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ORIGINAL PAPER

Mass deployment of sustainable transportation: evaluation of factors that influence electric vehicle adoption

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Abstract Mass penetration of electric vehicles into the market will have a number of impacts and benefits, including the ability to substantially reduce greenhouse gas emissions from the transportation sector. Therefore, it is expected that in coming years this technology will progressively penetrate the market. This research presents an analysis of factors that influence electric vehicle adoption by modeling the conditions under which an individual, particularly one with an engineering or technical background, is more or less likely to adopt an electric vehicle. This model is developed by considering demographic determinants as well as behavioral and attitudinal measures that affect individual adoption of the technology. The methodology involves applying logistic regression to provide a good fit and predict the response given explanatory variables. Analyzing these outcomes generates empirical findings that better inform electric vehicle technology and policy development. This study takes into account preferences of potential customers and analyzes how individuals with engineering and technology background differ in electric vehicle adoption considerations compared to the general population. Therefore, this research provides both engineers and policy makers with critical information for developing future electric vehicle technology. The model results show that several factors including willingness to pay for new appealing technology, distance driven, perceptions of electric vehicles as good for the environment, perception of EV speed are statistically significant in influencing willingness to purchase an electric vehicle.

Keywords Alternative fuel vehicles · Electric vehicles · Consumer attitudes · Electric vehicle adoption

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Introduction

Transport activities are one of the major contributors to global greenhouse gas (GHG) emissions. In the absence of aggressive mitigation policy measures, transportation emissions will increase at a faster rate compared to other energy end-use sectors due in part to economic growth and increase in population (Intergovernmental Panel on Climate Change 2014). Despite some technological advances, the progress in reducing the fuel consumption of conventional vehicles (gasoline and diesel powered internal combustion engine vehicles) has not been able to offset increasing mobility demand (Kihm and Trommer 2014). Due to their potential to reduce fossil fuel dependency and CO_2 emissions, it is undeniable that alternative fuel vehicles can significantly reduce the transportation sector's contribution to global warming (Rolim et al. 2012). Some alternative fuels in production or under development for use in alternative fuel vehicles include biodiesel, electricity, hydrogen, ethanol, natural gas and propane. One strategy to address GHG emissions and other challenges facing the transportation sector has been the introduction of electric vehicles (EVs) including battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and hybrid electric vehicles (HEVs). In addition to reducing GHG emissions associated with climate change and decreasing petroleum consumption, EVs can also substantially reduce air pollution due to transportation. Other benefits of EVs include reliability and efficiency (Lutsey and Sperling 2012).

In the past half-decade, policy support for EVs and supporting industries has increased significantly. According to Driscoll et al. (2013), public policy can influence the uptake of EVs. Many countries are investing significantly in the development of EV technology and infrastructure. This includes the establishment of subsidy and tax incentives programs to offset the high cost of EVs for consumers (Antweiler and Gulati 2013; Brand et al. 2013; Chandra et al. 2010; McConnell and Turrentine 2010; Sánchez-Braza et al. 2014). In addition, EV-related research and development have also received considerable funding (DFT 2009; EGCI 2011; Zheng et al. 2012). In the USA, the 2009 American Recovery and Reinvestment Act allocated $2.1 billion for EV-related endeavors including subsidies for battery development and other EV-related projects (Carley et al. 2013). Furthermore, a goal to have 1 million plug-in electric vehicles (PEVs) on US roads by 2015 was set by the US government (Voelcker 2011). The USA has also proposed the development of affordable PEVs for the average American household by 2022, which can compete with currently available gasoline-powered vehicles (DOE 2013)

Despite substantial investments in EV technology by governments and automobile manufacturers, EV adoption has not increased significantly and they presently represent a very small percentage of vehicles on the road. In the USA, cumulative PEV sales since market rollout in December 2010 reached only 557,000 units by the end of 2015 (EDTA 2017). This number indicates that the Obama administration's goal of one million PEVs on the road by 2015 was not achieved. One reason for the low level of adoption is that EVs have to compete with conventional vehicles. Conventional vehicles have been around for over a century and have a technology that is well developed. Due to the stability of the technology and the availability of supporting infrastructure such as gas stations and service stations, consumers may be reluctant to embrace the relatively new EV technology. According to Carley et al. (2013), the major challenge facing the EV industry is to boost market presence and customer demand despite the century long dominance of the internal combustion engine vehicles (ICEVs). In addition to the technological barriers that EVs face, consumers may have to change their usual driving patterns. A change in mobility will require changes in deeply rooted cultural patterns (Van Der Steen et al. 2012). This is especially true because consumers have strong connections to their vehicles. Consumers are used to a certain type of automotive experience so EVs have to match this experience and performance in order to be accepted (Deloitte 2010). Therefore, the adoption of EVs will involve meaningful shifts in both social and technical systems (Sovacool and Hirsh 2009).

This research aims to investigate issues that are pertinent to answering the question: Who are the potential buyers of electric vehicles? This paper builds on a previous study by Egbue and Long (2012a) on EV adoption to determine a combination of factors that influence customer intent to adopt EVs. This study is informed by the literature on consumer preferences for vehicles in general and alternative fuel vehicles and focuses on developing a model using a combination of both demographic and attitudinal variables as inputs. The methodological approach uses survey data on self-categorization by respondents in terms of their environmental interests, technical interests, attitudes toward specific EV attributes together with their demographic attributes to develop a binary logit model, which provides a good fit and predicts the response variable, adoption or non-adoption of EVs, well.

The "Background" section of this paper provides some background information on EVs and challenges facing the technology. The "Methodology" section provides a description of the research methodology used. Results and discussion are presented in the "Results and discussion" section while conclusions and implications of this research are in the "Conclusions" section.

Background

Types of electric vehicles

For the purpose of this study, EVs refer to BEVs, PHEVs and HEVs. HEVs use gasoline for net propulsion energy, but are also equipped with an electric motor and a battery pack to improve fuel efficiency (Michalek et al. 2012). They cannot be recharged by plugging into an electrical outlet. Examples of HEV models include Toyota Prius, Ford Fusion Hybrid, Toyota Camry Hybrid and Honda Insight Hybrid. PEVs refer to EVs that can be charged using electricity and include PHEVs and BEVs. PHEVs, such as Chevrolet Volt and Toyota Prius Plug-in, can operate using electricity, gasoline or both. PEVs generally have larger batteries and more powerful electric motors than HEVs. Currently, most PEVs use lithium-ion batteries because they possess performance advantages over other battery technologies (Egbue and Long 2012b). Depending on the drive train configuration, some PHEVs can operate in all-electric (AE) mode during the charge-depleting range, using only electricity from the battery, or in blended mode using both electricity and gasoline (Axsen and Kurani 2013). BEVs operate in all-electric mode and are powered solely by electricity. They rely primarily on an on-board battery for power and typically require larger batteries than PHEVs to enable longer travel between charges. Some examples of BEVs include Tesla Model S and Nissan Leaf. The 2016 Model S offers battery options ranging from a 70-kWh lithium-ion battery pack with an Environmental Protection Agency (EPA) estimated range of 240 miles, to an 85-kWh battery with a range of 270 miles. On the other hand, the base version of the 2016 Nissan leaf has a 24-kWh lithium-ion battery pack with an EPA estimated range of 84 miles.

