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Consumer Adoption and Grid Impact Models for Plug-in Hybrid Electric Vehicles in Dane County, Wisconsin

Part A: Consumer Adoption Models

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The power is within you.

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EXECUTIVE SUMMARY

This study focuses on assessing the demand for plug-in hybrid electric vehicles (PHEV) in Dane County, Wisconsin, and provides near term recommendations to manage its impacts on the electric grid.

This study has two main objectives:

- Enhance the understanding of consumers' perception of and demand for PHEVs, thereby informing policy development for wider PHEV deployment.
- Assess the market potential of PHEVs in Wisconsin and estimate the associated vehicle charging patterns, electricity consumption, and infrastructure needs.

Our analyses were limited to the Greater Madison area due to the time frame for the study. As such, the project serves as a demonstration of research methodology as well as a preliminary study for future expansion to analyzing the PHEV impacts to the entire state of Wisconsin.

The study objectives have been accomplished through three major research components: (i) infrastructure readiness assessment, (ii) consumer preference analysis and (iii) grid impact studies. This executive summary and the accompany report document the methodologies and findings relating to Part A of the study that focus on research components (i) and (ii).

Infrastructure Readiness Assessment

A PHEV readiness analysis at the community level using parcel level has been completed using Tax Assessment data for the City of Madison, WI. Nearly 70% of all residential parcels in Madison are found to be PHEV ready. That is, these parcels are occupied by single detached homes with either attached or detached garages. Based on results on the readiness analysis, a scenario analysis of electrical grid impact due to varying levels of PHEV adoption is also described. Compared to past studies of PHEV readiness that typically utilize aggregate data provided for census geographies, our parcel-level analysis provides much higher spatial accuracy regarding where the PHEV-ready households are. Both analyses serve to demonstrate the benefits and the need for parcel-level analysis to support utility planning and PHEV market promotion at a refined geographic scale. The methods allow electrical utilities to analyze their distribution network under scenarios of maximum near-term PHEV load.

However, recharging capability (at home or elsewhere) being a necessary but not a sufficient condition for early PHEV adoption, the likelihood of a household becoming an early adopter depends on a suite of factors ranging from infrastructure availability, charging methods, vehicle and fueling costs, vehicle performance characteristics, to household's income, life style, and attitudes towards environmental issues. Future studies are needed to better understand the relationship between PHEV preference and PHEV readiness, between the true market and the potential market pool.

In the long run, the possibility for recharging PHEV at commercial sites or public stations will not only change market behavior but also load distribution across the utility network. This aspect of PHEV is not covered herein, but to do so in the future would require an analysis of commercial/industrial geographic areas where such opportunities are more likely to be installed. It is hoped that our work presented here would assist with those expanded efforts.

Additionally, agencies that wish to adopt policies encouraging denser built environments with goals of fewer road miles may reveal a contradiction with PHEV home charging. If single unit personal garages remain the universal primary charging locations, the inclusion of those garages will use more land. Further, residents who choose to live in denser urban environments may be served well by PHEV if they must own personal vehicles, yet may not have adequate access to PHEV charging opportunities. It is anticipated that our geospatial approach would be extended to assist in these future assessments.

Consumer Preference Analysis

An in-depth consumer survey was conducted among consumers in the Madison area using a specifically designed survey instrument to study the impact of consumer preference on PHEV adoption.

Out of the 61% respondents that are interested in purchasing a vehicle in the next five years, 80.59% are willing to consider purchasing an alternative vehicle. This equates to 49% of the sample being willing to consider purchasing an alternative vehicle in the next five years. Applying this proportion to the population gives an estimated 70,000 households as the PHEV willing households in the Madison area in the five-year timeframe.

However, when one considers the expected price of PHEVs in the range of $30,000 and upwards including subsidies, this translates into an *upper bound* of about 21,000 households that are able *and* willing to purchase PHEVs in the next five years. This would represent an annual increase of about 4.3% of the residential electrical utility customer base of the Madison Gas and Electric. The present level of survey data does not definitively develop the geospatial locations of the households where this growth would occur, particularly in light of the inability in sharing confidential consumer information of the survey respondents for correlation with Madison Gas Electric’s customer information database. Thus any extrapolation on the resulting specific grid impact of the near term PHEV adoption by households connected to the distribution grid becomes highly speculative. On the other hand, infrastructure readiness analysis and worst-case transformer loading study results indicates that critical aspects of PHEV adoption that lead to circuit overloading tends to occur in rare occasions at rare locations. Therefore, in light of such uncertainties, it would rather be effective to focus on creative solutions that avert such rare events as opposed to developing guidelines or roadmaps for additional infrastructure investments in the distribution network. Preliminary investigations indicate that existing demand side management approaches may be effectively tailored for this purpose.

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ACRONYM

CATI:	Computer-Assisted Telephone Interview
CNG:	Compressed Natural Gas
EV:	Electric Vehicles
GHG:	Green House Gas
GIS:	Geographical Information System
HEV:	Hybrid Electric Vehicles
ICE:	Internal Combustion Engine
MG&E:	Madison Gas & Electric
PHEV:	Plug-In Hybrid Electric Vehicle
PUMS:	Public Use Microdata Sample

1 INTRODUCTION

1.1 Background

This study focuses on assessing the demand for plug-in hybrid electric vehicles (PHEV) in Wisconsin and provides near term recommendations to manage its impacts on the State's electric grid.

PHEVs are expected to provide a range of about 40 miles per drive cycle using plug-in recharging from the electric grid, in addition to the virtually unlimited range offered by conventional and hybrid vehicles. Given the concern over global warming and the need for reducing America's dependence on foreign oil, PHEV are among the emerging 'green' alternatives to conventional fossil-fuel vehicles. Although they are recognized to have the potential to play a key role in climate change and energy security strategies, projected levels of market adoption, charging patterns, and impacts on electricity market and infrastructure supply are uncertain.

