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Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions

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HIGHLIGHTS

- ► We sample technology enthusiasts to determine attitudes toward electric vehicles.
- ► Knowledge and perceptions differ across gender, age, and education groups.
- ► High degree of uncertainty is associated with electric vehicles.
- ► Battery range is the biggest concern followed by cost.
- ► Sustainability has less weight compared to electric vehicle cost and performance.

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ABSTRACT

Electric Vehicles (EVs) are promoted as a viable near-term vehicle technology to reduce dependence on fossil fuels and resulting greenhouse gas (GHG) emissions associated with conventional vehicles (CVs). In spite of the benefits of EVs, several obstacles need to be overcome before EVs will be widely adopted. A major barrier is that consumers tend to resist new technologies that are considered alien or unproved, thus, policy decisions that consider their critical concerns will have a higher level of success. This research identifies potential socio-technical barriers to consumer adoption of EVs and determines if sustainability issues influence consumer decision to purchase an EV. This study provides valuable insights into preferences and perceptions of technology enthusiasts; individuals highly connected to technology development and better equipped to sort out the many differences between EVs and CVs. This group of individuals will likely be early adopters of EVs only if they perceive them to be superior in performance compared to CVs. These results can guide policymakers in crafting energy and transportation policy. It can also provide guidance to EV engineers' decision in incorporating consumer preference into EV engineering design.

1. Introduction

The transportation sector is responsible for approximately 14% of global greenhouse gas emissions and this is projected to increase to 50% by 2030 (IEA, 2007). This projection implies that the current transportation system is unsustainable. A transformation of the global transportation sector is necessary to reduce greenhouse gas emissions, air pollution and dependence on fossil fuels. Electric Vehicles (EVs) are a viable near-term transportation technology capable of providing sustainable mobility. In the U.S., large deployment of EVs can play a significant role in addressing some of these problems (Natural Resources Defense Council, 2007). Recently, the U.S. government allocated considerable stimulus funding to promote the use of alternative fuels (Skerlos and Winebrake, 2010). The American Recovery and Reinvestment Act (ARRA) of 2009 provides over $2 billion for electric vehicle and battery technologies, geared toward achieving a goal of one million electric vehicles on U.S. roads by 2015 (Canis, 2011). These investments and targets imply that U.S. policymakers accept that large scale adoption of electric drive vehicles may be a sustainable solution to growing environmental, economic and energy concerns in transportation. In addition, almost all major car manufacturers are demonstrating interests in EVs and developing new passenger and commercial cars (Lieven et al., 2011).

Despite these potential advantages, significant barriers remain to widespread adoption of EV technology and currently, they represent a small market share of vehicles in service. Previous research suggests that battery technology limitations and high battery cost are the major obstacles to widespread adoption of

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Table 1
Description of electric vehicle types.

Vehicle type	Description	Benefits
HEV	Electric vehicles that use an internal combustion engine in addition to an electric motor.	Better fuel economy, less expensive to run and lower emissions than similar conventional vehicles
PHEV	Electric vehicles with smaller internal combustion engine and more powerful electric batteries that can be recharged.	Better fuel economy, less expensive to run and lower emissions than similar HEVs and conventional vehicles. Offers flexibility of fuel source
BEV	Electric vehicles that derive motive power exclusively from onboard electrical battery packs that can be charged with a plug through an electric outlet.	No liquid fuels and zero emissions at tailpipe. Less expensive to run than similar HEVs and conventional vehicles.

EVs (Axsen et al., 2010). As a result, much research is aimed towards addressing the limitations placed on performance by the weight, bulk and storage capacity of batteries (Payton, 1988; Sovacool and Hirsh, 2009). However, we argue that this view does not reveal key areas of consumer resistance to EVs. It is important to view EVs as part of a socio-technical system in order to break the divide between the technical and the social. The term ''social-technical'' encompasses technological, cultural, social, political and economic barriers (Sovacool and Hirsh, 2009). According to Sovacool (2009), technologists and policymakers usually separate technical concerns from social concerns while describing technological development. However, the ''social'' barriers may pose as much of a problem as the ''technical'' in the development of EVs for the mainstream consumer market. In this study, we analyze socio-technical barriers particularly relating to consumers.

In this research, we investigate how differences in consumer populations change opinions and perceptions about EVs and can be used to determine potential socio-technical obstacles to EV adoption. We address two questions regarding EVs: (1) what are the socio-technical barriers to consumer adoption of EVs? And (2) how much influence does sustainability have on EV purchase decision? Using a survey administered to technology enthusiasts and potential EV owners, we categorize perceptions and preferences in order to identify the barriers to widespread acceptance of electric vehicles. The task of comparing the attitudes and perceptions of our sample with the general population is left to future research. This research considers functional attributes of EVs such as driving range, battery life and EV costs. Furthermore, we examine symbolic attributes which have been determined to influence consumer decisions in general vehicle use (Steg, 2005; Steg et al., 2001; Verhoef and Wee, 2000) as well as in the use of Hybrid Electric Vehicles (HEVs) (Heffner et al., 2007; Kahn, 2007; Turrentine and Kurani, 2007) and Battery Electric Vehicles (BEVs) (Skippon and Garwood, 2011).

Insights gained from the results of this research will shed more light on public attitudes and preferences related to EVs. This information will guide policymakers in crafting energy and transportation policy based on the entire EV sociotechnical system. This research will also provide guidance to EV engineers' decision in incorporating consumer preference into EV engineering design.