HEVs have been in the market for well over a decade, and as a result, most major vehicle manufacturers offer HEVs. Consequently, global sales of HEVs have grown significantly over the years. HEV annual sales in 2015 was 384,404 or roughly 3.5 times the sales of PHEV and BEVs combined for the same year (EDTA 2017). However, the sale of PEVs has increased significantly in the years since market rollout.

PEVs operating only on electricity (i.e. BEVs) have zero tailpipe emissions. However, emissions may occur depending on the source of electricity used for charging. The environmental impact of PEVs is to a significant extent determined by the source of electricity used for charging. For instance, a PEV charged using electricity from renewable energy sources would have a lower carbon footprint compared to a vehicle that is charged using electricity generated mainly from fossil fuels. Therefore, in considering EV emissions, it is important to also consider the total emissions associated with fuel production and delivery to the vehicle or the well-to-wheel emissions. Onat et al. (2017) covers state-specific variation in electricity generation profile in the USA and the associated impacts on BEV environmental impacts. In terms of efficiency, data from www.fueleconomy.gov show that the conversion rate of electrical energy from the grid to power at the wheels is 59–62% for BEVs compared to about 17–21% conversion of energy from gasoline to power at the wheels for conventional vehicles. With respect to charging time, fully recharging a PEV battery pack can take anywhere from 4 to 8 h depending on the charger type. However, a "fast charge" to 80% capacity can take about 30 min. (https://www.fueleconomy.gov/feg/evtech.shtml). Fast charging stations typically require a significant investment and as a result are less common than other types of chargers or charging stations.

Challenges facing electric vehicle adoption

Despite the benefits of EVs, there are several concerns both technical and financial related to the batteries and charging (Caperello and Kurani 2012; Hidrue et al. 2011; Musti and Kockelman 2011; Zypryme 2010). A major challenge facing the deployment of HEVs, PHEVs, and BEVs is high purchase cost. Although EVs have superior power trains, they are significantly more expensive and provide limited functionality compared to ICEVs (Weiss et al. 2012). The high cost of EVs, particularly PHEVs and BEVs can be attributed to the battery pack, which represents a significant portion of the vehicle cost (Nemry and Brons 2010). As a result, batteries remain a significant factor in the development of EV technology. This price difference is particularly significant for PHEVs and BEVs because they typically have larger batteries than HEVs and battery cost increases linearly with size. However, PHEVs and BEVs have projected lifecycle costs that are significantly less than conventional vehicles (Offer et al. 2010). An analysis by Weiss et al. (2012) indicates that it will take several decades to close the price gap between BEVs and ICEVs if the current price dynamics continues. Currently, a target for the Department of Energy PEV program is to reduce battery costs from \$500 to \$125/kWh (DOE 2013)

In addition to a high purchase cost, BEVs and PHEVs have a limited range during all-electric operation. This poses more of a problem for BEVs, which rely primarily on an on-board battery for power. According to Tamor et al. (2013), limited range is a major factor that leads to the early demise of electric vehicles after the dawn of the automobile era. These vehicles, which represented roughly 30% of the early automobile market and were preferred over chemically fueled vehicles, were unsuccessful due to their range limitation. The range problem has presented itself again with the reintroduction of electric vehicles. This is attributed to the fact that current electric vehicle range is not significantly higher than that of electric vehicles that were available over a century ago (Tamor et al. 2013). Other concerns related to EVs include battery replacement costs, inconvenience of charging and limited availability of charging infrastructure.

Widespread adoption is ultimately dependent on consumers' willingness to purchase the technology. Drivers rely on several factors when making the decision to adopt EVs. These include utility-related concerns such as cost, range, durability and battery life (Lieven et al. 2011; Musti and Kockelman 2011). Consumers will likely choose options that maximize utility based on their preferences, knowledge of alternatives and budget (Roche et al. 2010). In addition to functional benefits, many consumers' purchase decisions in general vehicle use are motivated by intangible factors (Steg 2005; Verhoef and Wee 2000). For

EV adoption, symbolic and societal meanings associated with product use including environmental values and resource conservation concerns have been shown to influence consumer decisions (Axsen and Kurani 2012; Graham-Rowe et al. 2012; Skippon and Garwood 2011; Turrentine and Kurani 2007). Therefore, it is important to consider other dimensions of EV adoption besides utility concerns in order to have a more comprehensive understanding.

Although new technology is appealing to a few early adopters, most consumers will remain unreceptive of the new technology (Moore 2002). This can have a significant influence on the diffusion of any innovation. According to Rogers (2003), diffusion is the process by which an innovation is communicated through certain channels over time among participants in a social system. Rogers (2003) classifies the market for new technology into five main categories; innovators, early adopters, early majority, late majority and laggards. Innovators and early adopters are the first two groups to adopt any innovation and represent the first 2.5% and next 13.5% of adopters, respectively. The early adopters have the highest degree of opinion leadership among the adopter categories. Therefore, they have significant influence on the later adopter groups particularly the early majority. The adoption of an innovation by the opinion leaders (early adopters) usually marks a tipping point in the diffusion process and is a good indication that the innovation will be adopted by later groups. After the innovators and early adopters, the early majority (next 34% after early adopters) adopt the innovation, followed by the late majority (next 34%). The late adopters are skeptical about innovation and typically adopt it after the average person. Generally, laggards who represent the last 6% are the last to adopt any innovation.

Based on Rogers' innovation diffusion framework, adoption behavior follows a five-step process; acquiring information about the innovation through social networks, forming an attitude toward it, deciding to adopt it or not, implementing it and confirming the decision. In the second stage, consumers would typically form an attitude toward a new technology based on how they perceive its characteristics (Ozaki and Sevastyanova 2011; Tran 2012). Rogers points out that the perceived innovation characteristics can significantly explain the rate of adoption. Five characteristics including relative advantage, compatibility, complexity, trialability and observability can explain most of the variance in adoption rates.