Consumers have responded in a dramatic manner to the introduction of hybrid electric vehicles (HEV) in the last decade. The sales of such vehicles have grown as much as 80 percent annually, a particularly striking figure in the face of declining or flat sales trends in most categories of conventional vehicles. PHEVs take that dedication to "clean" alternative fuels to the next level. Not only are they the next step in the emergence of energy-efficient, pollution-reducing technologies designed to stem the growth of transportation-related greenhouse gas emissions, they could be recharged quite literally in the owner's backyard. But there are other considerations before U.S. consumers can adopt PHEVs as the nation's primary personal transportation. An increase in PHEV use will impact the patterns of electricity use, driving habits and the economics and operation of the electricity grid, which could mean more use of coal-powered energy plants to produce enough electricity. This study outlines whether PHEVs could become that primary transportation option and how such adoption would affect the U.S. electricity grid.

The discovery and use of a sustainable fuel is as important to Wisconsin as it is to the United States. Other than the fraction of vehicles represented by ethanol, the majority of energy used for personal transportation in Wisconsin is imported from outside the state. On the other hand, 80 percent of Wisconsin's electricity demand is obtained through in-state generation. Depending on the adoption and growth of PHEVs in Wisconsin, the mix of in-state and out-of-state resources to meet the new energy demand for transportation and electricity is bound to change. The additional demand for electricity arising from this new vehicle adoption could be met from a variety of primary sources, such as wind, solar, nuclear and coal, taking into account their accompanying impact on economic and environmental conditions. Thus, there is an opportunity for developing appropriate policy actions to direct a state-wide energy dependence scenario.

1.2 Research Objectives

To date, most PHEV-related analysis has focused on technology assessment, lifecycle analysis, battery R&D, and vehicle modeling. Also, a number of recent studies explored the environmental consequences of shifting transportation energy use from conventional fuels to electricity through wide deployment of PHEVs and showed promising GHG impacts and air quality benefits at the national and global levels. Yet, much uncertainty remains regarding the infrastructure and economic impacts of PHEVs at the local level.

This study has two main objectives:

- Enhance the understanding of consumers' perception of and demand for PHEVs, thereby informing policy development for wider PHEV deployment.
- Assess the market potential of PHEVs in Wisconsin and estimate the associated vehicle charging patterns, electricity consumption, and infrastructure needs.

In view of the time frame for the study, our analyses were limited to the Dane County area. As such, the project serves as a demonstration of research methodology as well as a preliminary study for future expansion to analyzing the PHEV impacts to the entire state of Wisconsin.

1.3 Approach

The objectives outlined above were accomplished through three major research components: (i) infrastructure readiness assessment, (ii) consumer preference analysis and (iii) grid impact studies. This report documents the methodologies and findings relating to Part A of the study that focus on research components (i) and (ii). These two components are described briefly below. The reader is referred to Report Part B for a description of research component (iii) of the study.

1.3.1 Infrastructure Readiness Assessment

PHEV Readiness is demonstrated by the availability of electricity and the capacity of the electric distribution network to furnish electricity at locations where reasonable demand for PHEV charging could be expected. In this study, a household is considered as being "PHEV ready" if it has the *ability* of at-home charging. PHEV readiness is therefore considered as the base criterion for a household to qualify as part of the market pool for early PHEV adoption.

The infrastructure readiness assessment began with determining where PHEV-ready households are. The demand load on the electric distribution network in these PHEV-ready areas was then analyzed for its capabilities; its readiness, to electrically charge and recharge a vehicle fleet at residential locations and represented by the potential market penetration of PHEV.

1.3.2 Consumer Preference Analysis

While the infrastructure readiness assessment is concerned with residents' *capability* of being early PHEV owners, the consumer preference analysis focuses on analyzing residents' likelihood – as defined by preference – of being early PHEV owners. The preference analysis entailed designing and administering a survey to sampled residents in Madison. Participants were asked a series of questions aimed at uncovering their desire to purchase a vehicle within a given time frame, the price range of that potential vehicle, and whether they would be willing to consider an alternative fuel vehicle, such as a PHEV, for that next purchase. The survey also collected standard demographic information to allow researchers to understand whether alternative fuel vehicles, such as PHEVs, could be accepted across all age, education and income levels.

1.4 Report Outline

This report is organized as follows. Chapter 2 discusses the literature relevant to PHEV infrastructure readiness and consumer preference. Chapter 3 evaluates the household and electricity grids readiness for PHEV adoption. Chapter 4 describes the consumer preference analysis effort and the key findings. The final chapter provides a summary of conclusions.

2 LITERATURE REVIEW

2.1 Past Studies of PHEV Readiness

The use of home charging/refueling ability to define the upper bound of early PHEV market is not new and is drawn from past observations of ICE vehicle adoption. At the advent of the ICE vehicle introduction, gas stations as we know them were not prevalent. Motorists purchased vehicle fuel in bulk for storage at home. Doing so among these early ICE adopters sustained ICE vehicle growth, until stations became profitably operable. The same may be for PHEV. After a period when motorists who elect to own PHEVs do so with the exclusive home charging, a PHEV fleet may grow to demand secure, public recharging or battery swap stations that resemble, replace or replicate the current gas station infrastructure. Such stations, thereby may preclude the need or desire for additional home recharge stations, and may induce a market to those without home structural capacity for recharge stations.

The correlation between PHEV adoption and home charging is evaluated to some degree by Williams and Kurani (2007) noting that 120VAC outlet accessibility defines “prospective owners”; what we would call a Pool Market for potential PHEV adoption. Williams and Kurani (2006) indicates that, while garages can define the Pool Market, they too may need modification before motorists bring PHEVs home for recharging. In fact, in writing about home 120 volt and 240 volt charging, Morrow et al (2008) only briefly mentions the use of a standard wall outlet for charging a PHEV. It is conjectured in the study that existing circuits currently in garages could be used, but a switch may be required that deactivates the wall socket in favor of PHEV charging socket and vice versa. In such cases, homeowners, electrical codes and installers will need to assess continuous power to other garage appliances.