2. Background

2.1. Electric vehicle technology

Conventional vehicles (CVs) have internal combustion engines (ICEs) that burn petroleum, operate inefficiently and emit a significant amount of greenhouse gasses. Alternative Fuel Vehicles (AFVs) are vehicles designed to operate on at least one alternative to petroleum and diesel and include EVs, bio-fuel vehicles, fuel cell vehicles, compressed natural gas vehicles etc. EVs or electric drive vehicles are vehicles in which partial or entire propulsion power is provided from electricity. EVs come in several varieties. The HEV combines the ICE along with an electric motor to achieve a higher fuel economy than similar-sized vehicles. Some commercially available HEVs include the Toyota Prius, Ford Escape Hybrid and Honda Civic Hybrid. The Plug-in Hybrid Electric Vehicle (PHEV) has a smaller internal combustion engine than the HEV and has a larger battery capable of powering the vehicle for distances between 20 and 60 miles (Sovacool and Hirsh, 2009). In addition, the PHEV battery is rechargeable and can be restored to full charge by connecting a plug to an external electric source. PHEVs offer the higher fuel efficiency of EVs within the all-electric range, but also the flexibility of conventional fuels for extended trips. Some examples of PHEVs currently in the market are the Chevrolet Volt and Toyota Prius Plug-in Hybrid. The BEV is powered solely by a rechargeable electric battery and has batteries that are usually larger than the PHEV and can travel for up to 100 miles on one full charge. BEVs represent a 'carbon free' mode of transportation if electricity for charging is generated from renewable include the Nissan leaf, Mitsubishi *i*-MiEV and Tesla Roadster. For the three categories of EVs shown in Table 1, there exist different variants each with a distinct range of electric driving depending on the battery capacity of the vehicle.

The fundamental technological constraint to the commercialization of EVs is energy storage (Anderman, 2007; Mandel, 2007). According to Axsen et al. (2010), battery technology is limited by tradeoff between five major attributes including power, energy, longevity, cost and safety. Energy storage and energy density determine the range and mass of the battery system, respectively. The battery range limits the distance an EV can travel on an all-electric range and on a single charge. The range issue has the greatest impact on BEVs, which do not have the flexibility of fuel source like HEVs and PHEVs and therefore may require charging en route during long trips that exceed the range of the batteries. Consequently, there is also a need for EV charging infrastructure to charge EVs during trips. In addition, high power is important because they translate into motive force for vehicle acceleration.

Battery cost is a key determinant in the economic viability of EVs especially PHEVs and BEVs. Pesaran et al. (2007) estimate that advanced batteries cost between \$800 to \$1000/kW h. One of the key goals of the U.S. Department Of Energy (DOE) Vehicle Technology Program (2010) is to reduce cost of high-energy, high-power batteries from \$1200/kW h in 2008 to \$300/kW h by 2014 to enable cost-competitiveness of PHEVs.

2.2. Consumer attitudes and motivation

Public attitudes and preferences for EVs must be considered in developing market share in this area. EVs must not only overcome the technological problems facing the battery technology but also social issues related to consumers in order to achieve commercial success. Consumer acceptance is crucial to the continuing success of a sustainable transportation sector (Ozaki and Sevastyanova, 2011). However, consumers tend to be resistant to new technology that is considered unfamiliar or unproven. Therefore, failure by EV manufacturers and policy makers to identify and overcome consumer issues may result in continued low acceptance of EVs long after the technical problems are resolved.

The theory of planned behavior (TPB) by Ajzen (1991) explains the factors influencing consumer behavior. According to TPB, the main determining factors of behavioral intention are attitudes, which are influenced by knowledge and experience, subjective norms that the consumer believes is acceptable by society, and the perceived impact of the behavior. In this context, consumer acceptance of technology is considered an intention to adopt, use, or support its development (Ajzen, 1991). The main reasoning of the TPB is that actions are chosen based on an analysis of the alternatives through which the optimum outcome is achieved (Lane and Potter, 2007).

Research shows that some common barriers to the adoption of any new technology include lack of knowledge by potential adopters, high initial costs and low risk tolerance (Diamond, 2009). A study by Oliver and Rosen (2010) indicates that consumer acceptance of HEVs is limited partly due to perceived risks with new products and tradeoffs between vehicle fuel efficiency, size and price. The general public's perception of risk is based on experience, emotions, the media and other non-technical sources (Sjoberg, 1998). In general, media and social networks often influence values that affect consumer choices (Rogers, 2003; Lane and Potter 2007).

In terms of financial benefits, individuals are more likely to choose options that maximize utility based on their preferences, knowledge of alternatives and budget (Roche et al., 2010). The initial cost of an EV is significantly higher when compared to a gasoline powered ICE vehicle and this cost increases linearly with battery size or the range of the car. Duvall (2002) estimates that the extra cost of owning a HEV ranges between $2500 and $14,000 compared to ICE vehicles. In Duvall's estimation, he used the average national gasoline price at the time, which was $1.65 per gallon. Due primarily to battery cost, EVs particularly PHEVs and BEVs are significantly more expensive than CVs. Another cost consideration is the price of gasoline. van Bree et al., (2010) found that increase in gas prices influences consumer behavior. In a study on consumer adoption of HEVs, Gallagher and Muehlegger (2011) found that consumers usually make the decision to buy HEVs in response to increase in gas prices and government incentives.

Non-financial reasons, especially those associated with environment and energy can influence consumers' decisions to purchase an EV (Zypryme Research and Consulting, 2010). Hence, the potential for EVs to create social benefits by reducing petroleum consumption and GHG emissions can appeal to certain consumers. Environmental values are powerful predictors of certain consumer actions and positively influence willingness to engage in actions that protect the environment (Oliver and Rosen, 2010). Heffner et al. (2007) found that, to this group of consumers, who show high levels of environmental awareness, choosing a HEV symbolizes ideas related to one's individuality and is used to communicate interests and values. Studying HEV purchases in Los Angeles County, Kahn (2007) found that environmentalists are more likely to purchase HEVs compared to non-environmentalists. Similarly, Gallagher and Muehlegger (2011) found that social preferences for environmental quality and energy security were a major determinant for consumer adoption of HEVs. Gallagher and Muehlegger concluded that social preferences increased HEV sales more than rising gas prices or tax incentives.

Furthermore, historical trends in technology adoption suggest that while new technology is intrinsically attractive to a few early adopters, including visionaries and technology enthusiasts, the majority of consumers will remain close-minded about the new technology (Moore, 2002). This small group of early adopters has positive attitudes to novelty and is likely to adopt new technologies (Heffner et al., 2007). On the other hand, some individuals are uncomfortable with technological change and uncertainty, and therefore are hesitant to accept innovations (Edison and Geissler, 2003). According to Modahl (1999), 50% of Americans are technology pessimists; are averse to technology. The majority of consumers, while making choices, stick to "notions of tradition and familiarity…' rather than embracing a new technology (Sovacool and Hirsh, 2009).