Adoption of EVs, particularly PEVs, is still in the early stages. Based on EV sales, current EV adopters fall into the innovators and early adopters' stage. Since 2007, EV sales in the USA have ranged from 2.2 to 3.8% of total vehicle sales (EDTA 2017). In 2016, EV sales represented 2.9% of total vehicle sales in the USA. Early adoption of EVs will likely continue into the near future before adoption by mainstream consumers. It remains unclear if mainstream consumers (including early and late majority) will switch from conventional vehicles to EVs (Carley et al. 2013). In contrast to the small group of early adopters, some individuals are uncomfortable with technological change and uncertainty, and therefore are hesitant to accept innovation (Edison and Geissler 2003). Most consumers when making purchase decisions prefer the status quo, choosing to stick with notions of tradition of and familiarity rather than embracing an innovation (Sovacool and Hirsh 2009). Carley et al. (2013) argue that mass commercialization of EVs, if it occurs, will happen over several years, with early adopters followed by niche consumers, and then lastly the regular car buyer. The authors point out that this process may be interrupted at any point by technology limitations, economic constraints, misinterpretation of consumer demand, or errors in marketing practices. This research examines the perceptions and attitude of consumers to elucidate characteristics that influence early adoption of electric vehicles.

Methodology

Data collection

Data for this study were collected over a three-month period using a web-based survey. The survey was distributed through the listserv of a professional engineering association and through social media (Facebook). The professional engineering organization includes members from a wide range of engineering disciplines including but not limited to Industrial Engineering, Engineering Management, Systems Engineering, Aerospace Engineering and Mechanical Engineering that are affiliated with academia, industry and governmental organizations. The survey was designed to obtain information related to respondents' perceptions, awareness of EVs, attitudes and vehicle preferences (Egbue and Long 2013). While 189 responses were received, only 157 responses were complete. Of the 157 complete responses, approximately 78% individuals in the sample identified their area of highest degree as engineering and technology; 9% indicated sciences, and 13% selected either business or arts and social sciences. After removing contradictory responses, data from 112 respondents from engineering and technology fields only were considered for the purpose of the logistic regression analysis in this study.

Demographic determinants

Egbue and Long (2012a) found that perceptions and attitudes about electric vehicles differ across gender, age and education groups. Although Egbue and Long (2012a) did not find household income to have a statistically significant effect on attitudes toward EVs, other studies have reported that income influences decisions regarding EV adoption. For instance, in their study on PHEV penetration, Cui et al. (2012) argued that demographic attributes such as income and household size influence penetration rate of PHEVs. Therefore, it is expected that demographic factors will be influential in determining individual adoption of EVs.

Table 1 shows characteristics of the sample of respondents for this study compared with the socioeconomic and sociodemographic characteristics of the general population of the USA. The sample has a higher representation of males and individuals in the 18–44 age group at 77.68% compared to the US population at 49.20%. In addition, the sample has a higher representation of more educated and wealthier individuals. It is important to note that the data for US population show educational attainment and therefore include only levels of education that have been completed and as a result, the total percentage for all education attainment categories sums up to 86.29%. In our survey, respondents reported their highest level of education, including degrees they were still working on.

Due to the nature of the sample, consisting mainly of individuals in a professional engineering society that are at least 18 years old, it was not anticipated that this will be a representative sample when compared to the general US population. Considering the substantial difference in the demographic information of the general population compared to the sample in this study, the results of this study are more applicable to people with an engineering or technical background. As such, matching the exact demographic distribution of the population is not necessary as long as the results are interpreted to be applicable only to a more technically oriented subpopulation rather than the general US population. This sample was selected specifically to provide insights into the factors that influence adoption of EVs by individuals with a technical or engineering orientation because this group is likely to have a more comprehensive understanding of the technical details of EVs. This means that they are likely to have a better awareness of the benefits and drawbacks of EVs compared to the general public.

Table 1 Sample compared to 2010 US population. *Source*: United States Census Bureau (USCB 2010, 2011)

Total number of respondents	112	
	Respondents (%)	2010 US pop. (%)
Gender		
Male	77.68	49.20
Female	22.32	50.80
Age group of respondents (years)		
Under 18	0.00	24.00
18–44	55.36	36.50
45–64	31.25	26.40
65 and older	13.39	13.00
Education		
High school/GED	0.89	31.05
Some college/associates degree	1.79	27.96
Undergraduate degree	25.89	18.01
Graduate or professional degree	71.43	9.27
Household income		
Under $25,000	10.71	25.06
$25,000–$49,999	7.14	24.43
$50,000–$74,999	10.71	18.00
$75,000–$99,999	13.39	11.74
$100,000–$149,999	18.75	12.06
over $150,000	19.64	8.71
Prefer not to say	19.64	–

Attitudinal determinants

In addition to demographic determinants, some questions were included in the survey to capture attitudes, which is expected to influence adoption of EVs. Respondents were asked to categorize themselves in terms of their attitudes to the environment and technology using a five-point Likert scale (from 1 = strongly disagree to 5 = strongly agree). As previously mentioned, appreciation for the environment can have a positive effect on adoption of EVs. Previous studies (Gallagher and Muehlegger 2011; Griskevicius et al. 2010; Heffner et al. 2007; Kahn 2007; Turrentine and Kurani 2007) found that social preferences for the environment influenced HEV adoption. In particular, Turrentine and Kurani (2007) found that HEV adoption may be driven by the desire to project a strong environmental image. Furthermore, Gallagher and Muehlegger (2011) found that these preferences had more positive influence on sales of HEVs than tax incentives and increase in gas prices. In the study on PHEV adoption by Krupa et al. (2014), 25% of the participants indicated that making a strong environmental statement has a high importance in their adoption decision. To capture attitudes on the environment, the following five statements were included in the survey and respondents indicated how strongly they agreed or disagreed with the statements.

1. I have high environmental values.
2. I am a trendsetter for environmentally friendly technology.
3. I try to reduce my carbon footprint.
4. I try to preserve the environment.
5. I am willing to pay more for environmentally friendly products.

As previously discussed, new technology may not be appealing to the majority of consumers. Therefore, how an individual perceives their behavior toward new technology may influence their willingness to adopt EVs. For example, an individual who is willing to pay more for new technology may be more willing to buy an EV if they view the technology favorably. The following five statements were added to gauge how individuals classify themselves in terms of technological knowledge and how this can influence intent to adopt an EV.

1. I have high technological knowledge.
2. I closely follow global technology trends.
3. I like to have the latest technology.
4. I am willing to pay more for a new technology that appeals to me.
5. I closely follow vehicle technology trends.

