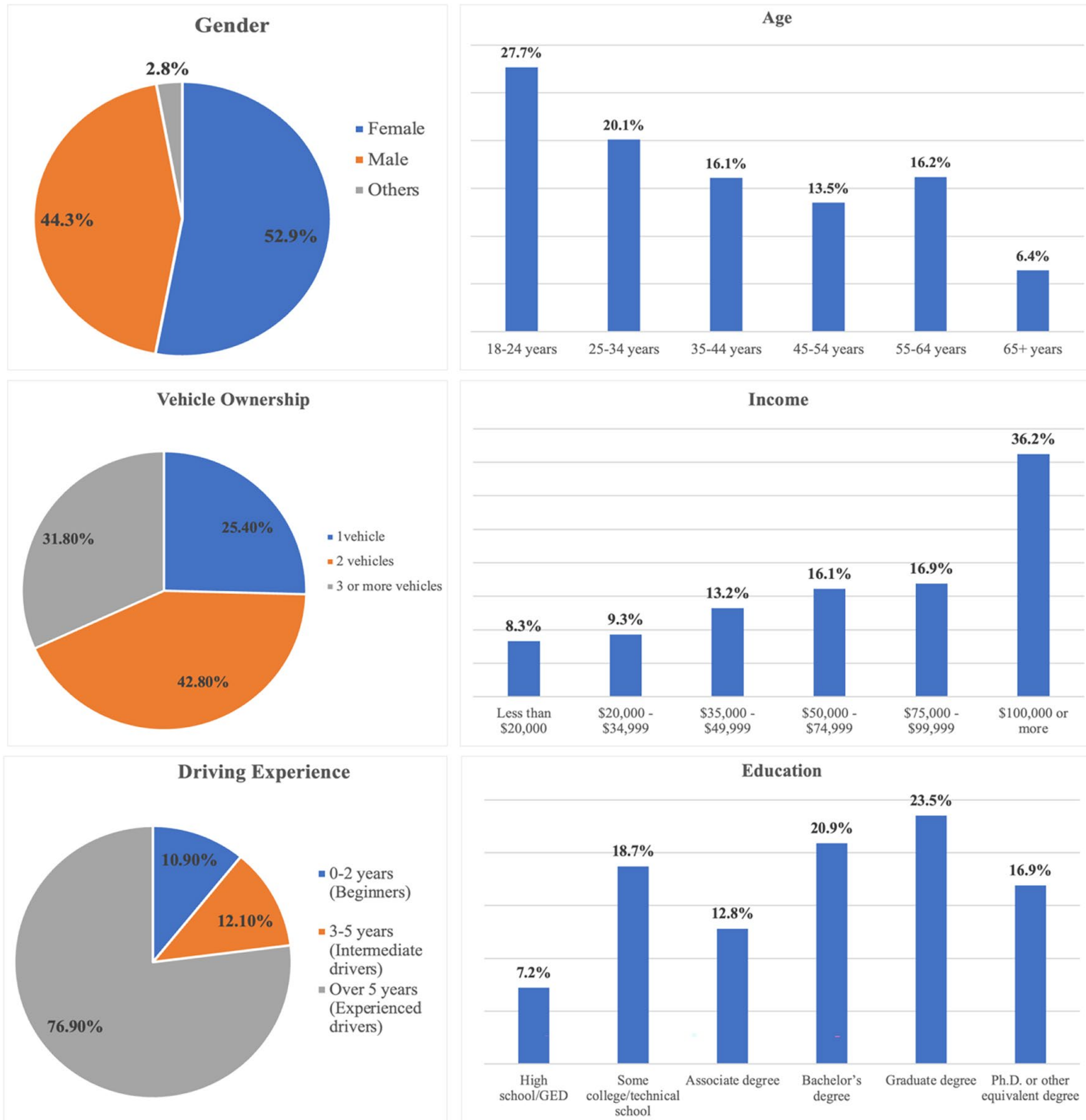

Fig. 1 Demographics of survey respondents

low ranking to the EV battery life and driving range. This could be attributed to the gradual improvement in battery performance over time. As of our understanding, there has been no analysis of the barrier pertaining to the reliability of charging power grids, which ranked tenth out of 17 in our survey. The responses on the ecological consequences of battery manufacturing and the challenges associated with battery disposal exposed concerns about the environmental advantages of EVs, aligning with certain findings in the literature (Giansoldati et al. 2020). Overall, our respondents were convinced of the environmental benefits of substituting traditional vehicles with EVs. The growing share of green energy sources in power generation, as extensively documented on social networking platforms, along with the technological progress in battery recycling, undoubtedly played a significant role in achieving this result.