Two studies conducted surveys to quantify access to home charging locations. In Axsen and Kurani (2008a), 52.4% of 2,372 U.S. nationwide household respondents “identified an electrical outlet within 25 feet of their vehicle parking spot at their home location at some time during their 24-hour day”. The precision of that question does account for vehicle owners who may not park in single home garages, yet still have access to an outlet. In Graham et al (2001), 400 consumers in Boston, Atlanta, Phoenix and Los Angeles were sampled for among other PHEV related items, “relatively easy access to a plug, with 120 volt systems being relatively hassle free”. Unfortunately, the phrasing of the question is not evident and with 86% of households reporting such access, which seems intuitively excessive, by no means matches the rate reported by Axsen and Kurani (2008a). Nonetheless, the precision of not necessarily relying on single home garage information is noted.

For a larger sample size, Williams and Kurani (2006) uses the 1% Public Use Microdata Sample (PUMS) of the 2000 Census of the State of California. This data was used for the purpose of analyzing not just capabilities for only electric home refueling but for future hydrogen refueling as well. With it, housing stock built after 1974 was used as a proxy for “home connection hardware”. Buildings built since 1974 have been wired according to the National Electric Code revision of that year, and those authors intimate that code as sufficient for the purpose of their study. This limits the precision of the PHEV Pool market by underestimating older homes and specifically their garages that could easily have been wired for PHEV charging and overestimating the number of buildings, which could include apartments and condominiums. The result of that assessment was a Pool Market of 15% of households. Similarly the publicly available American Housing Survey is used by Vyas et al (2009) to identify the existence of a "garage or carport" amenity at a single unit house is a proxy for "likely PHEV buyers". The Pool Market assessment in this case yields 38.7% of households. Extending electricity to carports may be more code cost prohibitive than even doing so with detached garages, since electrical raceways exposed to the elements do require additional code adherence. So, assuming that builders included costs to serve carports with electricity may have overestimated the Pool market in this case.

The four abovementioned studies have delivered significantly different assessments of Pool Markets. As described above, Pool Markets among households are either 52.4%, 86%, 15% or 38.7%. Intuitively, the values, 86% and 15% seem respectively too large and too small. The values, 52.4% and 38.7% both seem reasonable, yet where 38.7% of single homes have garages or carports might overestimate the Market Pool on behalf of carports, that value is still less than the survey respondents' 52.4% Market Pool. Perhaps opening the Market Pool of that survey to include any outlets within 25 feet subsequently overestimated it.

A report on compressed natural gas (CNG) infrastructure of the 1980's shares lessons about alternative fuel transportation (Flynn, 2002). That report does call exception to the electricity utility infrastructure, "which is already available in homes, (…and…) can avoid this issue (inadequate infrastructure) through affordable repowering". The report also stated that "the main barrier was a lack of infrastructure to support the converted vehicles", and, "utilities or energy suppliers can be allies, but need to ensure that their actions are strategic in building the market".

2.2 Past Studies of Consumer Preference for PHEV

The field of consumer adoption modeling as it concerns alternative fuel vehicles has been of increasing interest in recent years. The drive for citizens and politicians across the globe to decrease their country's dependence on foreign oil as a primary energy source has led more engineers to study alternative fuels. That research has triggered the field of consumer adoption research as a means to uncover which potential energy source would be the most acceptable to consumers.

One of the focal points of the research has been the study of hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV). Some critics have said that the United States is unprepared to shift from gasoline to electric and alternative fuel vehicles. However, one out of every three new vehicle purchasers has both the desire to purchase a PHEV and the infrastructure to support plug-in recharging already (Axsen and Kurani, 2007). Even that switch to non-gasoline operation could cut the U.S consumption of gasoline in half as it concerns transportation (Axsen and Kurani, 2007).

For the purposes of this study, it has been necessary to narrow this literature review to deal with studies that dealt with consumer modeling. Moreover, we focus on studies which utilized surveys for at least one section of their data analysis and attempted to discern the degree to which alternative fueled vehicles, such as electric, could become viable transportation alternatives.

Stated preference surveys are one of the most popular methods for determining a consumer's opinion on alternative fuel for vehicle transport. "In such an approach respondents are asked to express preferences for hypothetical products described in terms of their attributes. Statistical models are then applied to estimate the relative values of the attributes to consumers" (Bunch, et al., 1993: p.238). The benefit of using a stated preference survey is that it allows the construction of scenarios based on current or future vehicle technology. Such scenarios allow the researcher to find out what consumers would choose when given potential "real-life" decisions regarding vehicle attributes. They are better than standard binomial surveys because a respondent can give an opinion on one attribute in relation to the others available instead of a rating each attribute on its merits alone and the surveys could be tailored for individual respondents.

For example, Ewing and Sarigöllü (2000) created stated preference surveys for respondents with different fuel costs and a different range of vehicle attributes. Tompkins, et al., (1998) described current market conditions for alternative fuel vehicles in the participant's community as well as other technological information, such as purchasing incentives. "The disadvantage of this approach is that it is based solely on the stated intentions of survey respondents, and has not been adjusted to incorporate available information on actual market-based behavior" (Bunch, et al., 1992: 34).

2.2.1 Analysis Focus

Stated preference surveys are used to determine whether consumers would accept and purchase vehicles that use a cleaner fuel than current gasoline engines (Tompkins, et al., 1998; Brownstone, et al., 1999; Bunch, et al., 1992; Ewing and Sarigöllü, 2000; Bunch, et al., 1995; Segal, 1995; Golob, et al., 1991). The studies reviewed a wide-range of alternative fuels, such as electrical, ethanol, methanol, and natural gas, and compared them to the performance attributes of a conventional gasoline-powered internal combustion engine (ICE). Where it concerned electric vehicles, the studies examined true electric vehicles (EV) that ran on battery power, HEV that used a combination of electric and gasoline power, and PHEV that usually used the same engine as an HEV, but allowed the owner to recharge the battery through a cord that could be plugged into an electrical outlet.