In recent times, however, there are increasing reasons to adopt EVs including rising and volatile gasoline prices, greenhouse gas emissions, increased dependence on imported petroleum, and the very high fuel economy of EV.

3. Methodology

3.1. Survey

An internet-based survey (see appendix A) was developed and used in this research to collect data from a sample population. The target population comprised mainly of current owners of CVs with the intention of capturing opinions, perceptions and attitudes of individuals who are prospective owners of EVs. Data was collected from students, faculty and staff at a technological university that specializes mainly in science, technology and engineering undergraduate and graduate programs. In terms of knowledge considerations, we consider the vast majority of the sample population as technology enthusiasts. Technology enthusiasts are individuals that are better connected with global technology development, have high level of quantitative skills and are more equipped to sort out the many technological, financial and environmental differences between EVs and conventional gasoline powered vehicles. For this study, we consider these individuals to be likely early adopters only if they perceive EVs to be superior in performance compared to ICE vehicles.

Over 500 responses were received but some were rejected due to incompleteness. As a result, 481 responses were used for further analysis. The main objective of the survey was to characterize potential EV owners in order to elucidate knowledge, interests, perceptions, attitudes, and barriers pertaining to EVs as well as views on sustainability. A secondary purpose of the survey was to relate certain socio-economic characteristics including age, education, gender, experience and income to the individual perceptions and attitudes towards EVs. We hypothesize that these factors would influence individual attitudes and perceptions. Furthermore, we test to see if there are any statistical differences between students and non-students.

The survey included four sections. The first section of the survey asked for respondents' gender, age, and other socio-economic details. Respondents' perceptions and attitudes towards EV attributes were examined in the second section. In the third section, respondents were questioned about environmental and sustainability issues. Finally, in the fourth section, respondents were asked changes desired in the EV technology and pressing questions.

3.2. Statistical data analysis

The chi-square test was employed to investigate the differences in perceptions and attitudes among the sample population (Greenwood and Nikulin, 1996; Janes, 2001). The chi-square test for two-way tables is in the form of

$$Q_p = \sum_{i=1}^{s}\sum_{j=1}^{r}\frac{(n_{ij}-m_{ij})^2}{m_{ij}}$$

and

$$m_{ij} = \frac{n_i n_{ij}}{n}$$

where m_{ij} is the expected value of the frequencies in the ith row and jth column and n_{ij} are marginal totals. Q_p is the Pearson chi-square statistic and has an asymptotic chi-square distribution with (s–1) (r–1) degrees of freedom when the row and column variables are independent.

The chi-square test is used to investigate statistical association between variables. This is done primarily by testing the null hypothesis of no association between a set of groups and outcomes for a response. For large values of Q_p, this test rejects the null hypothesis in favor of the alternative hypothesis of general association. We use the standard 5% or 0.05 cut-off for defining what is a statistically significant difference. Therefore an associated p-value < 0.05, means that there is significant evidence of an association between variables.

In the following sections, we summarize the results from the surveys and then relate the responses based on different categories.

4. Results and discussion

4.1. Sample description

The sample has a significantly higher representation of males (71%) compared to females (29%). The overall sample is relatively young with majority of respondents (88%) between the ages of 18 and 44. The age of respondents can be attributed to the fact the majority of the population are undergraduate and graduate students. From an education standpoint, the majority (84%) of the sample is working towards or has completed an undergraduate degree or graduate degree. One should note that the sample collected may not necessarily be representative of the general population; however, it provides helpful information about technology enthusiasts. Detailed demographic attributes of the sample are presented in Table 2.

Table 2
Characteristics of the sample population.

Sample attributes		(%)
Sample size		481
Gender	Male	71%
	Female	29%
Ethnicity	White	85%
	Asian	7%
	African American	2%
	Hispanic Latino	1%
Age	18–24	62%
	25–44	26%
	45 and over	12%
Occupation	Students	80%
	Faculty	11%
Education	Some college/associates	14%
	Undergraduate (Complete/in progress)	51%
	Graduate (Complete/in progress)	32%
Household Income	Under $25,000	22%
	$25,000–$49,999	15%
	$50,000–$74,999	16%
	$75,000–$99,999	12%
	$100,000 and above	20%

Table 3
Experience with AFVs.

Experience with electric vehicles and other alternative fueled vehicles	Number of responses	(%)
None	225	47
Hybrid electric	184	38
Battery electric	80	17
Biofuel	67	14
Plug-in hybrid electric	36	7
Other	20	4

4.2. EV knowledge, experience and interest

Fifty-three percent of the sample had some experience with AFVs and 47% ($n=225$) reported having no experience. Further breakdown of survey results shown in Table 3 illustrates that 38% had experience with HEVs, 17% with BEVs and 7% with PHEVs.

Chi-square analysis showed that there were significant differences in prior experiences with AFVs based on gender ($Q_p=17.442$; $df=1$, $p=<0.0001$). The results suggest that males were more likely than females to indicate some experience with EVs. Moreover, no significant differences based on age ($Q_p=3.801$, $df=2$, $p=0.1495$), level of education ($Q_p=2.0976$, $df=1$, $p=0.1475$), and income ($Q_p=7.7106$, $df=3$, $p=0.0524$) were observed. Differences between students and non-students was also not statistically significant ($Q_p=0.0005$, $df=1$, $p=0.9829$). In gauging awareness of particular EV types, respondents identified that they were most aware of HEVs (95%) followed by PHEVs (81%) and lastly BEVs (76%).

It is interesting to see that the level of awareness reflects the technology curve and the market; HEVs are most prevalent in the market, PHEVs, which are not as widespread as HEVs, are more popular than BEVs are.

Respondents were also asked to rate their interest in AFVs on a 4 point likert scale from 1 (no interest) to 4 (high interest). Considering that the majority of the sample consists of engineers or engineers in the making our initial hypothesis was that a strong interest towards AFVs would be evident. The majority of the population indicated moderate (43%) or high interest (38%) in AFVs. The overall average rating of self-reported interest in AFVs was a composite score of 3.14 out of 4. Chi-square tests showed statistically significant association between interest in AFV, gender ($Q_p=15.6035$, $df=3$, $p=0.0014$) and education ($Q_p=12.4608$, $df=3$, $p=0.006$). Again, males were more likely than females to indicate some interest in AFVs. In addition, individuals with graduate degrees expressed more interest in AFV than those individuals with undergraduate or lower degrees. When asked specifically about interests in EVs, respondents showed less interest. There were significant differences in interests in EVs based on gender, education and age. There were no statistically significant differences in interest based on income. Furthermore, there were no statistical differences between the student population and the non-student population. As was the case with interests in AFVs, males and individuals working towards or had completed a graduate degree expressed more interest in EVs. The level of appeal of different types of EVs to respondents followed the same trend as respondents' level of awareness of EV types, with HEVs being ranked as the most appealing type of EV followed by PHEVs and then BEVs.