The rankings of the two financial obstacle higher electricity costs associated with charging and diminished resale value were nearly identical to those reported in prior research (Berkeley et al. 2018). Reliability concerns poor safety received the lowest scores among technological barriers. A significant proportion of the participants did not consider these barriers to be crucial, as evidenced by their mean score being below 3. This result corroborates the findings of Noel et al. (2020) regarding Denmark and Giansoldati et al. (2020) regarding Italy.

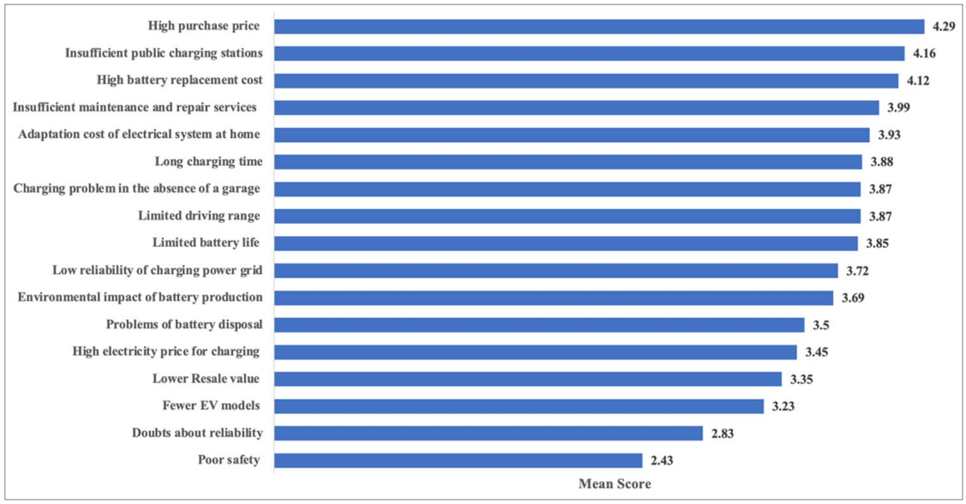

Fig. 2 Mean scores of identified barriers

Identifying homogenous respondent groups

Cluster analysis was adopted to identify the homogenous groups of respondents. A clustering technique was performed in two stages utilizing SPSS 29, with the 17 identified barriers as the clustering variables. The initial step involved the implementation of a hierarchical clustering methodology to generate viable clustering outcomes, utilizing Ward's linkage technique with agglomeration coefficient, as previously employed in a few scholarly investigations (Jaiswal et al. 2022; Saleem et al. 2018). The outcome of the hierarchical analysis led to an assessment of the variance percentage in the heterogeneity-stopping rule, ultimately concluding that a three-cluster solution was the most suitable. Subsequently, a *K*-means algorithm was employed to examine the membership of the clusters. Upon completion of the cluster analysis and attainment of an optimal cluster solution, an ANOVA was executed to ascertain the presence of statistically significant differences among the groups. The results indicate significant differences among the three groups for all the variables. Table 2 provides an overview of the three cluster memberships, with 43.1%, 12.7%, and 44.2% of respondents belonging to Cluster 1, Cluster 2, and Cluster 3, respectively.

Table 2 Respondent scores of each cluster

Barrier	Cluster 1 ($n_1 = 316$) Indifferents	Cluster 2 ($n_2 = 93$) Enthusiasts	Cluster 3 ($n_3 = 324$) Skeptics	Significance
Limited driving range	3.79	2.14	4.45	< 0.001
Long charging times	3.70	2.10	4.56	< 0.001
Limited battery life	3.58	1.99	4.65	< 0.001
Poor safety	2.10	1.57	2.99	< 0.001
Doubts about reliability	2.35	1.74	3.60	< 0.001
Fewer EV models	2.98	1.83	3.87	< 0.001
Problems of battery disposal	3.06	1.77	4.42	< 0.001
Environmental impact of battery production	3.36	1.99	4.50	< 0.001
High acquisition price	4.21	2.99	4.74	< 0.001
High battery replacement cost	3.87	2.47	4.83	< 0.001
High electricity cost for charging	3.00	1.66	4.40	< 0.001
Lower resale value	3.09	1.73	4.07	< 0.001
Cost of adapting a residential electrical infrastructure	3.64	2.14	4.73	< 0.001
Inadequate public charging stations	4.16	2.51	4.64	< 0.001
Charging problem in the absence of a garage	3.68	2.12	4.56	< 0.001
Insufficient maintenance and repair services	3.85	2.05	4.69	< 0.001
Unreliable charging electricity grid performance	3.41	1.62	4.62	< 0.001