Bunch, et al., (1995) took it one step farther and wanted to analyze the preferences of individuals and businesses with more than one vehicle. Most studies focused on the type of vehicle that consumers would buy as it relates to alternative fuel attributes (Tompkins, et al., 1998; Brownstone, et al., 1999; Bunch, et al., 1992; Ewing and Sarigöllü, 2000; Bunch, et al., 1995; Segal, 1995; Golob, et al., 1991). The reason vehicle type was the primary focus had to do with the fact that alternative fuel studies want to determine whether consumers would buy certain vehicles with alternative technology, not simply that they would be in favor of alternative technologies.

The studies focused on the most feasible methods of alternative fuel, such as electricity and ethanol. Tompkins, et al. (1998) looked at whether vehicles could be run on propane. A few studies tested whether it would be possible for vehicles to run on natural gas (Brownstone, et al., 1999; Bunch, et al., 1995; Segal, 1995).

2.2.2 Model Structure

Most studies use a multinomial model for data analysis. However, some studies preferred to use conjoint analysis (Segal, 1995) or the transactions model (Bunch, et al., 1995) when creating the survey or analyzing the data. In a conjoint analysis, researchers take data and break it down in order to understand which data attributes are the most important, such as the Segal study (1995) where he used conjoint analysis on various vehicle performance attributes, such as driving range when fully fueled, to determine how consumers might rank those attributes if they had to choose between them. Through the transactions model, researchers can "predict whether a vehicle transaction will occur during the current period and what type of transaction it will be" (Bunch, et al., 1995: 2).

2.2.3 Survey Methodology

In order to get a quality sample of participants, most studies start with a large population of at least 1,000. Tompkins, et al. (1998) and Brownstone, et al. (1999) had more than 4,000 participants for one section of their studies. Golob, et al. (1991) had less than 400, but still found that to be a highly effective sample for their study.

Stated preference surveys consist of a series of scenarios where the participant gets to chose various vehicles from a variety of performance attributes. The most popular form of participant collection is through random selection and surveys can be sent to the participant or conducted through the Internet. Telephone contact of participants is possible to obtain general information, but it is quite difficult for a stated preference survey because participants must see and analyze different options (Golob, et al., 1991). The researchers use the computer-assisted telephone interview (CATI) process, where researchers read a script off the computer, to gather preliminary information from the participant. Then they use that information to design the scenarios available in the actual stated preference survey. Some studies want more than vehicle preferences and ask participants to record their daily driving information to determine whether driving behavior would make alternative fuel vehicle adoption more likely (Brownstone, et al., 1999). Bunch, et al. (1995) and Segal (1995) used the data from their stated preference phase as a means of forecasting the future of alternative fuel vehicle acceptance.

2.2.4 Question Design

When it comes to stated preference survey design, most studies focus on giving participant selections based on fuel type and vehicle performance attributes. Some studies use the alternative fuel selection as the main criteria for the survey scenarios (Brownstone, et al., 1999). Other studies combine fuel type with vehicle type, such as small car or truck (Tompkins, et al., 1998). Bunch, et al., (1992) wanted to see which vehicle drivers, such as sports cars or pick-up trucks, would be most willing to adopt alternative fuel vehicles. Most studies use the alternative fuels as a means to creating a selection of vehicle performance attributes, such as driving range when fueled to the maximum or vehicle price, and then let participants chose from a variety of attributes (Golob, et al., 1991; Bunch, et al., 1992; Segal, 1995). Once the participants chose their particular vehicle attributes, the data is analyzed to determine if consumers would adopt a new technology in their transportation vehicles or, if they wouldn't, what improvements would need to be made to alternative fuel vehicles to give them a better chance of consumer acceptance.

The studies varied in terms of how many options the stated preference surveys gave to participants. Tompkins, et al. (1998) used 192 different options on selected choice cards. Bunch, et al. (1992) combined their attributes to produce 64 "design treatments" and 16 different versions of the survey. In their later survey, Bunch, et al. (1995) produced 14 different vehicle body types and sizes with five different fuel choices. Although, each participant received one set of choices and none of them received every possible choice combination.

Most studies analyzed performance attributes in regards to whether they made alternative fuel vehicles more or less attractive. The most common attributes were purchase price, range from maximum to minimum fuel, fuel cost and fuel availability. Studies found that when purchase price increased, interest in owning an alternative fuel vehicle decreased. The same result was found regarding fuel cost. Range and fuel availability had the opposite effect on alternative fuel interest. When the range between refueling increased or the alternative fuel could be purchased at a greater number of locations, alternative fuel interest increased. The more consumers lost performance attributes relative to conventional vehicles, the less attractive they found alternative fuel vehicles (Golob, et al., 1991; Ewing and Sarigöllü, 2000).

2.2.5 Response Rates

The response rates for the studies varied depending on the survey design. Most of the studies recorded a response rate of 60 percent or more (Tompkins, et al., 1998; Brownstone, et al., 1999; Bunch, et al., 1995). Not all studies were that successful. Bunch, et al. (1992) conducted a study with multiple "waves" where the response rate started at 40 percent and dropped to 20 for the third and final wave. Segal (1995) had a study were the response rate never rose above 30 percent.

2.2.6 Results

The studies had some interesting findings. Bunch, et al. (1992) found that consumers liked a vehicle that could run on more than one fuel. Tompkins, et al. (1998) found that the "prestige" of owning an alternative fuel vehicle made a higher purchase price more acceptable. Ewing and Sarigöllü (2000) looked at attributes in relation to age demographics and found that younger respondents were more interested in alternative fuel vehicles because they were the most concerned about environmental issues. Segal (1995) found that people that commuted daily, younger consumers, consumers with more than one vehicle, and consumers with more income had the most interest in purchasing an alternative fuel vehicle. Also, the study found a significant interest in alternative fuel vehicles in households earning less than $25,000 per year even though alternative fuel vehicles are projected to cost that much at the least. These results weren't uniquely American. In their study of consumer adoption in Canada, Ewing and Sarigöllü (2000) found that the gasoline vehicle was the least preferred one when compared to alternative fuels such as electric. But the study was limited in that it focused on environmental impacts, an area where gasoline-fueled vehicles fail miserably compared to alternative fuels.