Most associations with EVs were with regard to environment, battery performance and charging, efficiency, high purchase cost, fossil fuels, alternative energy and the future in that order. Respondents who generally had a very positive view of EVs cited the efficiency of EVs in terms of fuel saving; "higher MPG" and "non-gas-guzzler". Furthermore respondents referred to EVs as the future of transportation; "the way of the future" and "future of travel. Environmental benefits were also associated with EVs; "green", "zero emissions" and "environmental friendly". Negative associations with EVs included high purchase cost, limited battery longevity, battery range, long recharging time, and environmental impacts from increased fossil fuels use at power plants to generate electricity for charging EVs.

Results showed an average likelihood to purchase an AFV with an overall interest composite score of 2.59 out of 4; 49% of respondents indicated that they were either likely or very likely to purchase an AFV. Thirty seven percent and 15% chose 'somewhat likely' and 'not at all likely', respectively. Chi Square test showed no statistical significant differences in likelihood to purchase an AFV based on gender (Q_p=2.6291, df=3, p=0.4524), age (Q_p=6.8569, df=6, p=0.3343), income (Q_p=0.4589, df=3, p=0.2668), and level of education (Q_p=2.5921, df=3, p=0.4589). There were also no significant differences between students and non-students (Q_p=2.6318, df=3, p=0.4519).

Furthermore, respondents identified decrease or elimination of the use of petroleum as the most appealing attribute of an EV followed by lower maintenance costs and then greenhouse gas reduction (See Table 4). Comfort and style received the lowest ratings. A summary table showing chi-square results is shown in table 5.

4.3. Concerns about EVs

Overall, EV battery range limitation was cited as the biggest concern (33%, n=141) followed by high cost (27%, n=117) and charging infrastructure (17%, n=58). These concerns reaffirm some of the issues identified initially by respondents when asked about associations with EVs. Chi-square analysis showed significant evidence of an association (Q_p=14.2165, df=5, p=0.0143) between concerns and gender with the largest number of males expressing concern about battery range while the largest number of females were most concerned about cost. There were no statistically significant differences in concerns based on age, education, income or between students and non-students. A full breakdown of concerns is presented in Table 6.

Despite the fact that less than 1% of respondents identified safety as the most important concern, only 57% of the respondents agreed or strongly agreed that EVs are a safe mode of transportation while 26% indicated they were unsure. The large number of 'unsure' responses suggests that there is limited understanding of EV safety even among technology enthusiasts. Differences in responses regarding EV safety were statistically significant based on gender (Q_p=30.5974, df=5, p= < .0001) with males (27%) more likely to strongly agree that EVs were safe compared to females (10%). Also, females were more unsure and neutral about the safety of EVs compared to males. Furthermore, individuals that indicated some experience with AFVs were more likely to strongly agree that EVs were safe compared to individuals lacking experience. Individuals that had no prior experience with EVs were more uncertain about EV safety at 16% compared

Table 6
Concerns about EVs.

Biggest concern about EVs	Number of responses	(%)
Battery range	158	33
Cost	129	27
Charging infrastructure	83	17
Other	58	12
Reliability	47	10
Safety	6	1

Table 4
Ranking of electric vehicle attributes.

Attribute	5 (most appealing)	4	3	2	1 (least appealing)	Mean (N=438)	Std. Dev. (N=438)
Decrease/eliminate the use of petroleum	176	91	48	59	64	3.5845	1.4808
	40%	21%	11%	13%	15%		
Less maintenance	88	100	146	57	47	3.2853	1.2287
	20%	23%	33%	13%	11%		
Reduced greenhouse gas emissions	70	100	93	74	101	2.9178	1.3972
	16%	23%	21%	17%	23%		
Looks/style	48	64	65	100	161	2.4018	1.3875
	11%	15%	15%	23%	37%		
Comfort	56	86	83	148	65	2.8174	1.2672
	13%	20%	19%	34%	15%		

Table 5
Summary of Chi Square results.

Variables	Demographics											
	Gender			Age			Education			Income		
	Q_p	df	p-value	Q_p	df	p-value	Q_p	df	p-value	Q_p	df	p-value
Concerns	14.2165	5	0.0143	12.2402	10	0.2692	8.689	5	0.1221	17.0461	15	0.316
Safety	30.5974	5	< .0001	17.2026	10	0.0700	10.0075	5	0.075	24.0643	15	0.064
Experience with AFVs	17.4419	1	< .0001	3.801	2	0.1495	2.0976	1	0.1475	7.7106	3	0.0524
Familiarity with 'Sustainability'	0.4398	1	0.5072	7.3624	2	0.0252	6.0624	1	0.0138	5.857	3	0.1188
Interest in AFV	15.6035	3	0.0014	8.385	6	0.2112	12.4608	3	0.006	6.4584	9	0.6933
Interest in EV	23.3997	3	< .0001	15.2957	6	0.0181	15.363	3	0.0015	5.6689	9	0.7725
Likelihood to purchase AFV	2.6291	3	0.4524	6.8569	6	0.3343	2.5921	3	0.4589	11.1313	9	0.2668
EV sustainability	23.492	4	0.0001	7.0611	8	0.5301	9.276	4	0.0546	5.3243	12	0.9463

to only 4% of individuals who indicated having some experience with EVs. These findings indicate a relationship between prior experience and perceptions of EV safety. Exposing individuals to EVs will likely reduce perceptions of EVs as being unsafe.