Significant at $p < 0.05$

Identifying the clusters based on demographic characteristics and using cross-tabulations of various demographic factors and segment memberships further enhanced our understanding of the clusters. The sociodemographic attributes of the respondents in each cluster are presented in Table 3. The cluster profiles are discussed below, based on the results from Table 2 and 3.

The indifferents

The first cluster group, labeled the "indifferents," was the second largest cluster, comprised of 316 respondents. Most of them indicated that they were neutral on all the barriers, except for poor safety ($X = 2.10$), doubts about reliability ($X = 2.35$), high purchase price ($X = 4.21$), and insufficient public charging infrastructure ($X = 4.16$). Safety and reliability barriers were perceived to be less important in this cluster; the purchase price and lack of enough public charging stations were perceived to be more important.

As illustrated in Table 3, analysis of the demographic characteristics of this cluster showed that the proportion of male (49%) and female respondents (47.5%) was almost the same, with most of them (53.8%) below the age of 34. The majority (23.7%) of them held a bachelor's degree; 23.4% held a graduate degree. Approximately 35.8% had an annual household income greater than $100,000, and 44.2% owned two vehicles. About 74.7% of them are experienced drivers.

The enthusiasts

The "enthusiasts" were the smallest cluster, representing 12.7% of the respondents. This group has the lowest score on all the barriers as compared to other two groups. In addition, all these values are less than sample means, and they did not find any of the 17 barriers to be of importance. This indicates that the respondents in this cluster perceive EVs positively, and they tend to adopt EVs in the future.

As shown in Table 3, the majority (58.1%) of the enthusiasts were males, and 38.6% of them were between the ages

Table 3 Sociodemographic characteristics based on individual clusters

Demographic	Item	Indifferents $n_1 = 43.1\%$ %	Optimists $n_2 = 12.7\%$ %	Pessimists $n_3 = 44.2\%$ %
Gender	Female	47.5%	37.6%	62.6%
	Male	49.0%	58.1%	35.8%
	Other	3.5%	4.3%	1.5%
Age	18–24	27.8%	21.6%	29.3%
	25–34	26.0%	21.6%	13.9%
	35–44	14.9%	13.9%	17.9%
	45–54	11.7%	19.3%	13.6%
	55–64	14.9%	19.3%	16.7%
	65 +	4.7%	4.3%	8.6%
Education	High school/GED	8.6%	5.4%	6.5%
	Some college/technical school	15.6%	14.0%	23.1%
	Associate degree	10.7%	10.8%	15.4%
	Bachelor's degree	23.7%	14.0%	20.1%
	Graduate degree	23.4%	31.1%	21.3%
	Ph.D. or other equivalent degree	18.0%	24.7%	13.6%
Household income	Less than $20,000	10.4%	8.6%	6.2%
	$20,000–$34,999	10.1%	4.3%	9.9%
	$35,000–$49,999	13.0%	7.5%	15.1%
	$50,000–$74,999	15.8%	15.1%	16.7%
	$75,000–$99,999	14.9%	18.3%	18.5%
	$100,000 or more	35.8%	46.2%	33.7%
Vehicle ownership	1vehicle	30.1%	23.7%	21.3%
	2 vehicles	44.3%	45.2%	40.7%
	3 or more vehicles	25.6%	31.2%	38.0%
Driving experience	0–2 years	12.3%	7.5%	10.5%
	3–5 years	13.0%	8.6%	12.3%
	Over 5 years	74.7%	83.9%	77.2%

of 45 and 64, which is higher than those in the other two clusters. Most of them held either a graduate or postgraduate degree (surpassing individual contribution of each of the other two clusters and the total sample average) with the highest percentage (24.7%) holding a Ph.D. or other equivalent degree. Regarding income, the enthusiasts have the highest proportion of individuals in the highest income category ($100,000 and more, 46.2%). In addition, 45.2% of respondents own two vehicles, and 83.9% of them are experienced drivers.