Tompkins, et al. (1998), and in a limited way Bunch, et al., (1992), looked at consumer adoption in regards to final purchase price. They wanted to determine how much more consumers would be willing to pay for an alternative fuel vehicle with the same performance attributes as their current gasoline-fueled vehicle. For example, Bunch, et al., (1992) found that a one-cent per mile reduction in fuel cost equated to $1,400 reduction in purchase price. Tompkins' research team (1998) segregated the attributes to determine how much more consumers would be willing to spend on specific attributes, such as whether they would pay more for an alternative fueled vehicle in order to have more refueling or recharging stations. But the researchers derived these results from analyzing data and not direct questions.

Bunch, et al. (1992) found that electric vehicles weren't more attractive if the consumer could recharge at work. This result has been refuted in later studies that found people wanted the ability to recharge as often as possible (Brownstone, et al., 1999). Brownstone, et al. (1999) found that a participant's lack of knowledge regarding alternative fuel vehicles and their true levels of performance made results questionable.

Most studies concluded that there is a substantial interest in alternative fuel vehicles, if consumers don't lose the performance characteristics that they get in their conventional vehicles (Golob, et al., 1991; Ewing and Sarigöllü, 2000; Bunch, et al., 1992; Tompkins, et al., 1998). Then the studies come to different conclusions based on their design. Tompkins, et al., (1998) found that consumers would pay $1,660 for more electric recharging facilities. Brownstone, et al. (1999) found that electrical vehicles could eventually make up 20 percent of the U.S. automobile market. Bunch, et al., (1992) found that consumers were willing to pay more for an alternative fuel if they could get the same performance from their alternative vehicle as they did their conventional vehicle.

However, many studies suffered from fuel conclusions that have been discredited. Two studies stated that natural gas could be a good alternative fuel (Bunch, et al., 1995; Segal, 1995). Segal (1995) also found that young drivers were less attracted to electric vehicles than older drivers. In his study, Golob (1991) said that hybrid electric vehicles aren't a viable option when compared to dedicated electric vehicles. The HEV model Toyota Prius has been a popular vehicle for the last decade, while there is no dedicated electric vehicle available from a major automaker. Also, he found that recharging at work is not an added advantage while other studies have proven that the more places an owner can recharge a vehicle, the more popular electric vehicles could be (Tompkins, et al., 1998; Bunch, et al., 1992).

3 PHEV READINESS ASSESSMENT

In order to accurately assess current and future infrastructure needs, it is imperative that the electrical utility organizations and agencies know both how much PHEV load will be added to their infrastructures and the locations where that PHEV load will be added. For that, local utilities will need quantitative and geospatial insight into assessments of the PHEV Pool Market. The work described below is intended as a tool for this purpose. Specifically, we present a method of geospatially determining PHEV electricity demand for distribution planners. This may be one of only a few, if any, methods that will assist the assessment of PHEV Readiness at the community level.

3.1 Operational Definition of PHEV Readiness

The ability for motorists to refuel their personal vehicles at home with connection to an electric outlet is one of the touted advantages of PHEVs. Focusing on the present for a first assessment of PHEV infrastructure support directs consideration of detached housing units that are known to have the secure and convenient personal vehicle parking location of a garage. A survey conducted by the research team confirms that of the 267 sampled households residing in single detached houses with attached garages in the City of Madison, WI, 98.5% have access to 120 volts in their garages. Of the 43 sampled households residing in single detached houses with detached garages, 100% have access to 120 volts in their garages. Acknowledged are potential early or present PHEV adopters who have no access to home charging sources, yet know they can rely on electrical outlets at their employers' parking locations or their other activities' parking locations. Similarly acknowledged are potential PHEV adopters, who live in condominiums or apartment complexes, yet can still arrange vehicle charging connections. While such dwelling facilities may or may not, and moreover infrequently, have secure charging amenities, we are certain that most garages associated with detached homes do.

Based on earlier reasoning above, our analysis of PHEV readiness in the City of Madison, WI, is based on the assumption that all single detached houses with garages in the City of Madison, Wisconsin, have electric service in their garages for recharging. Differing from previous studies that used the Census data to identify the aggregate distribution of such housing units across census reporting units, we opt for the City's Property Tax Assessment data which provides housing information at the land parcel level. This allows us to pinpoint the exact locations of housing units that are PHEV ready or not.

3.2 Tax Assessment Data

In the United States, municipalities such as cities or counties maintain databases that contain information regarding myriad attributes of each and every land parcel. Each parcel of land is assessed for a monetary value according to the parcel's use and the quantities and qualities of attributes associated with improvements to the parcel. The predominant improvements to the land parcel are subsequently related to the structure(s) on it. The municipality levies a tax to each parcel according to the assessed total monetary value of it, and bills the owner of the property accordingly. Some parcels, that are themselves municipally owned or otherwise tax exempt, are assessed accordingly, but incur no tax levy. All such assessments and levies in the United States are public information, and subsequently, entire digital databases containing such information for all parcels are available for no to a nominal fee ($150, -2009 for the City of Madison, WI). The agency responsible for a municipality's tax assessment and levying is thus usually referred to as the assessor.

Each parcel in the tax assessment data is key-coded with a number and in more and more municipalities, each number is associated with standard Geographical Information System (GIS) coding with which the parcel's polygon can be displayed with appropriate computer software. An assessor or its database may not necessarily contain the GIS data. However, that data, if not available from the assessor will likely be available from a municipality's associated metropolitan planning organization (MPO), again for no to little fee. For geospatial display of assessment data, the assessor database and the GIS database may need to be merged.

3.3 Data for City of Madison

For our PHEV readiness analysis for Madison, WI, we acquired the tax assessment database from the City of Madison Assessor's Office. The database was provided in the format of multiple MS Excel tables. As such, one of our first steps in preparing the data for analysis is to link it to the Madison Area Transportation Planning Board's land parcel boundary data in ArcGIS format. Since the tax assessment data and the GIS data come from different custodians, it was not surprising that some discrepancies existed between the datasets and the joining of the two datasets by parcel ID was more than a straight forward task. According to the City of Madison Assessor's Office, work is underway in providing future assessment data in a geospatial database format.