The average cost of gasoline ($/gallon) at which respondents ($n=395$) will be persuaded to purchase an EV was calculated to be $5.42/gallon with confidence interval of $1.75 and using $\alpha=0.05$. The mode and median were $5.00 and $5.00, respectively. There was a wide range of gas prices given and several individuals indicated that price is conditional on factors such as initial cost of the EV, electricity cost, performance and range. A considerable number of respondents showed unconditional willingness to purchase EVs by indicating that they needed no persuasion to purchase an EV whereas a few respondents expressed strong resistance and indicated they will 'walk first' implying that drastic increase in gas prices alone was not enough incentive to purchase an EV. Mainly individuals with this position indicated prices ranging from $50 to an infinite amount of dollars. There was considerable skepticism among respondents and the word 'depends' featured considerably in responses. In general, the results are consistent with findings of Diamond (2009) that as long as PHEV purchase price is high, market penetration will not increase significantly unless gasoline prices rise. The same reasoning can also be applied to the adoption of HEVs and BEVs as our results indicate a relationship between general EV adoption and gasoline price. This finding suggests that higher gasoline prices together with lower EV purchase price will positively impact market penetration of EVs. As gas prices rise, more people consider EVs to be worthwhile investments. Consequently, a significant number of the sample population believe that prices will rise in the future and that purchase of an EV represent an intelligent response to the higher prices.

Our results are contrary to a previous study on EVs that show that cost is the main attribute governing vehicle purchase decision (Zypryme Research and Consulting, 2010). The expectation in this study was that cost would be the greatest concern considering that the majority of our sample population consists of college students earning limited income. However, the fact that cost was ranked lower than battery range may be ascribed to that fact that the technologically minded target group is more likely to rank technical problems higher than financial problems.

A comparison of the 10-year cost of ownership for a CV (Chevy Cruze), a HEV (Toyota Prius), a PHEV (Chevy Volt) and a BEV (Nissan LEAF) is presented in Table 7. The CV, HEV and PHEV in this study have a combined fuel economy of 30 miles per gallon (mpg), 50 mpg, and 37 mpg, respectively. In addition, the PHEV and BEV use lithium-ion batteries that are capable of an all-electric range of 35 miles and 100 miles, respectively. It is assumed that the vehicles are driven for 15,000 miles per year over a period of 10 years. The cost is calculated for two different gasoline price scenarios. The cost of ownership at the average 2011 U.S. regular gasoline price of $3.52/gallon is compared with $5.42/gallon which is the average gasoline price indicated by the study sample. The baseline manufacturer's suggested retail price (MSRP) for each vehicle was used. The cost of electricity for charging the PHEV and BEV is held constant at 11.9 cents/kW h based on the 2011 U.S. average residential electricity retail price. The maintenance and repair costs are obtained from Kelly Blue Book, which provides five-year ownership costs for vehicles. After the fifth year, we assume that repair and maintenance costs remain constant throughout the rest of the vehicle lifetime. Currently the EVs under consideration have warranties on batteries for 8 years/100,000 miles. We assume that the EV batteries will need replacing at the end of the warranty period. The U.S. DOE vehicle technologies program 2014 goal of $300/kW h is used to calculate battery cost for the 16 and 24 kW h lithium-ion batteries of the BEV and PHEV, respectively. A local Toyota dealership provides an estimate of approximately $2500 for a new Prius nickel–metal hydride battery with roughly $500 for installation. This installation estimate is also added to the PHEV and BEV battery replacement cost. Finally, we consider the impact of the 2009 ARRA $7500 tax credit on the cost of ownership of the PHEV and BEV. This calculation does not consider other direct costs such as depreciation, insurance, registration and vehicle taxes.

At $3.5/gallon of gasoline, the additional cost of ownership compared to a CV is $1137, $16,268 ($8768 with tax credit) and $12,329 ($4829 with tax credit) for the HEV, PHEV and BEV, respectively. At $5.42/gallon of gasoline this cost is reduced to −$2661, $7915 ($415 with tax credit) and $2834 (−$4666 with tax credit) for the HEV, PHEV and BEV, respectively. Our calculations indicate that at $5.42/gallon of gasoline the BEV and PHEV are economically competitive if AARA incentives are considered. The difference in cost of ownership between the EVs and CVs are significantly higher partly due to battery replacement costs. Therefore, if EV battery lifetime is improved and/or battery cost further reduces this cost difference will be less.

4.4. Battery: driving range and battery charging

In terms of fuel source and storage, EVs (particularly BEVs) have two disadvantages compared to ICE vehicles; EV batteries

Table 7
Comparison of vehicle 10-year cost of ownership.

	10-year vehicle ownership cost							
	$3.52/gallon gasoline				$5.42/gallon gasoline			
Item	**CV(Chevy Cruze)**	**HEV (Toyota Prius)**	**PHEV (Chevy Volt)**	**BEV (Nissan Leaf)**	**CV(Chevy Cruze)**	**HEV (Toyota Prius)**	**PHEV (Chevy Volt)**	**BEV (Nissan Leaf)**
Vehicle purchase price	$16,800	$24,000	$39,145	$35,200	$16,800	$24,000	$39,145	$35,200
EV battery replacement	–	$3,000	$5,300	$7,700	–	$3,000	$5,300	$7,700
240 V charger installation	–	–	–	$2,200	–	–	–	$2,200
Repairs	$5,480	$4,624	$5,424	$4,480	$5,480	$4,624	$5,424	$4,480
Maintenance	$6,496	$5,331	$5,060	$4,846	$6,496	$5,331	$5,060	$4,846
Gasoline	$17,605	$10,563	$2,117	$0	$27,100	$16,260	$3,259	$0
Electricity	0	0	$5,603	$4,284	–	–	$5,603	$4,284
Total	$46,381	$47,518	$62,649	$58,710	$55,876	$53,215	$63,791	$58,710
Total with AARA 2009 incentive			$55,149	$51,210			$56,291	$51,210

are more expensive and bulky, and refueling is typically slow; approximately 1–20 kW for electric versus 5000 kW for gasoline (Pearre et al., 2011). This means that initial BEVs, which rely solely on onboard batteries, will have less range than gasoline powered vehicles, and cannot be quickly refueled en route. These problems do not impact PHEVs as much because they can be refueled by either electricity or liquid fuels. With regard to our driving range analysis, this study focuses mainly on BEVs because they present the greatest range limitation.