The skeptics

The third cluster group labeled the “skeptics” was the largest group, representing 44.2% of the sample. They ranked all of the barriers high except poor safety, doubts about reliability, and fewer EV models. The mean values of this cluster were higher than those of the other two groups and higher than those of the sample means. This shows that the skeptics considered almost all the identified barriers highly important and indicates their negative and unfavorable views towards adopting EVs.

Table 3 presents a sociodemographic profile of the skeptics, which is primarily distinguished by the exceedingly larger percentage of females (62.6%) over males (35.8%) in comparison to other groups examined in the study. On the income scale, the respondents in this cluster have relatively low income. In addition, when compared with the other clusters, this group has lower proportion of graduates and post-graduates and has a greater number of beginners and intermediate drivers compared to other two clusters.

Barriers and socioeconomic characteristics of respondents

Respondents were classified by gender, age, education, income, vehicle ownership, and driving experience to determine whether individual characteristics substantially impact the public’s views about purchasing an electric vehicle. Table 4 shows that each barrier was cross-tabulated with each socioeconomic characteristic to test the null hypothesis H_0 that the two variables X and Y are independent. This study employed a significance level of 5%; i.e., if the p value was less than 0.05, the null hypothesis was rejected.

As presented in Table 4, 10 of the 17 barriers exhibited statistically significant differences regarding gender. This demonstrates that females and males had distinctly different perspectives of most of the barriers, which is consistent with

Table 4 Summary of respondent personal characteristics

Barrier	Gender (df = 8)	Age (df = 20)	Education (df = 20)	Income (df = 20)	Vehicle ownership (df = 8)	Driving experience (df = 8)
Limited driving range	**0.006***	0.685	0.483	0.134	**0.007***	0.075
Long charging times	**0.009***	0.114	0.051	0.209	0.053	**0.011***
Limited battery life	0.142	**0.040***	**0.002***	0.706	**0.022***	0.189
Poor safety	**< 0.001***	0.102	0.164	**0.010***	0.406	**0.043***
Doubts about reliability	**< 0.001***	**0.002***	0.320	**0.028***	0.213	0.213
Fewer EV models	0.291	**0.005***	0.723	0.338	**0.003***	0.682
Problems of battery disposal	**0.045***	0.331	**< 0.001***	0.495	**0.029***	0.304
Environmental impact of battery production	**0.002***	0.315	**0.017***	0.368	**0.019***	0.791
High acquisition cost	0.112	0.091	**0.023***	**0.028***	**0.020***	0.230
High battery replacement cost	0.158	0.199	0.252	0.130	**0.007***	0.298
High electricity cost for charging	< **0.001***	0.147	**0.011***	**0.023***	0.507	0.058
Lower resale value	0.020	0.108	**0.015***	0.277	0.391	0.553
Adaptation cost of electrical system at home	**< 0.001***	0.086	0.189	0.106	0.273	0.113
Insufficient public charging stations	0.183	0.098	**0.026***	0.925	0.260	0.341
Charging problem in the absence of a garage	0.295	**< 0.001***	**0.001***	**< 0.001***	**0.020***	0.094
Insufficient maintenance and repair services	**0.004***	0.109	0.452	0.367	0.127	0.501
Unreliable charging electricity grid performance	**< 0.001***	0.333	< 0.001	0.131	**0.001***	0.721

*Refers to p value < 0.05

previous studies (Giansoldati et al. 2020; Kongklaew et al. 2021). The data indicates that males exhibit a higher propensity to adopt electric vehicles, as compared to females, as the latter group expressed greater apprehension towards most of the barriers associated with EV adoption.

Statistically significant age group differences were observed for the barriers of limited battery life, doubts about reliability fewer EV models, and charging problem in the absence of garage. The age group of 18–24 years exhibited a greater level of concern towards the barriers. The findings indicate that individuals aged 45 and above exhibit comparatively lower mean scores, suggesting that middle-aged respondents are more inclined towards adopting electric vehicles.

The level of education attained by the respondents weighed heavily on the statistics pertaining to eight barriers: limited battery life, battery disposal problems, environmental impact of battery production, high purchase price, high electricity cost for charging, resale value, insufficient public charging stations, and charging problem in the absence of garage. Respondents possessing a higher level of education asserted that these barriers were not of great concern for EV adoption. This indicates that respondents with higher education levels showed the significant interest towards EV adoption.