The assessor's database contained data describing land parcels of four property classes: Residential, Commercial, Industrial and Agricultural. The Residential Class include land parcels with the Property Use codes of "Vacant", "Single Family", "Condominium", "2-Unit", "3-to-7 Unit" and "Other". Note that larger (eight or more units) apartment building parcels were not included in the residential class. Instead, those were included in the Commercial Class, which include Property Use codes such as "Apartments", "Apartments and Rooms" and "Rooming House".

The assessor's database did not explicitly attribute any electrical receptacle data to parking spots. The only variables related to any aspect of parking are garage type, number of garage stalls and shared-driveway. Further, only the parcels in the Residential Class had garage data available. Some residential units, such as condominiums and some apartments, were not attributed with any of those values. Garage Type was coded as "none", "detached", "attached" and "underground"[1] and was a key variable for our subsequent analysis. The other two garage-related variables were not used.

3.4 PHEV Readiness Analysis for City of Madison

Based on the operational definition of PHEV readiness developed in Section 3.1, we propose to designate a land parcel with the following properties as PHEV ready:

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[1] In Wisconsin, "carport", which is an attributed "other structure", occurs infrequently enough and the National Electric Code installation of electrical receptacles for such locations is restrictive enough to consider any carports as "none" for garage type.

Property Class = “Residential”
Property Use Code = “Single Family”
Garage Type = “Detached” or “Attached”

Of the 59,879 land parcels in the City of Madison Tax Assessment Data, 50,039 are classed as “Residential” (seven or fewer dwelling units on a physical land area). Of these residential parcels, 46,774 are occupied by single family houses. Figure 1 shows the spatial distribution of garage types among these single detached housing units. The proportions of single home with attached garage, single home with detached garage, single home with no garage, and non-single home parcels are 49.2%, 19.4%, 5.7%, and 25.7%, respectively. The first two groups of the four (coded in two shades of gray in Figure 1) correspond to what we refer to as PHEV ready residential units, which represent nearly 70% of all residential parcels. One can see that these PHEV ready parcels show up in distinct clusters which not only represent the market pool for PHEV early adoption, but also areas where utility agencies need to pay special attention. Notably interesting is also those parcels with single detached homes without garages. The spatial distribution of this varies from very few within single-home clusters to distinct micro-clusters of themselves (for example, to the southwest of Lake Mendota).

It must be emphasized that, since the garage type information is not available for condominiums and parcels with eight or more apartment units, these housing units were excluded from our PHEV readiness analysis. There are at least two good reasons for which one should analyze the current electrical receptacle availability or potential for future accommodation in these housing structures separately from the analysis of single detached homes. First, the decision making regarding parking and utility infrastructure is different between these two scenarios. For single detached homes, the decision is up to either the occupants or the landlord. For multi-unit housing structures, parking in these housing structures is usually limited and is provided through underground parking garages, parking ramps or street parking. The facilities are usually centrally administered by private or public property management entities who have different considerations from the occupants. Second, residents in high density housing structures are generally considered to use transit and non-vehicular modes of transportation more than occupants of single detached houses. As policy makers are looking to the private car users as the market pool to promote PHEV, it is of less public interest at the moment to enable (or encourage) the likely transit riders, cyclists, and pedestrians to make the shift to PHEV use. For the above two reasons, PHEV readiness among single detached homes is of higher priority.

3.5 Assessment of Grid Readiness

Charging PHEVs in household garages substantiates a notable change in household electricity use, which in turn impacts the temporal and spatial load distribution seen by utilities. For instance, charging a fully depleted PHEV-40 from a standard 120 volt outlet would be on the order of operating a small hair dryer or one-third of a central air conditioning unit (different voltages aside), non-stop for two hours every other day (assuming full depletion of the PHEV-40 is a result of 40 miles all-electric driving; 20 miles/day x 2 days) all year. This could potentially be the second largest energy load in the cooling months and, in the course of a year, perhaps the single largest energy load, at the household level.