The majority of respondents (71%) travel fewer than 20 miles per day, 79% travel fewer than 30 miles per day while 87% travel fewer than 40 miles per day. These results are consistent with the National Household Travel Survey (2011) which shows that on average a person travels about 36 miles. Our analysis shows that even with limited range, first-generation PHEVs and BEVs, which are generally between 40 and 100 miles could provide a large percentage of daily travel needs, assuming that batteries are charged daily. However, occasional long trips may not be possible on BEVs without recharging the battery during the trip.

In general, greater range is more desirable but as the range of the battery increases so does the cost. The question is: what is the minimum range that you require before considering to purchase a BEV? Only 32% of respondents were interested in BEVs with a battery range between 0 and 100 miles, 23% chose ranges between 100 and 200 miles, while 45% chose ranges greater than 200 miles. The average minimum range desired was 215 miles. Table 8 compares actual daily driving distance to desired BEV range. These results stand in stark contrast to self-reported average daily driving distances. There is clearly a large gap between individual expectations of the driving range of a BEV and actually daily driving distance. This disparity may be partly due to range anxiety, which is the fear of being stranded in a BEV because it has insufficient range to reach its destination. Battery technology is advancing rapidly and range limitations will not be a lasting problem (Pearre et al., 2011). If battery performance continues to improve at a steady rate then a major issue to be addressed is attracting an adequate market for EVs to support limited range EVs in the period before battery technology improves.

Many responses indicated that choice of battery range would depend on how long it took to recharge the battery. Many respondents also indicated that if EVs could quickly be recharged on the go that they would not expect the range to be as great. Only 32% of the sample thought charging an EV was convenient compared to refueling a gasoline vehicle. Thirty-six percent of respondents consider charging an EV inconvenient whereas 32% were unsure.

Another option for long distance travel with EVs is the idea of battery swapping. Battery swapping refers to quickly replacing a EVs depleted battery with a fully charged one at a battery swap station. In this case, the battery ownership would likely be separated from vehicle ownership, meaning that the initial price of EVs would decrease but consumers would then pay for a monthly subscription, similar to a cell phone plan to cover the cost of the battery ownership and the price of recharging and/or swapping the battery. Thirty one percent of respondents indicated willingness to purchase an EV if the ownership of the battery and vehicle were separated and such a battery swapping plan were available for a monthly subscription. Twenty-five percent of respondents were against the notion of battery swapping, while 43% were unsure. An advantage of the battery swapping idea is the separation of the battery ownership from the vehicle. Considering that EV battery constitutes a large portion of the cost of the vehicle, early failure of the battery was a concern for some respondents because of the high cost of replacement. Despite being informed that EVs coming to the market today have warranties on their batteries of around 8–10 years, 42% of respondents indicated that they would be “very worried” about the degradation or possible failure of their EV’s battery and 48% were “somewhat worried”.

4.5. Sustainability of EVs as a transportation option

Eighty-three percent ($n=401$) of respondents indicated some familiarity with the concept of sustainability. In addition, 79% ($n=379$) of the sample indicated that sustainability influenced their decision when purchasing a vehicle. Chi-square analysis showed significant evidence of differences in familiarity with sustainability based on age ($Q_p=7.3624$, $df=2$, $p=0.0252$) and education ($Q_p=6.0624$, $df=1$, $p=0.0138$). More individuals working towards or had completed a graduate degree were familiar with the idea of sustainability compared to those working towards or had completed an undergraduate degree. Also, respondents in the 18–24 age range were more likely to be unfamiliar with the term sustainability compare to those ages 25 and above. Those respondents that indicated they were knowledgeable about sustainability were asked to provide a definition in their own words. Although definitions varied, three different categories were evident. The vast majority of definitions were related to product/resource longevity (32%), resource conservation (26%), and protecting the environment (14%). In addition, a number of respondents also provided overall definitions of sustainability that addressed environmental, economic and social dimensions; “having a zero net impact on environment, economy, and social structure.”

BEVs were ranked the most environmentally sustainable EV, followed by PHEVs and then HEVs (see Table 9). This shows an inverse of the responses for awareness and appeal of EVs. A significant percentage (43%, $n=206$) of respondents were neutral about EVs being more sustainable than traditional CVs and other AFVs. The results, shown in table 10, suggest that while sustainability considerations influence respondents’ vehicle purchase choice, majority remain uncertain about sustainability of

Table 8
Actual daily driving distance (in miles) vs. preferred BEV range (in miles).

Average miles driven per day vs. desired BEV range		
Distance/range (miles)	Average miles driven per day (%)	Desired BEV range (%)
Less than 10	47	0
11–20.	24	0
21–30	8	4
31–40	8	2
41–50	5	9
Greater than 50	9	86

Table 9
Ranking of electric vehicles based on environmental sustainability.

	Ranking of EV sustainability				
Attribute	**3 (most sustainable)**	**2**	**1 (least sustainable)**	**Mean (N=481)**	**Std. dev. (N=481)**
BEV	220	94	167	2.13	0.8904
	46%	20%	35%		
HEV	126	148	207	1.83	0.814
	26%	31%	43%		
PHEV	135	239	107	2.06	0.7069
	28%	50%	22%		

Table 10
Perceptions of sustainability of EVs relative to other vehicles.

Electric vehicles are more sustainable compared to traditional gasoline-powered vehicles and other alternatives		
	Number of responses	(%)
Strongly agree	32	7
Agree	119	25
Neutral	206	43
Disagree	88	18
Strongly disagree	36	7

EVs compared to CVs and other alternatives. This view of EVs can be attributed to some comments made by respondents such as; "no use of fossil fuels in the car but increase fossil fuels used at power plants to fuel the car.", "Vehicles that run on electricity generated from gas or coal power", "transferring greenhouse gasses from roads to power plants" and "…aren't even green considering most of our electricity comes from coal plants". This finding implies that some individuals with high environmental awareness may not consider purchasing EVs as beneficial to the environment. Such perceptions of EVs serve as a potential obstacle to EV adoption.

Differences based on gender ($Q_p=23.492$, $df=4$, $p=0.0001$) were statistically significant with 57% of females being more neutral on the sustainability of EVs compared to 37% of males. There was no significance in differences based on education level. Individuals that indicated they consider sustainability before purchasing a vehicle indicated an average gas price of $5.20 in order to be persuaded to buy an EV compared to $6.30 for individuals that do not consider sustainability when making vehicle purchase decisions. This suggests that individuals with high sustainability awareness are likely to adopt EV technology sooner that individuals with low sustainability awareness.