The impact of household income was observed on 5 out of 17 barriers. Participants with an annual income exceeding $100,000 reported fewer concerns regarding economic factors, such as the high cost of purchase and battery replacement expenses. They also appeared less concerned with the charging problem in the absence of garage as majority of them might be homeowners.

As pertains to driving experience, of the 17 barriers, only two, high charging time and poor safety, were found to be statistically different among the three groups. The average score related to charging time increased with the respondents' driving experience, which may be because it takes longer time to charge an EV than it takes to fill a conventional vehicle with gas. In addition, experienced drivers were also more concerned about the safety of driving an EV.

Conclusion

In this study, the barriers to EV adoption from the consumers' perspectives were explored by analyzing 733 responses to a survey questionnaire. The results showed that of 17 identified barriers, 3 were considered the most critical: high acquisition price, inadequate public charging stations, and the battery replacement cost. Unlike previously conducted studies, we found that the driving range facilitated by one charge was not of primary importance to our survey group. In addition, they felt that the adoption of EVs would lessen the environmental effects of conventional cars and appreciated the technological features that facilitate safety and reliability, which shows that few initial concerns regarding EVs have been alleviated. The respondents were, however, extremely sensitive to the availability of charging stations. Lastly, our study shows that the promotion of EVs should focus on male, middle-aged experienced drivers, as they show a strong interest and inclination to adopt one, and a concentrated effort should be made to increase the public's knowledge of the benefits of the EV technology.

The findings also suggest that the enthusiasts are more inclined to purchase EVs, as manufacturers could readily target them as early adopters using extrinsic incentive measures. In addition, this segment should be informed about the fundamental advantages of EVs, including savings on fuel cost and environmental conservation, through increased social persuasion and a positive attitude into using such vehicles. The findings also revealed that the indifferents are the second largest cluster, emerging with a neutral attitude of adopting EVs. This homogeneous cluster might be converted into potential EV adopters with convincing evidence demonstrating the significant benefits of EV use, including its affordability and environmental friendliness. Manufacturers should increasingly target young women as potential EV buyers considering this demographic. The findings of this study will provide valuable guidance to EV makers, designers, marketers, and other groups in effectively educating the public about the benefits of eco-friendly transportation and in shaping their inclination to possess an EV.

The results of this study propose a series of enhancements that various stakeholders could implement to overcome some of the barriers to EV adoption. To avoid economic barriers, policymakers may consider introducing tax reductions or similar supporting initiatives to reduce the financial burden of EV vehicle taxes. Purchase subsidies for electric vehicles and batteries, as well as subsidized programs for replacing batteries, could be implemented as incentives to lower the cost of owning an EV. The advantage of EV lies in their considerably lower operating expenses, which can eventually compensate for the difference in the cost of the initial purchase. Considering the consumers' inadequate understanding of maintenance and operational costs, it is crucial to emphasize extensive public outreach on EVs in the future. Moreover, there exist significant infrastructure demands, including inadequate availability of charging stations on highways and unclear policies regarding parking charges at charging stations and residential complexes. To facilitate charging, policymakers must consider factors such as the quantity and placement of charging stations, as well as their distribution and ease of access. It is advisable to establish and extensively implement innovative business models concerning charge infrastructure, such as public–private partnerships, to draw higher societal financing. Policymakers should actively advocate for the positive environmental impacts of electric vehicles to potentially boost their rate of adoption. However, the government's adoption of using renewable resource for energy generation and standardized methods to recover and recycle old batteries has the potential to appeal to a wider group of users and reduce public skepticism about EVs, particularly among ecologically sensitive consumers.

This study has few limitations. This study employed a web-based survey to gather data. The sociological and psychological literature states that younger individuals are generally more inclined to participate in online surveys due to their greater comfort with technology. Additionally, higher education and socioeconomic status may also contribute to increased participation in online surveys. These characteristics could influence green transportation purchasing behaviors. Employing this method may introduce sample bias as it excludes users who do not have internet access. Future studies may conduct a paper-based survey and apply our findings. The dependent variable used in this study is intention to adopt an EV, rather than actual behavior. Although they are closely related, it is more probable that the research outcomes will be satisfactory when the former is used. Lastly, the applicability of our study's results beyond the state of Texas may be constrained by the fact that the data were collected solely in this geographical area and there is a possibility of discrepancies in research outcomes when attempting to apply results to various regions due to inherent variations.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Apurva Pamidimukkala, Sharareh Kermanshachi, Jay Michael Rosenberger, and Greg Hladik. The first draft of the manuscript was written by Apurva Pamidimukkala, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Adhikari M, Ghimire LP, Kim Y, Aryal P, Khadka SB (2020) Identification and analysis of barriers against electric vehicle use. Sustainability 12(12):4850