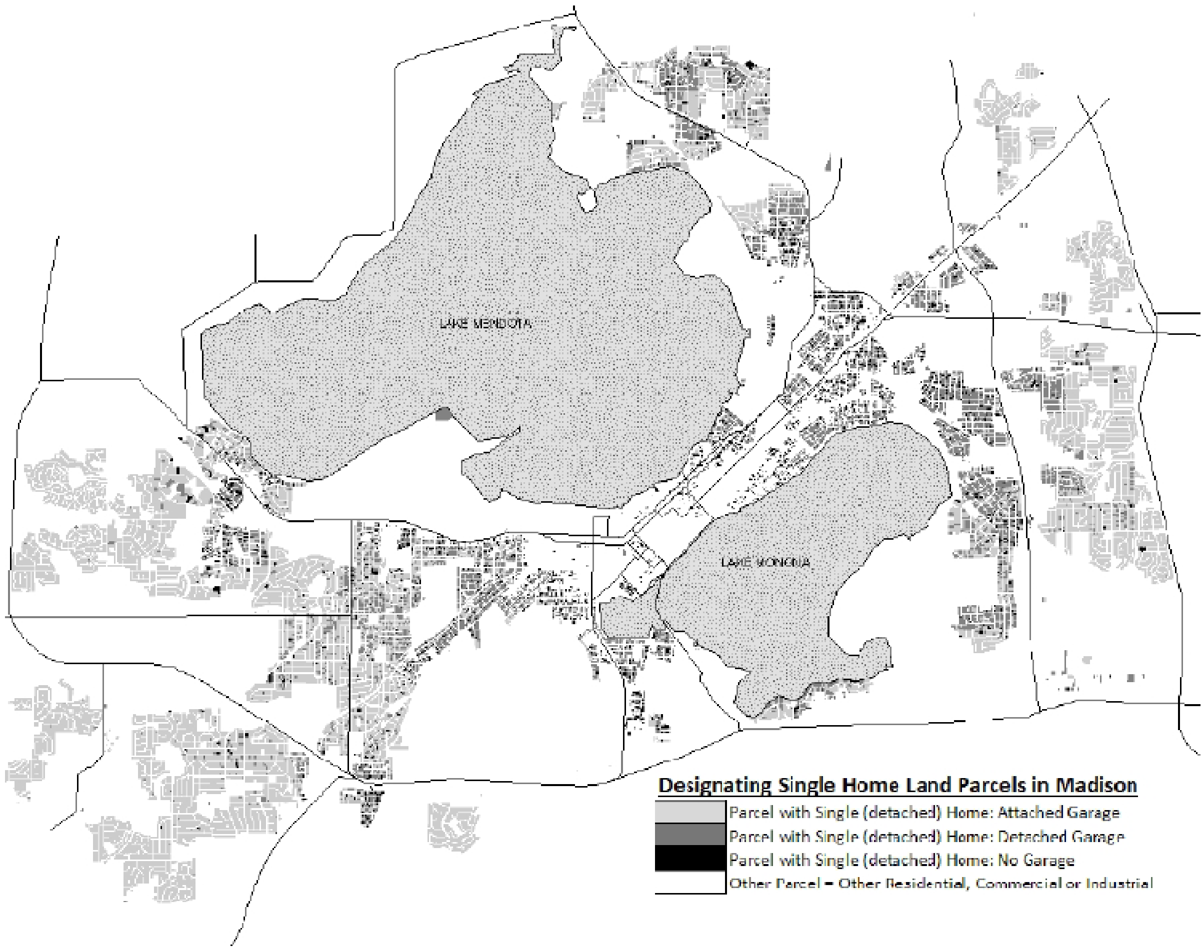


Figure 3-1. Distribution of single family residential units by garage type

Fundamentally all electrified homes, and subsequently their garages, are connected to electric power utilities, and the generators that serve them, through a network of transmission equipment and distribution lines. With the aforementioned substantial load of one household's PHEV in mind, the aggregate load of many households with PHEVs will merit study.

Following from out PHEV readiness analysis, we present a preliminary analysis performed to gauge the impact of adding significant PHEV load at the transformer level. According to a study performed by Duke Energy, the most significant impacts of PHEV market penetration will likely be due to geographic clustering of vehicles (1). Such demand clustering suggests the need for analyzing areas with high concentration of PHEV ready households.

Our grid impact analysis is based on data provided by Madison Gas & Electric (MG&E), the local utility serving the City of Madison, Wisconsin. MG&E provided a typical peak-day load curve for the daily consumption of eight customers fed from a single 50kVA transformer. The data obtained is an approximation based on the load curve for a primarily residential feeder within MG&E's service territory. This approximation was used because MG&E does not record hourly load data at the transformer level.

As a case study, a small neighborhood clustered with eight PHEV ready households in Madison who share a selected transformer is the focus for our grid impact analysis. The scenarios of one, two, three, …, and up to all eight of these households becoming owners of PHEV are examined. These households are assumed to charge their vehicle from a standard 120VAC 15A outlet available in their garage. Although these outlets are rated to provide power up to 1.44kW, preliminary studies on actual charging patterns from converted Hymotion Prius PHEVs show that the average power drawn by the vehicle when charging is approximately 0.77kW (Mohseni and Stevie, 2009).

Combining the transformer data and the vehicle data we were able to determine the energy impact of adding discrete PHEV load to the selected transformer. Given that the transformer is rated at 50kVA, and assuming an average residential power factor of 0.8, it is possible to determine how adding PHEV load will impact the percent loading of the transformer. Utilities may likely attempt to minimize PHEV contribution to peak load by implementing certain rate structures. These issues are discussed in more detail in Chapters 5 and 6. However, as a worst-case scenario, we can assume that customers will elect convenience over cost and charge their vehicles in the late afternoon. In this case, the additional loading coincides with the typical residential peak load. Figure 2 illustrates the impact of adding PHEVs to the selected 50kVA transformer assuming each adopter owns a single PHEV.

It should be noted that, prior to adding any PHEV load to the system, this selected transformer is already approaching its rated value. Recall that this is not the typical load seen by the transformer, but rather the load seen on a particularly warm day within the last five years. Thus in the worst case scenario, adding four PHEVs to this transformer does increase the percent loading to over 107% and adding eight PHEVs to this transformer increases the percent loading to nearly 115%. It may be concluded that it will be important for utility planners to understand when, where, and how much the PHEV load will add to the system in order to adequately plan maintenance, upgrades, and additions to the distribution system, or seek other measures to shift the peak load as discussed further in Chapters 5 and 6.

3.6 Discussion

This chapter described an analysis of PHEV readiness at the community level using parcel level, Tax Assessment data for the City of Madison, WI. Nearly 70% of all residential parcels in Madison are found to be PHEV ready. That is, these parcels are occupied by single detached homes with either attached or detached garages. Based on results on the readiness analysis, a scenario analysis of electrical grid impact due to varying levels of PHEV adoption is also described. Both analyses serve to demonstrate the benefits and the need for parcel-level analysis to support utility planning and PHEV market promotion at a refined geographic scale. Compared to past studies of PHEV readiness that typically utilize aggregate data provided for census geographies, our parcel-level analysis provides much higher spatial accuracy regarding where the PHEV-ready households are. Our analysis also allow electrical utility organizations and agencies to analyze their distribution network under scenarios of maximum near-term PHEV load.