4.6. Unaddressed concerns about electric vehicles

In concluding the survey respondents were asked, "What, if anything, could be done to make you want to purchase an EV?" Some representative responses include; "Show me they are truly sustainable"; "I want something cost-efficient that doesn't burn a hole through my energy bill"; "Reduce Cost, Increase Range, Decrease Recharge Time"; "Give a bigger tax credit. "; "Evidence of its reliability, safety and cost savings". Other comments include "Cost not much more than a gasoline ICE vehicle" and "Cost of gasoline reaches insane levels".

The majority of respondents had questions relating to the battery technology, raw material supply, environmental impacts, appearance, operation and performance of EVs, cost, and how electric cars compare to conventional vehicles and other AFVs. Respondents were interested in learning more about the mechanisms of charging, how the battery range limitation can be overcome and how to secure the mineral resources necessary for large-scale battery manufacturing. Concerns about cost were evident because cost was the subject of several questions (17%); this includes the initial cost, maintenance cost and payback period. In addition, questions were asked about how EVs could be made more economically competitive to conventional gasoline powered vehicles. Some respondents wondered when EVs will become widely available and questioned if there were some battery problem which manufacturers were not being open about.

In terms of environmental impacts, the sampled individuals were very critical about environmental impacts of EVs especially regarding fuel sources for generating electricity to charge EVs. They demanded answers that disproved the notion that adoption of EVs was just "trading one problem for another'; reducing gasoline but increasing fossil fuel generated electricity. These responses indicate that some of the sampled technologically minded individuals question environmental impacts of EVs and calls for more communication and debate on the subject. Questions posed showed gaps in the understanding of the environmental impacts of EVs because studies (Duvall et al., 2007; Jaramillo et al., 2009) have shown that PHEVs have the potential to substantially reduce greenhouse gas emissions. In addition, lifecycle analyses by Jaramillo et al. (2009) show that PHEVs emit 50% less greenhouse gas compared to gasoline and diesel vehicle fuels, even when coal is the primary source of electricity.

From the open-ended questions posed in the survey, it is evident that there was a somewhat strong awareness and understanding of the benefits and constraints of EVs. Considerable understanding of the comprehensive technical details of EVs may have contributed to more reserved judgment. This argues for more communication; otherwise, there is a risk of negative perceptions being embedded in public opinion.

5. Conclusions and implications for transportation policymakers

The sample used in this study may not be representative of the entire population due to differences in environmental awareness, education and income of majority of respondents; however, it provides helpful insights into preferences and attitudes of technologically minded individuals. Our results show that attitudes, knowledge and perceptions related to EVs differ across gender, age, and education groups. Furthermore, our findings suggest that although sustainability and environmental benefits of EVs have a major influence on EV adoption they are ranked behind cost and performance. Overall, we conclude that a moderate to high interest in EVs exists despite several reservations expressed towards EVs. In general, attitudes towards EVs were neither wholly positive nor wholly negative, however, completely negative attitudes to EV technology detected, though minimal, should not be ignored.

Evidence provided in this study emphasizes the need to address socio-technical barriers facing EVs. As previously mentioned, some major challenges faced by EVs include battery technology, battery costs and charging infrastructure. However, consumer acceptance is important as it is key to the commercial success (or failure) of EVs, even if the other criteria are met. A major potential barrier to widespread EV adoption detected among our technologically minded target group is the uncertainty associated with the EV battery technology and sustainability of fuel source. Some of this uncertainty may be attributed to unfamiliarity with the EV technology but may also be due to the fact that several individuals in this group are not convinced that EVs are a better option than some currently available CVs. The fact that some members of this group question the sustainability and environmental performance of EVs compared to ICE vehicles may mean that some individuals with high environmental awareness or values may not consider the purchase of an EV as beneficial to the environment.

Current incentives such as tax credits to subsidize the cost of EVs and fuel taxes may have little effect on EV market penetration if consumers have low confidence in EV technology. Therefore, certain measures need to be taken to increase the market share of EVs. These measures, some of which are already being explored, include education, increased investments in EV technology, infrastructure, battery swap programs, strong warranties on the EV batteries and perhaps increased tax credits to subsidize the cost of EVs. Since public opinion can be influenced through media and social networks, policy makers can use this medium to influence the public appreciation for non-financial benefits of adopting EVs such as energy security and reduction of ecological footprint

Table A1

Electric vehicle consumer survey		(%)
1. What is your gender?		
Male	342	71
Female	136	28
Prefer not to say	3	1
Total	481	100
2. What ethnicity best describes you?		
White	408	85
Native American/ American Indian	2	0
African-American	8	2
Hispanic/Latino	4	1
Asian	36	7
Other, please specify	23	5
Total	481	100
3. What is your age (in years)?		
481 Responses		
4. What is your occupation?		
Student	385	80
Faculty	52	11
Other Missouri S&T Staff, please specify	44	9
Total	481	100
5. Please indicate your highest level of education (include degree you are currently working on)		
Elementary	0	0
High school/GED	9	2
Some college/ associates	69	14
Undergraduate degree	247	51
Masters	77	16
PhD	74	15
Post doctorate	5	1
Total	481	100
6. Area of highest degree/major?		
481 Responses		
7. What is your annual family income from all sources before taxes?		
Under $25,000	108	22
$25,000–$39,999	42	9
$40,000–$49,999	28	6
$50,000–$74,999	76	16
$75,000–$99,999	56	12
$100,000–$149,999	75	16
over $150,000	21	4
Prefer not to say	75	16
Total	481	100
8. Please describe in a few words what comes to your mind when you think about electric vehicles:		
481 Responses		
9. What type of electric vehicles or other vehicles that use alternative energy sources have you had experience with? Select all that apply.		
None	225	47
Biofuel	67	14
Hybrid electric	184	38
Plug-in hybrid electric	36	7
Battery electric	80	17
Other, please specify	20	4
10. How would you rate your interest in cars that use alternative energy sources?		
No interest	22	5

Table A1 (*continued*)