Adnan N, Nordin SM, Amini MH, Langove N (2018) What make consumer sign up to PHEVs? Predicting Malaysian consumer behavior in adoption of PHEVs. Transp Res Part A: Policy Pract 113:259–278

Ali I, Naushad M (2022) A study to investigate what tempts consumers to adopt electric vehicles. World Electr Veh J 13(2):26

Anastasiadou K, Gavanas N (2022) State-of-the-art review of the key factors affecting electric vehicle adoption by consumers. Energies 15(24):9409

Archsmith J, Muehlegger E, Rapson DS (2022) Future paths of electric vehicle adoption in the United States: predictable determinants, obstacles, and opportunities. Environ Energy Policy Econ 3(1):71–110

Barman P, Dutta L, Bordoloi S, Kalita A, Buragohain P, Bharali S, Azzopardi B (2023) Renewable energy integration with electric vehicle technology: a review of the existing smart charging approaches. Renew Sustain Energy Rev 183:113518

Berkeley N, Jarvis D, Jones A (2018) Analysing the take up of battery electric vehicles: an investigation of barriers amongst drivers in the UK. Transp Res Part d: Transp Environ 63:466–481

Cherchi E (2017) A stated choice experiment to measure the effect of informational and normative conformity in the preference for electric vehicles. Transp Res Part A: Policy Pract 100:88–104

Egbue O, Long S (2012) Barriers to widespread adoption of electric vehicles: an analysis of consumer attitudes and perceptions. Energy Policy 48:717–729

Gehrke SR, Reardon TG (2022) Patterns and predictors of early electric vehicle adoption in Massachusetts. Int J Sustain Transp 16(6):514–525

Ghosh A (2020) Possibilities and challenges for the inclusion of the electric vehicle (EV) to reduce the carbon footprint in the transport sector: a review. Energies 13(10):2602

Giansoldati M, Monte A, Scorrano M (2020) Barriers to the adoption of electric cars: evidence from an Italian survey. Energy Policy 146:111812

Gnann T, Stephens TS, Lin Z, Plötz P, Liu C, Brokate J (2018) What drives the market for plug-in electric vehicles?-A review of international PEV market diffusion models. Renew Sustain Energy Rev 93:158–164

Haddadian G, Khodayar M, Shahidehpour M (2015) Accelerating the global adoption of electric vehicles: barriers and drivers. Electr J 28(10):53–68

IEA (2020) World Energy Outlook 2020. IEA, Paris. Retrieved on July 20, 2023. https://www.iea.org/reports/world-energy-outlook-2020

Illmann U, Kluge J (2020) Public charging infrastructure and the market diffusion of electric vehicles. Transp Res Part D: Transp Environ 86:102413

Jaiswal D, Deshmukh AK, Thaichon P (2022) Who will adopt electric vehicles? Segmenting and exemplifying potential buyer heterogeneity and forthcoming research. J Retail Consum Serv 67:102969

Khan MA, Patel RK, Pamidimukkala A, Kermanshachi S, Rosenberger JM, Hladik G, Foss A (2023) Factors that determine a university community's satisfaction levels with public transit services. Front Built Environ 9:1125149

Kim M-K, Oh J, Park J-H, Joo C (2018) Perceived value and adoption intention for electric vehicles in Korea: moderating effects of environmental traits and government supports. Energy 159:799–809

Kongklaew C, Phoungthong K, Prabpayak C, Chowdhury MS, Khan I, Yuangyai N, Yuangyai C, Techato K (2021) Barriers to electric vehicle adoption in Thailand. Sustainability 13(22):12839

Kumar RR, Alok K (2020) Adoption of electric vehicle: a literature review and prospects for sustainability. J Clean Prod 253:119911

Li W, Long R, Chen H, Geng J (2017) A review of factors influencing consumer intentions to adopt battery electric vehicles. Renew Sustain Energy Rev 78:318–328

Lim MK, Mak HY, Rong Y (2015) Toward mass adoption of electric vehicles: Impact of the range and resale anxieties. Manuf Serv Oper Manag 17(1):101–119