In their previous study of technology enthusiasts, Egbue and Long (2012a) found that some individuals that have moderate or high environmental values and high technological knowledge might not consider purchasing EVs because of negative perceptions of the technology and environmental benefits of EVs. These individuals indicated that EVs have negative impacts on the environment (e.g., moving emissions from the tail pipe of vehicles to power plants). There were also concerns about the quality of EV technology compared to the technology of conventional vehicles. Therefore, statements (using 6-point Likert scales) were also added to capture how individuals perceive EVs. The respondents were asked to indicate whether they agreed or disagreed with statements related to EV safety, speed, purchase price, maintenance cost, range, EV sustainability and the impacts to the environment. Other variables considered in this study include travel distance and experience with EVs.

Logistic regression model

The logistic regression analysis described below was employed to estimate the relationship between the probability of adopting EVs and individual explanatory variables. This model illustrates how each explanatory variable affects the probability of adopting an EV by 2023 while controlling for other variables. The explanatory variables include the demographic information, socioeconomic factors, technological awareness, environmental awareness and perceived advantages and disadvantages, and familiarity with EVs. For each variable, the odds ratio shows the odds of a sample subcategory adopting an EV relative to the reference group.

This study develops a binary logit or logistic model to extract the demographic and attitudinal variations from the survey data to explain EV adoption. Examples of possible binary variables include success or failure, interest or non-interest, the presence or absence of an attribute. Survey respondents were asked to indicate if they would adopt an EV in 10 years (by 2023). The dependent variable is the vehicle adoption intention and can take one of two possible values denoted by 0 and 1, where 0 indicates that an individual is not willing to adopt an EV by 2023 and 1 indicates that an individual is willing to adopt an EV by 2023. Binary logit regression was then run to generate a set of predicted probabilities for the intent to adopt of EVs given the explanatory variables. Binary logistic regression was chosen for this analysis because it is a good method for predicting the outcome of a categorical dependent variable (Egbue and Long 2013). In particular, logistic regression analysis is an optimal method for regression analysis of binary-dependent variables (Allison 2012). Binary logistic regression is appropriate for when the response, say Y, can only take one of two possible values and is commonly used to analyze the probability that binary variables will occur.

Specifically, the probability of the response variable taking a particular value (in this case Y = 1 indicating the adoption of EV) is modeled based on the combination of values taken by the predictors or explanatory variables. If there is only a single explanatory variable X, the n the Probability that Y = 1 is modeled as F(g(x)), where F is the cumulative distribution function of the logistic distribution and g(X) is some linear function of X. If there are more than one explanatory variables, then g would be a linear function of all these explanatory variables (Ledolter and Hogg 2010). The goal is to find a model that includes variables, which provide a good fit and predict the response well.

A ten-year timeframe is used to capture early adopters with the assumption that within this period EV technology would have developed to the point where it becomes more competitive with conventional vehicles. According to Sovacool and Hirsh (2009), an American usually owns a car for 6 years. More recently, LeBeau (2012) found that due to the recession, Americans expect to own their cars for about 6–8 years; therefore, most individuals that currently own cars will likely replace their vehicles within a 10-year period. It is important to note that choosing a different timeframe will likely change the results.

Equation (1) below gives the binary logistic regression

$$\pi(x) = P(Y = 1|x) = \frac{1}{1 + e^{-g(x)}} \quad (1)$$

where $\pi(x)$ denotes the probability of adoption of an EV given x, the vector of explanatory variables (in this case demographic and attitudinal variables). The function $g(x)$ given in Eq. (2) links the explanatory variables with the probability defined in Eq. (1) through the relationship:

$$g(x) = \alpha + \beta' x \quad (2)$$

where α is the intercept parameter and β is the vector of slope parameters.

Results and discussion

Model results

Thirty explanatory variables were considered during the building of the model. Nine of these variables were selected into the model using the stepwise procedure. Use of a variable selection procedure is necessary because of the large number of independent variables relative to the number of observations. Stepwise selection can be employed to identify statistically significant factors that explain EV adoption while taking into consideration the effect of other variables included in the model. Table 2 shows the logit regression model. The overall model is statistically significant; likelihood ratio Chi-square value at 9 df. is 68.6974 and $p < 0.0001$. Hosmer and Lemeshow test shows no evidence of a lack of fit in the selected model ($p = 0.3415$). Furthermore, using an estimated probability, $\hat{\pi}(x)$ of 0.5 or higher as indicative of EV adoption, a correct classification rate of 83.9% was obtained.

The procedure encountered quasi-complete separation when obtaining maximum likelihood estimates. This phenomenon occurred when the education variable was entered into the model because the value taken by the response variable is to a large degree predictable by the education variable. More specifically, all respondents under the some college/associates degree and high school/GED categories responded yes to adopting an EV. This is illustrated in Table 3. This indicates that for this sample, education almost perfectly predicts EV adoption when education = high school/GED and education = some college/associates degree. Rather than exclude the education variable from the model, education was re-classified into two levels, without graduate degree and graduate degree. This removed the technical issue associated with quasi-complete separation, while allowing us to keep education in the model, albeit in a cruder form. Why those with an education level below an undergraduate degree opted for adoption while those with more education did not is an interesting question. First, the small sample size of those without an undergraduate degree may suggest that this is a chance occurrence. It may be also possible that these individuals are early adopters or do not (or are unable to) recognize the technological drawbacks associated with EVs.

Surprisingly some predictor variables do not behave in theoretically expected ways. Variables such as *income*, and *location* (rural vs. urban), that were expected to significantly influence EV adoption were not statistically significant and were not added to the model by the stepwise procedure. It may also be that a variable such *as willing to pay for new appealing technology* is acting as a proxy for income.

Variable values not listed in Table 2 include *Education*: W*ithout graduate degree*; *Use of public transportation*: *None*. These categories serve as the reference groups in the model; therefore, odds ratio estimates of other categories of the same variable represent the preferences relative to the reference category. For example, the odds ratio estimate of *Education: Graduate* represents the odds of a person that has received or is working toward a graduate degree adopting an EV compared to the odds of a person that has not received and is not working toward a graduate degree adopting an EV.