Little interest		69	14		
Moderate interest		209	43		
High interest		181	38		
Total		481	100		
11. How would you rate your interest towards electric vehicles (EVs)?					
No interest		44	9		
Little interest		82	17		
Moderate interest		213	44		
High interest		142	30		
Total		481	100		
12. How likely would you be to consider purchasing a vehicle that uses alternative fuel?					
Not at all likely		73	15		
Somewhat likely		176	37		
Likely		123	26		
Very likely		109	23		
Total		481	100		
13. Which of the three electric vehicle types are you aware of? Please check all that apply.					
Hybrid electric vehicle (HEV)		455	95		
Plug-in hybrid electric vehicle (PHEV)		389	81		
Battery electric vehicle (BEV)		365	76		
14. Please rank the following EV types in terms of which appeals to you the most (1 being the most appealing and 3 being the least appealing) An ICE (internal combustion engine) is an engine used in most conventional cars in which combustion of fuel (usually gas and diesel) occurs A HEV (hybrid electric vehicle) adds a battery and electric motor to a car that uses internal combustion (IC) engine which is usually powered by gasoline or diesel. A PHEV (Plug-in hybrid electric vehicle) uses HEV technology but its battery can be recharged via the electric grid, providing purely electric power for a limited range. A BEV (Battery electric vehicle) operates solely on an electric battery and also features a plug in charger					
Top number is the count of respondents selecting the option. Bottom is percent of the total respondents selecting the option.	1	2	3		
HEV	208 43	128 27	145 30		
PHEV	134 28	253 53	94 20		
BEV	139 29	100 21	242 50		
15. Please rank the following attributes of EVs in terms of which appeals to you the most (1 being the most appealing and 5 being the least appealing)					
Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Decrease/eliminate the use of petroleum	183 40	92 20	52 11	63 14	64 14
Less maintenance	93 21	103 23	151 33	57 13	47 10
Reduced greenhouse gas emissions	81 17	106 23	96 21	77 17	103 22
Looks/style	50 11	71 16	70 15	101 22	165 36
Comfort	58 12	94 20	97 21	155 33	67 14

Table A1 (*continued*)

16. How many miles per day do you drive on average?		
Less than 10	226	47
20-Nov	117	24
21–30	38	8
31–40	37	8
41–50	22	5
Greater than 50	41	9
Total	481	100
17. As the size of an EV battery increases, the range increases, but so does the cost. With that in mind, how many miles minimum would the vehicle range have to be before you would consider buying a battery electric vehicle (BEV):		
481 Responses		
18. What do you consider your biggest concern about EVs?		
High cost	129	27
Battery range	158	33
Safety	6	1
Reliability	47	10
Charging infrastructure	83	17
Other, please specify	58	12
Total	481	100
19. How much ($/gallon) would gasoline have to cost to persuade you to drive an EV?		
481 Responses		
20. Do you consider charging an EV an inconvenience?		
Yes	177	37
No	148	31
Unsure	156	32
Total	481	100
21. "Quick-charging" refers to a higher voltage charging that is capable of charging your vehicle's battery in a shorter period of time than a standard wall outlet. If such chargers were available at public stations similar to gas pumps, how quickly would you expect your battery to be charged from empty to full?		
1–5 min	144	30
5–10 min	185	38
10–15 min	88	18
Greater than 15 min	64	13
Total	481	100
22. EVs that are coming to the market today have warranties on their batteries of around 8–10 years. Knowing that batteries constitute a large portion of the cost of an EV, how concerned are you about the degradation or possible failure of your EV's battery.		
Very worried	205	43
Somewhat worried	230	48
Not worried	46	10
Total	481	100
23. Would you be more willing to purchase an EV if the ownership of the battery and the vehicle were separated such that you could purchase the vehicle without the battery for a lower price and instead pay for a monthly subscription, similar to a cell phone plan, which covers the cost of battery ownership and the price of recharging and/or swapping your battery?		
Yes	154	32
No	120	25
Unsure	207	43
Total	481	100
24. Do you like the idea of "battery swap stations" where your depleted battery could be swapped out and replaced with a fully charged battery in one minute?		
Yes	320	67
No	63	13
Unsure	98	20
Total	481	100

Table A1 (*continued*)

25. Do you have accessibility to an external electrical outlet to charge an EV where your car is parked at your primary residence?		
Yes	244	51
No	237	49
Total	481	100
26. Electric vehicles are a safe mode of transportation		
Strongly agree	89	19
Agree	188	39
Neutral	120	25
Disagree	26	5
Strongly disagree	13	3
Unsure	45	9
Total	481	100
27. Are you familiar with the term "sustainability"?		
Yes	401	83
No	80	17
Total	481	100
28. If you answered "yes" to question 27, what does sustainability mean to you?		
380 Responses		
29. When purchasing a vehicle, does sustainability of the vehicle influence your decision?		
Yes	379	79
No	102	21
Total	481	100
30. Electric vehicles are the most sustainable choice of personal transportation when compared with traditional gasoline-powered vehicles and other alternatives		
Strongly agree	32	7
Agree	119	25
Neutral	206	43
Disagree	88	18
Strongly disagree	36	7
Total	481	100

31. Rank the following types of electric vehicles in terms of which is a more environmentally sustainable mode of transportation. (1 being the most environmentally sustainable and 3 being the least environmentally sustainable)			
Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3
Battery electric vehicle	220 46	94 20	167 35
Hybrid electric vehicle	126 26	148 31	207 43
Plug-in hybrid electric vehicle	135 28	239 50	107 22

32. What, if anything, could be done to make you want to purchase an EV?	
336 Responses	
33. What questions, if any, do you have about electric vehicles and alternative energy vehicles, in general?	
175 Responses	

6. Future work

This study focused on the perceptions and attitudes of a technological minded group towards EVs. Future research will compare the attitudes and perceptions of this sample with those of the general public in other to provide insight on how different types of consumers perceive EVs as well as to highlight individual similarities and differences between the two different consumer groups.

The cost of vehicle ownership discussed in this paper also leads to opportunities for future work. In Europe, gas prices are typically much higher compared to the United States. Therefore, without other incentives, consumers will likely be more motivated to purchase EVs in Europe than in the United States. A follow-up research will apply the same methodology used in this study to European data.

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Appendix A

See Table A1 here.

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