Linzenich A, Arning K, Bongartz D, Mitsos A, Ziefle M (2019) What fuels the adoption of alternative fuels? Examining preferences of German car drivers for fuel innovations. Appl Energy 249:222–236
Liu R, Ding Z, Jiang X, Sun J, Jiang Y, Qiang W (2020) How does experience impact the adoption willingness of battery electric vehicles? The role of psychological factors. Environ Sci Pollut Res 27:25230–25247
Liu Z, Song J, Kubal J, Susarla N, Knehr KW, Islam E, Nelson P, Ahmed S (2021) Comparing total cost of ownership of battery electric vehicles and internal combustion engine vehicles. Energy Policy 158:112564
Moeletsi ME (2021) Socio-economic barriers to adoption of electric vehicles in South Africa: case study of the Gauteng province. World Electr Veh J 12(4):167
Noel L, de Rubens GZ, Kester J, Sovacool BK (2020) Understanding the socio-technical nexus of Nordic electric vehicle (EV) barriers: a qualitative discussion of range, price, charging and knowledge. Energy Policy 138:111292
Pamidimukkala A, Patel RK, Kermanshachi S, Rosenberger JM, Tanvir S (2023a) A review on shared mobility and electric vehicles. In: International Conference on Transportation and Development 2023, ASCE, Reston, VA, pp 333–342
Pamidimukkala A, Kermanshachi S, Rosenberger JM, Hladik G (2023b) Evaluation of barriers to electric vehicle adoption: a study of technological, environmental, financial, and infrastructure factors. Transp Res Interdiscip Perspect 22:100962
Pamidimukkala A, Kermanshachi S, Rosenberger JM, Hladik G (2023c) Adoption of electric vehicles: a state-of-art review. Transp Res Procedia 73:313–320
Pamidimukkala A, Kermanshachi S, Rosenberger JM, Hladik G (2023d) Barriers to electric vehicle adoption: a structural equation modeling analysis. Transp Res Procedia 73:305–312
Pamidimukkala A, Kermanshachi S, Rosenberger JM, Hladik G (2024) Barriers and motivators to the adoption of electric vehicles: a global review. Green Energy Intell Transp, p 100153
Parker N, Breetz HL, Salon D, Conway MW, Williams J, Patterson M (2021) Who saves money buying electric vehicles? Heterogeneity in total cost of ownership. Transp Res Part D: Transp Environ 96:102893
Patt A, Aplyn D, Weyrich P, van Vliet O (2019) Availability of private charging infrastructure influences readiness to buy electric cars. Transp Res Part A: Policy Pract 125:1–7
Patyal VS, Kumar R, Kushwah S (2021) Modeling barriers to the adoption of electric vehicles: an Indian perspective. Energy 237:121554
Ramesan S, Kumar P, Garg SK (2022) Analyzing the enablers to overcome the challenges in the adoption of electric vehicles in Delhi NCR. Case Stud Transp Policy 10(3):1640–1650
Rietmann N, Lieven T (2019) How policy measures succeeded to promote electric mobility–worldwide review and outlook. J Clean Prod 206:66–75
Saleem MA, Eagle L, Low D (2018) Market segmentation based on eco-socially conscious consumers' behavioral intentions: evidence from an emerging economy. J Clean Prod 193:14–27
Sanguesa JA, Torres-Sanz V, Garrido P, Martinez FJ, Marquez-Barja JM (2021) A review on electric vehicles: technologies and challenges. Smart Cities 4(1):372–404
She Z-Y, Sun Q, Ma J-J, Xie B-C (2017) What are the barriers to widespread adoption of battery electric vehicles? A survey of public perception in Tianjin, China. Transp Policy 56:29–40
Singh V, Singh V, Vaibhav S (2020) A review and simple meta-analysis of factors influencing adoption of electric vehicles. Transp Res Part D: Transp Environ 86:102436
Stockkamp C, Schäfer J, Millemann JA, Heidenreich S (2021) Identifying factors associated with consumers' adoption of e-mobility—a systematic literature review. Sustainability 13(19):10975
Xue Y, You J, Shao L (2014) Understanding socio-technical barriers to sustainable mobility–insights from demonstration program of EVs in China. Problemy ekorozwoju–problems of sustainable development 9(1):29–36
Zhou Y, Wen R, Wang H, Cai H (2020) Optimal battery electric vehicles range: a study considering heterogeneous travel patterns, charging behaviors, and access to charging infrastructure. Energy 197:116945