Furthermore, the variable *I like to have latest technology* was deleted before model selection. This was due to strong association with the variable *I am willing to pay for new*

Table 2 Logit model estimating probability of EV adoption

Likelihood ratio: $p = <.0001$
Hosmer and Lemeshow goodness-of-fit test: $p = 0.3415$

Variable	Odds ratio	Standard error	Wald Chi-square	Pr > Chi-square
Education: graduate	0.252	0.3651	3.5623	0.0591
Use of public transportation: none	0.274	0.3522	3.3807	0.0660
Willing to pay for new appealing technology	2.440	0.3491	6.5289	0.0106
Environmental trendsetter	1.703	0.2985	3.1821	0.0744
Distance driven	1.537	0.2017	4.5447	0.0330
EVs are slow	0.452	0.3238	6.0296	0.0141
Like look of EVs	2.325	0.3400	6.1605	0.0131
EVs are sustainable	1.521	0.2646	2.5130	0.1129
EVs good for environment	2.437	0.3328	7.1658	0.0074

Table 3 Response to "Would you purchase an electric vehicle in the next 10 years?" by education

Education	Yes	No
High school/GED	1	0
Some college/associates	2	0
Undergraduate degree	21	8
Masters	27	10
PhD/post doc	24	19

appealing technology. This relationship is illustrated in Table 4 where 1 = Strongly Disagree and 5 = Strongly Agree. Thus, the inclusion of both variables in the model can result in multicollinearity, thus yielding coefficient estimates and odds ratios that can be misleading.

Five variables in the model are statistically significant based on a 0.05 significance level for identifying effects that are statistically different from zero. For self-reported willingness to pay for new and appealing technology, the odds of a person purchasing an EV by 2023 increases for every unit increase on the Likert scale (from 1 to 5). This suggests that a person who is willing to pay for new technology that he/she finds appealing is more likely to adopt an EV compared to a person that is less willing. Some of these individuals may fall into the category of technology enthusiasts that may be more willing to take the risk in owning new and relatively unproven technology. This result indicates that when controlling for other variables in the model, a willingness to buy new and appealing technology may have a positive effect on adoption. According to the model estimates, individuals that consider EVs slow have smaller odds of purchasing an EV compared to those that disagree with that concept. In fact, for every unit increase in the Likert scale approaching "strongly agree," the odds for an individual purchasing an EV in 2023 decreases by 55%. In terms of distance driven (in miles), a person is more likely to purchase an EV with increase in the distance driven. Finally, when accounting for the other variables in the model, the odds of purchasing an EV increases for each additional unit increase in the variables *Like the look of EVs* and *EVs are good for environment*. The results indicate that the more a person agrees they like the look of EVs or that they believe that EVs are good for the environment; the more likely they are to adopt an EV.

Three more variables are statistically significant at a 0.1 significance level. At this level, *education* is statistically significant; the odds ratio shows that the odds of an individual with a graduate degree or working toward a graduate

Table 4 Two-way table comparing variables "I like to have latest technology" versus "I am willing to pay for new appealing technology"

Table of "I like to have latest technology" by "I am willing to pay for new appealing technology" (%)

	Willingness to pay for new appealing technology					
Like to have latest technology	1	2	3	4	5	Total
1	0	1.79	0	0	0	1.79
2	1.79	2.68	0	3.57	0	8.04
3	0	5.36	9.82	15.18	0.89	31.25
4	0	0	7.14	25	5.36	37.5
5	0	0	0.89	8.04	12.5	21.43
Total	1.79	9.82	17.86	51.79	18.75	100

degree purchasing an EV is 75% less than the odds for a person with an education below the graduate level. This finding is contradictory to previous studies that indicate that early adopters tend to have higher levels of education. The converse of this previously identified phenomenon may be true for the respondents in this study who have a better knowledge of technology compared with the general population. This result is consistent with that found in the study by Egbue and Long (2012a) that suggested that a comprehensive knowledge of EV technology and its limitations may lead to reservations about adopting the technology. Odds ratio for the *environmental trendsetter* variable suggests that the more a person considers himself or herself an environmental trendsetter, the more likely the person is to purchase an EV. Previous studies have found that stronger environmental attitude is associated with intent to purchase an EV. Respondents that indicated that there was no public transportation including buses and trains where they live, that they cannot rely on public transportation for any of their daily travel needs, or that they did not use available public transportation have odds of adopting an EV that is 73.6% lower than the respondents who indicated that they can rely on public transportation for some or all of their daily travel needs.

Previous ownership of an EV was not found to be significantly related to willingness to purchase an EV by 2023. Thus, this variable was not added to the model by the stepwise procedure. Furthermore, the number of vehicles owned was not added to the model as a variable that influences intent to adopt an electric vehicle. Similar to findings by Carley et al. (2013) who conducted an analysis on PHEV adoption, the most significant predictors of intention to adopt are the variables that gauge perception of EVs advantages and disadvantages. Variables such as *EVs are slow, Like the look of EVs* and *EVs are good for the environment* are statistically significant.

Reasons for non-adoption

An important question posed to the respondents was "What is the main reason you do not own an EV?" to determine critical factors preventing adoption. The top ten reasons given in response to this question are presented in Table 5. Some respondents provided more than one reason for not adopting EVs. Therefore, the percentage associated with each rank does not add up to 100%. Cost of EVs has been shown to be the main factor hindering their penetration into the market (Deloitte 2010; Zypryme 2010). This is consistent with this study with cost being by far the most cited reason for non-adoption. Several respondents specifically indicated that the major obstacle to purchasing an EV at present is the purchase price. A few individuals also specifically mentioned maintenance cost (see no. 6 in Table 5) with most of them referring to the battery replacement cost of an EV. This is a valid concern since a significant part of the additional cost of an EV compared to a conventional vehicle is due to the battery. However, there may be significant changes in battery prices that will increase EVs competitiveness with conventional vehicles. There are also leasing options that may reduce the cost to an EV driver.

Table 5 Reasons for non-adoption of EVs

Rank	Reason cited	% ($N = 107$)
1	Cost	47.66
2	Range	28.04
3	Technology	11.21
4	Charging infrastructure	7.48
4	Environment/pollution	7.48
4	Speed/power	7.48
5	Do not need new car	4.67
5	Reliability and safety	4.67
6	Size	3.74
6	Maintenance cost	3.74

Range limitation was the second most commonly cited reason for non-adoption. This "range anxiety" can be partly because consumers expect EVs to have the same range as conventional vehicles. This concern especially affects BEVs since these vehicles rely solely on on-board batteries for energy. Despite the fact that current PHEVs and BEVs can fulfill most of a person's travel needs, consumers continue to display range anxiety. According to Tamor and Milačić (2015), the suitability of an EV of a given range compared to a conventional vehicle is not limited by the daily travel within the vehicle's range but by the inconvenience of finding alternative transportation for the occasional long trip. Therefore, the willingness of consumers to accept an EV is based on the availability and convenience of alternative transportation (Pearre et al. 2011; Tamor et al. 2013). In addition, the willingness to use the replacement will likely affect EV adoption.

Some respondents mentioned technology as a reason for not adopting EVs with representative comments like "Technology is not there yet" and "Too new of a concept—not enough time for EVs to be fully understood and designed for optimal performance and reliability." There were also several concerns about the unavailability of charging infrastructure particularly for BEVs. The availability of charging stations can play a critical role in easing range anxiety. Consumers have reservations because the number of EV charging stations is very limited compared to the availability of gas stations. However, Kley et al. (2011) discovered in their study that range anxiety is more psychological than physical; this insight is confirmed by pilot tests conducted in Europe that show that public charging infrastructure is used relatively rarely. Nevertheless, consumers feel more comfortable if there are available charging stations, particularly when they travel longer distances than usual. A chicken and egg problem results because drivers will be hesitant to purchase a PEV if charging stations are not available but investments in charging infrastructure will remain limited without positive prospect of consumers (Hong et al. 2012). Furthermore, recharge time poses a problem. Consumers will likely be more willing to adopt EVs if they consider vehicle charging to be convenient. Moreover, while EV charge time has improved, it still pales in comparison with the short time it takes to re fuel a conventional vehicle.

Some individuals also cited negative environmental impacts of EVs as the main reason they do not currently own an EV. Concerns about the environment and pollution include pollution from EV manufacturing, greenhouse gas emissions and pollution from generating electricity for charging PEVs from non-renewable sources, lack of recycling for batteries. In fact, responses to the question about why respondents do not currently own an EV revealed that some respondents are convinced that the total negative environmental effects of an EV surpass that of a conventional vehicle. Compared to conventional vehicles, EVs can substantially reduce GHG emissions. For instance, studies have shown that HEVs (Duvall 2002) and PHEVs (Jaramillo et al. 2009; Smith 2010) have the potential to significantly reduce GHG emissions. Graham-Rowe et al. (2012) came to the same conclusion about PEVs in general. However, from a lifecycle perspective, the extent of this reduction is determined by the composition of regional sources for generating electricity (Lewis et al. 2012). Tamayao et al. (2015) studied the regionally specific life cycle CO_2 emissions per mile traveled for a EVs and sales weighted average ICEVs in the USA under different assumptions for regional electricity emission factors, regional boundaries and charging schemes. The authors found that the BEV and HEV have lower expected life cycle emissions than the average ICEV in all regions and across all scenarios. The probability of the PEV being lower emitting than ICEVs across all scenarios is 100% except in two instances where they are 88 and 55%. Furthermore, Manjunath and Gross (2017) found that the BEVs have highly varying spatial environmental impacts of which in some cases, particularly in locations that depend heavily on fossil fuels, may be greater than impacts of conventional vehicles. Therefore, a transition to cleaner and more environmentally friendly energy sources will increase the positive effects of PEVs.

Other reasons preventing the purchase of EVs are related to technology (largely untested, batteries), size (too small), speed/power (too slow) and reliability and safety. Concerns about speed highlighted in Table 5 support the results of the logistic regression model in this study that shows that the odds of purchasing an EV is less for an individual that agrees that EVs are slow compared to a person that disagrees that EVs are slow.

Conclusions

The goal of this research was to build a model that determines demographic and attitudinal factors that influence EV adoption. Although the model developed includes both demographic and attitudinal variables, some of the predictor variables, namely age, income, and location, were not included in the model. It is important to note that the sample used in this study may not be representative of the general population but instead provides insights into factors that influence adoption among individuals with technology and engineering backgrounds. However, these individuals that are likely to have a more comprehensive knowledge about EVs and technology in general compared to the general public may be able to influence adoption of EVs by others. Future work will involve the use of a larger sample size to confirm these results.

The logistic regression model in this study shows that when other variables in the model are accounted for, association of EVs with environmental benefits positively influences EV adoption. However, a significant number of respondents did not share this view. One of the top four reasons respondents indicated for non-adoption of EVs was the negative environmental impacts of EVs. Comments from some respondents indicate that they do not believe PEVs are equally effective with regard to the reduction in greenhouse gas emissions due to negative environmental impacts from generating electricity for charging PEVs from fossil fuels. This electricity generation mix varies spatially. These environmental concerns related to charging of PEVs can be addressed by improvements to the electricity generation system including building more efficient power infrastructure, increased use of renewable and alternative energy sources and pollution abatement to reduce the impact of PEVs at the grid. Reduction in the emission intensity of the power grid will in turn improve the environmental footprint of PEVs. It is important to consider regional strategies for increasing EV adoption that will target the area specific needs to achieve the greatest impact. It is also important to address the emissions and pollution generated from manufacturing and disposal of EVs. These improvements could address the perceptions of

EVs not being a good transportation option for the environment.

The main reasons individuals provided for not presently owning an EV include high cost, limited range, lack of charging infrastructure, negative environmental impacts and undeveloped technology in that order. Addressing these concerns is critical before EV penetration can increase significantly. Several of the issues identified can be resolved via public policy and education. Therefore, it is critical to have government policies that support market penetration of these vehicles if energy and environmental goals are to be met. One strategy to encourage EV adoption includes additional tax incentives. As shown in the result of this study, when other variables in the model are considered, a willingness to pay for new and appealing technology is positively associated with EV adoption. Although this group may be willing to purchase EVs at higher prices due to their appeal, other consumers may not be willing to pay such a price without financial incentives. This is illustrated by the fact that the top reason cited for non-adoption of EVs was cost. During the early stages of adoption, tax incentives can be a very effective strategy for encouraging EV adoption. However, these subsidies are not sustainable because they simply transfer money from taxpayers to EV buyers and should only serve as an incentive for early adopters of the technology until demand increases and advances in technology make EVs more economically competitive with conventional vehicles. In addition, education on the benefits of EVs including reduced carbon footprint and local pollution abatement can also lead to more people being willing to purchase EVs at higher prices than ICEVs. Furthermore, education together with advances in technology will help address the perception that EVs as slow as this was shown to have a negative impact on EV adoption.

Additional strategies to increase penetration of EVs into the mainstream market include more stringent Corporate Average Fuel Economy (CAFE) standards and emission limits, carbon taxes and other subsidies for vehicles and charging equipment. To address range anxiety and the perception of inconvenience of charging, it is critical to increase the number of public charging stations and increase investment in level 3 or fast charging infrastructure and technology.

References

Allison PD (2012) Logistic regression using the SAS system: theory and application. SAS Institute, Cary

Antweiler W, Gulati S (2013) Market-based policies for green motoring in Canada. Can Public Policy 39:S81–S94. doi:10.3138/CPP.39.Supplement2.S81

Axsen J, Kurani KS (2012) Interpersonal influence within car buyers' social networks: applying five perspectives to plug-in hybrid vehicle drivers. Environ Plan A 44:1047–1065

Axsen J, Kurani KS (2013) Hybrid, plug-in hybrid, or electric—what do car buyers want? Energy Policy 61:532–543. doi:10.1016/j.enpol.2013.05.122

Brand C, Anable J, Tran M (2013) Accelerating the transformation to a low carbon passenger transport system: the role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. Transp Res Part A Policy Pract 49:132–148

Caperello ND, Kurani KS (2012) Households' stories of their encounters with a plug-in hybrid electric vehicle. Environ Behav 44:493–508

Carley S, Krause RM, Lane BW, Graham JD (2013) Intent to purchase a plug-in electric vehicle: a survey of early impressions in large US cites. Transp Res Part D 18:39–45

Chandra A, Gulati S, Kandlikar M (2010) Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. J Environ Econ Manag 60:78–93. doi:10.1016/j.jeem.2010.04.003

Cui X, Kim HK, Liu C, Kao S-C, Bhaduri BL (2012) Simulating the household plug-in hybrid electric vehicle distribution and its electric distribution network impacts. Transp Res Part D Transp Environ 17:548–554. doi:10.1016/j.trd.2012.05.011

Deloitte (2010) Gaining traction a customer view of electric vehicle mass adoption in the US automotive market. http://www.deloitte.com.br/publicacoes/2007/MFG.Gaining_Traction_customer_view_of_electricvehicle_massadoption.pdf. Accessed 12 Dec 2015

DFT (2009) Ultra-low carbon vehicles in the UK. Department for Transport, UK. http://webarchive.nationalarchives.gov.uk/20090609003228/http://www.berr.gov.uk/files/file51017.pdf. Accessed 13 Apr 2016

DOE (2013) EV everywhere, grand challenge blueprint. US Department of Energy. http://energy.gov/sites/prod/files/2014/02/f8/eveverywhere_blueprint.pdf. Accessed 03 Dec 2015

Driscoll A, Lyons S, Mariuzzo F, Tol RSJ (2013) Simulating demand for electric vehicles using revealed preference data. Energy Policy 62:686–696

Duvall M (2002) Comparing the benefits and impacts of hybrid electric vehicle options for compact sedan and sport utility vehicles. Electric Power Research Institute, Palo Alto

Edison SW, Geissler GL (2003) Measuring attitudes towards general technology: antecedents, hypotheses and scale development. J Target Meas Anal Market 12:137–156

EDTA (2017) Electric drive sales dashboard. Electric Drive Transportation Association. Electric Drive Transportation Association. http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952. Accessed 24 June 2016

Egbue O, Long S (2012a) Barriers to widespread adoption of electric vehicles: an analysis of consumer attitudes and perceptions. Energy Policy 48:717–729. doi:10.1016/j.enpol.2012.06.009

Egbue O, Long S (2012b) Critical issues in the supply chain of lithium for electric vehicle batteries. Eng Manag J 24:52–62

Egbue O, Long S (2013) Developing a prediction model for the adoption of electric vehicles. In: International annual conference of the American society for engineering management 2013, Bloomington, Minnesota 2013, pp 269–275

EGCI (2011) European green cars initiative PPP multi-annual roadmap and long-term strategy. EGCI Ad hoc Industrial Advisory Group. http://www.egvi.eu/uploads/Modules/Publications/egci-roadmap.pdf. Accessed 24 June 2016

Gallagher KS, Muehlegger E (2011) Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. J Environ Econ Manag 61:1–15. doi:10.1016/j.jeem.2010.05.004

Graham-Rowe E, Gardner B, Abraham C, Skippon S, Dittmar H, Hutchins R, Stannard J (2012) Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: a qualitative analysis of responses and evaluations. Transp Res Part A Policy Pract 46:140–153. doi:10.1016/j.tra.2011.09.008

Griskevicius V, Tybur JM, Van den Bergh B (2010) Going green to be seen: status, reputation, and conspicuous conservation. J Personal Soc Psychol 98:392–404. doi:10.1037/a0017346

Heffner RR, Kurani KS, Turrentine TS (2007) Symbolism in California's early market for hybrid electric vehicles. Transp Res Part D Transp Environ 12:396–413. doi:10.1016/j.trd.2007.04.003

Hidrue MK, Parsons GR, Kempton W, Gardner MP (2011) Willingness to pay for electric vehicles and their attributes. Resour Energy Econ 33:686–705. doi:10.1016/j.reseneeco.2011.02.002

Hong J, Koo Y, Jeong G, Lee J (2012) Ex-ante evaluation of profitability and government's subsidy policy on vehicle-to-grid system. Energy Policy 42:95–104. doi:10.1016/j.enpol.2011.11.053

Intergovernmental Panel on Climate Change (2014) Climate change 2014: mitigation of climate change, vol 3. Cambridge University Press, Cambridge

Jaramillo P, Samaras C, Wakeley H, Meisterling K (2009) Greenhouse gas implications of using coal for transportation: life cycle assessment of coal-to-liquids, plug-in hybrids, and hydrogen pathways. Energy Policy 37:2689–2695. doi:10.1016/j.enpol.2009.03.001

Kahn ME (2007) Do greens drive hummers or hybrids? Environmental ideology as a determinant of consumer choice. J Environ Econ Manag 54:129–145. doi:10.1016/j.jeem.2007.05.001

Kihm A, Trommer S (2014) The new car market for electric vehicles and the potential for fuel substitution. Energy Policy 73:147–157. doi:10.1016/j.enpol.2014.05.021

Kley F, Lerch C, Dallinger D (2011) New business models for electric cars—a holistic approach. Energy Policy 39:3392–3403. doi:10.1016/j.enpol.2011.03.036

Krupa JS, Rizzo DM, Eppstein MJ, Brad Lanute D, Gaalema DE, Lakkaraju K, Warrender CE (2014) Analysis of a consumer survey on plug-in hybrid electric vehicles. Transp Res Part A Policy Pract 64:14–31. doi:10.1016/j.tra.2014.02.019

LeBeau P (2012) Americans buying fewer new cars in lifetime. http://www.cnbc.com/id/49504504. Accessed 23 June 2016

Ledolter J, Hogg RV (2010) Applied statistics for engineers and physical scientists. Pearson Higher Ed, London

Lewis AM, Kelly JC, Keoleian GA (2012) Evaluating the life cycle greenhouse gas emissions from a lightweight plug-in hybrid electric vehicle in a regional context. In: Sustainable systems and technology (ISSST), 2012 IEEE international symposium on, 16–18 May 2012, pp 1–6. doi:10.1109/ISSST.2012.6403806

Lieven T, Mühlmeier S, Henkel S, Waller JF (2011) Who will buy electric cars? An empirical study in Germany. Transp Res Part D Transp Environ 16:236–243. doi:10.1016/j.trd.2010.12.001

Lutsey N, Sperling D (2012) Regulatory adaptation: accommodating electric vehicles in a petroleum world. Energy Policy 45:308–316. doi:10.1016/j.enpol.2012.02.038

Manjunath A, Gross G (2017) Towards a meaningful metric for the quantification of GHG emissions of electric vehicles (EVs). Energy Policy 102:423–429. doi:10.1016/j.enpol.2016.12.003

McConnell V, Turrentine T (2010) Should hybrid vehicles be subsidized? Resources for the future. Washington D.C, USA. http://www.rff.org/RFF/Documents/RFF-BCK-McConnellTurrentine-Hybrids.pdf

Michalek JJ, Chester M, Samaras C (2012) Getting the most out of electric vehicle subsidies. Issues Sci Technol 28:25–27

Moore G (2002) Crossing the chasm: marketing and selling high-tech product to main stream customers. Harper Collins, New York

Musti S, Kockelman KM (2011) Evolution of the household vehicle fleet: anticipating fleet composition, PHEV adoption and GHG emissions in Austin, Texas. Transp Res Part A Policy Pract 45:707–720. doi:10.1016/j.tra.2011.04.011

Nemry F, Brons M (2010) Plug-in hybrid and battery electric vehicles: market penetration scenarios of electric drive vehicles. http://ftp.jrc.es/EURdoc/JRC58748_TN.pdf. Accessed 12 Oct 2015

Offer GJ, Howey D, Contestabile M, Clague R, Brandon NP (2010) Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy 38:24–29. doi:10.1016/j.enpol.2009.08.040

Onat NC, Noori M, Kucukvar M, Zhao Y, Tatari O, Chester M (2017) Exploring the suitability of electric vehicles in the United States. Energy 121:631–642. doi:10.1016/j.energy.2017.01.035

Ozaki R, Sevastyanova K (2011) Going hybrid: an analysis of consumer purchase motivations. Energy Policy 39:2217–2227. doi:10.1016/j.enpol.2010.04.024

Pearre NS, Kempton W, Guensler RL, Elango VV (2011) Electric vehicles: how much range is required for a day's driving? Transp Res Part C Emerg Technol 19:1171–1184. doi:10.1016/j.trc.2010.12.010

Roche MY, Mourato S, Fischedick M, Pietzner K, Viebahn P (2010) Public attitudes towards and demand for hydrogen and fuel cell vehicles: a review of the evidence and methodological implications. Energy Policy 38:5301–5310. doi:10.1016/j.enpol.2009.03.029

Rogers EM (2003) Diffusion of innovations, 5th edn. Free Press, NewYork

Rolim CC, Gonçalves GN, Farias TL, Rodrigues Ó (2012) Impacts of electric vehicle adoption on driver behavior and environmental performance. Proced Soc Behav Sci 54:706–715. doi:10.1016/j.sbspro.2012.09.788

Sánchez-Braza A, Cansino JM, Lerma E (2014) Main drivers for local tax incentives to promote electric vehicles: the Spanish case. Transp Policy 36:1–9. doi:10.1016/j.tranpol.2014.06.010

Skippon S, Garwood M (2011) Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. Transp Res Part D Transp Environ 16:525–531. doi:10.1016/j.trd.2011.05.005

Smith WJ (2010) Plug-in hybrid electric vehicles—a low-carbon solution for Ireland? Energy Policy 38:1485–1499. doi:10.1016/j.enpol.2009.11.031

Sovacool BK, Hirsh RF (2009) Beyond batteries: an examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 37:1095–1103. doi:10.1016/j.enpol.2008.10.005

Steg L (2005) Car use: lust and must. Instrumental, symbolic and affective motives for car use. Transp Res Part A Policy Pract 39:147–162. doi:10.1016/j.tra.2004.07.001

Tamayao M-AM, Michalek JJ, Hendrickson C, Azevedo IML (2015) Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States. Environ Sci Technol 49:8844–8855. doi:10.1021/acs.est.5b00815

Tamor MA, Gearhart C, Soto C (2013) A statistical approach to estimating acceptance of electric vehicles and electrification of personal transportation. Transp Res Part C Emerg Technol 26:125–134. doi:10.1016/j.trc.2012.07.007

Tamor MA, Milačić M (2015) Electric vehicles in multi-vehicle households. Transp Res Part C Emerg Technol 56:52–60. doi:10.1016/j.trc.2015.02.023

Tran M (2012) Agent-behaviour and network influence on energy innovation diffusion. Commun Nonlinear Sci Numer Simul 17:3682–3695. doi:10.1016/j.cnsns.2012.01.016

Turrentine TS, Kurani KS (2007) Car buyers and fuel economy? Energy Policy 35:1213–1223. doi:10.1016/j.enpol.2006.03.005

USCB (2010) Census briefs, 2010. US Census Bureau. http://www.census.gov/population/www/cen2010/glance/files/2010CensusBriefs.pdf Accessed 12 Oct 2015

USCB (2011) American community survey 1-year estimates. US Census Bureau. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_11_1YR_DP03&prodType=table. Accessed 12 Oct 2015

Van Der Steen M, Van Deventer P, De Bruijn H, Van Twist M, Heuvelhof ET, Haynes KE, Chen Z (2012) Governing and innovation: the transition to E-mobility—a Dutch perspective GMU. School of public policy research paper

Verhoef ET, Wee B (2000) Car ownership and status: implications for fuel efficiency policies from the viewpoint of theories of happiness and welfare economics. Eur J Transp Infrastruct Res 41–56

Voelcker J (2011) One million plug-in cars by 2015? IEEE Spectr 48:11–13. doi:10.1109/MSPEC.2011.5738384

Weiss M, Patel MK, Junginger M, Perujo A, Bonnel P, van Grootveld G (2012) On the electrification of road transport—learning rates and price forecasts for hybrid-electric and battery-electric vehicles. Energy Policy 48:374–393. doi:10.1016/j.enpol.2012.05.038

Zheng J, Mehndiratta S, Guo JY, Liu Z (2012) Strategic policies and demonstration program of electric vehicle in China. Transp Policy 19:17–25. doi:10.1016/j.tranpol.2011.07.006

Zypryme (2010) The electric vehicle study. Zypryme research and consulting. http://www.Zpryme.com/SmartGridInsights/The_Electric_Vehicle_Study_Zpryme_Smart_Grid_Insights_Airbiquity_Sponsor_December_2010.pdf. Accessed 05 Dec 2015