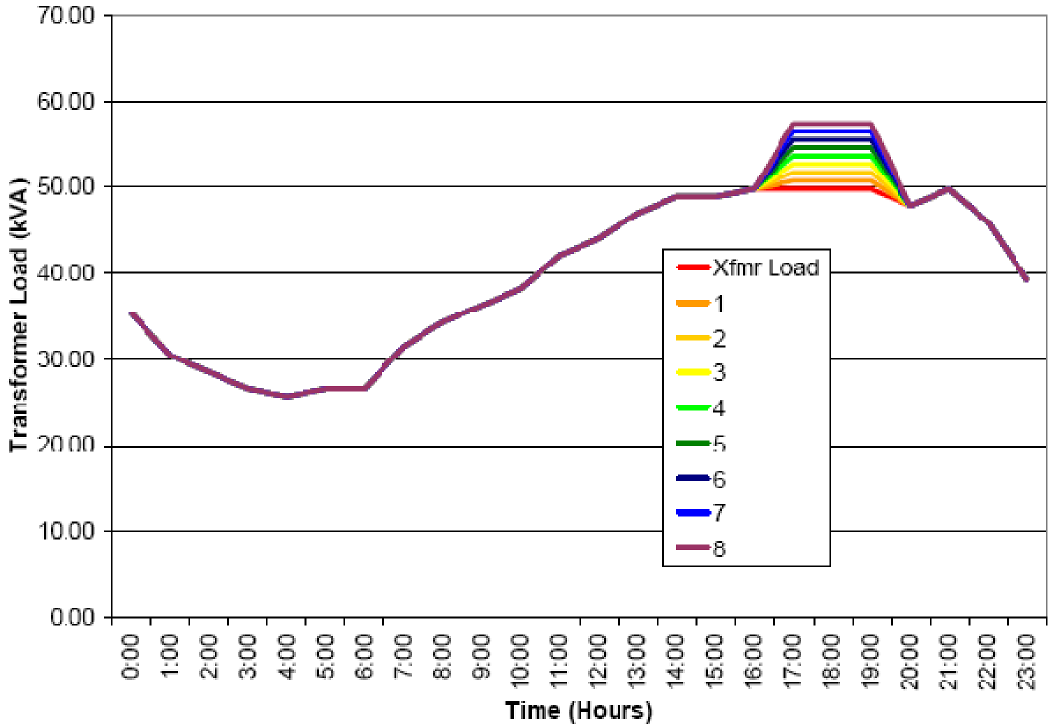


Figure 3-2. Worst-case transformer load profiles for the base and the eight levels of PHEV adoption scenarios

Obviously, the tax assessment database is still not ideal for a comprehensive PHEV readiness analysis of all housing stock and commercial recharging opportunities. The analysis presented in this paper was limited to that of the single detached homes and its accuracy depends on the assumptions made along the way (for example, having either an attached or detached garage is equated to having recharging capability). Our analysis should also not be mistaken as a PHEV market analysis. Recharging capability (at home or elsewhere) is a necessary but not a sufficient condition for early PHEV adoption. In fact, the likelihood of a household becoming an early adopter depends on a suite of factors ranging from infrastructure availability, charging methods, vehicle and fueling costs, vehicle performance characteristics, to household's income, life style, and attitudes towards environmental issues. Future studies are needed to better understand the relationship between PHEV preference and PHEV readiness, between the true market and the potential market pool.

In the long run, the possibility for recharging PHEV at commercial sites or public stations will not only change market behavior but also load distribution across the utility network. This aspect of PHEV is not covered herein, but to do so in the future would require an analysis of commercial/industrial geographic areas where such opportunities are more likely to be installed. It is hoped that our work presented here would assist with those expanded efforts.

Additionally, agencies that wish to adopt policies encouraging denser built environments with goals of fewer road miles may reveal a contradiction with PHEV home charging. If single unit personal garages remain the universal primary charging locations, the inclusion of those garages will use more land. Further, residents who choose to live in denser urban environments may be served well by PHEV if they must own personal vehicles, yet may not have adequate access to PHEV charging opportunities. It is anticipated that our geospatial approach would be extended to assist in these future assessments.

4 CONSUMER PREFERENCE ANALYSIS

4.1 Survey Design

The data used in the consumer preference analysis was collected through a survey carried out in Madison, Wisconsin in 2009. The initial household sample of 1500 was randomly selected from 12 zip code zones covering urbanized area of Greater Madison. The households' telephone numbers and addresses were purchased from a proprietary provider.

The survey was designed as a computer-aided telephone interview (CATI). Each telephone number was contacted a maximum of three times. During each call, there were three possible outcomes. First, a member of the household answered the phone and accepted the request to participate in the survey. Second, a member of the household answered the phone and rejected the request. Third, the call went unanswered. If the household member participated in and completed the survey, they were included in the survey sample. If they rejected the request, they were eliminated from the sample. If the call went unanswered, the phone number was called a second and possibly third time. After the third unanswered call, the phone number was removed from the sample.

As shown in Appendix B, the survey instrument started with an introduction that introduced the caller, identified the reason for the call, and then asked respondents if they would be willing to participate in Phase 1 of the study. If they accepted the request, the participants were asked 20 questions, starting with three questions concerning the number and type of vehicles owned by the participants and concluded with a question that asked the participants if they planned to purchase a new vehicle in the next five years. If they did intend to make that purchase, they were asked seven additional questions regarding the type of vehicle they wished to purchase, the price of that vehicle, and whether they had the desire and infrastructure to support an alternative fuel vehicle as that next purchase.

Regardless of whether the participants planned to purchase a new vehicle in the next five years, all participants were asked nine basic demographic questions to ensure that the survey provided an adequate representation of Madison residents. The questions in this section asked participants about their age, education, household income, number of people in the household, number of licensed drivers in the household, and the type of housing where they reside.

Then the telephone calls concluded with thanking for participants for their time.

4.2 Survey Deployment

A group of students from the University of Wisconsin were hired and trained for the survey. The interviewers were trained on basic telephone etiquette, use of CATI, and interview techniques.

The telephone calls were made between the hours of 5 p.m. and 9 p.m. from Monday through Friday. On Saturday and Sunday, the telephone calls were made between the hours of 11 a.m. and 9 p.m. The study designers took special care to guarantee that no calls were made after 9 p.m. In special instances, callers asked permission to continue a telephone survey if the survey started before 9 p.m. but continued past that time of day.

4.3 Analysis and Results

From the 1,500 telephone numbers in the sample population, 497 households answered and completed our study. SPSS was used to analyze the 497 valid responses. The findings are summarized below.

4.3.1 Parking facility and electricity access by housing type

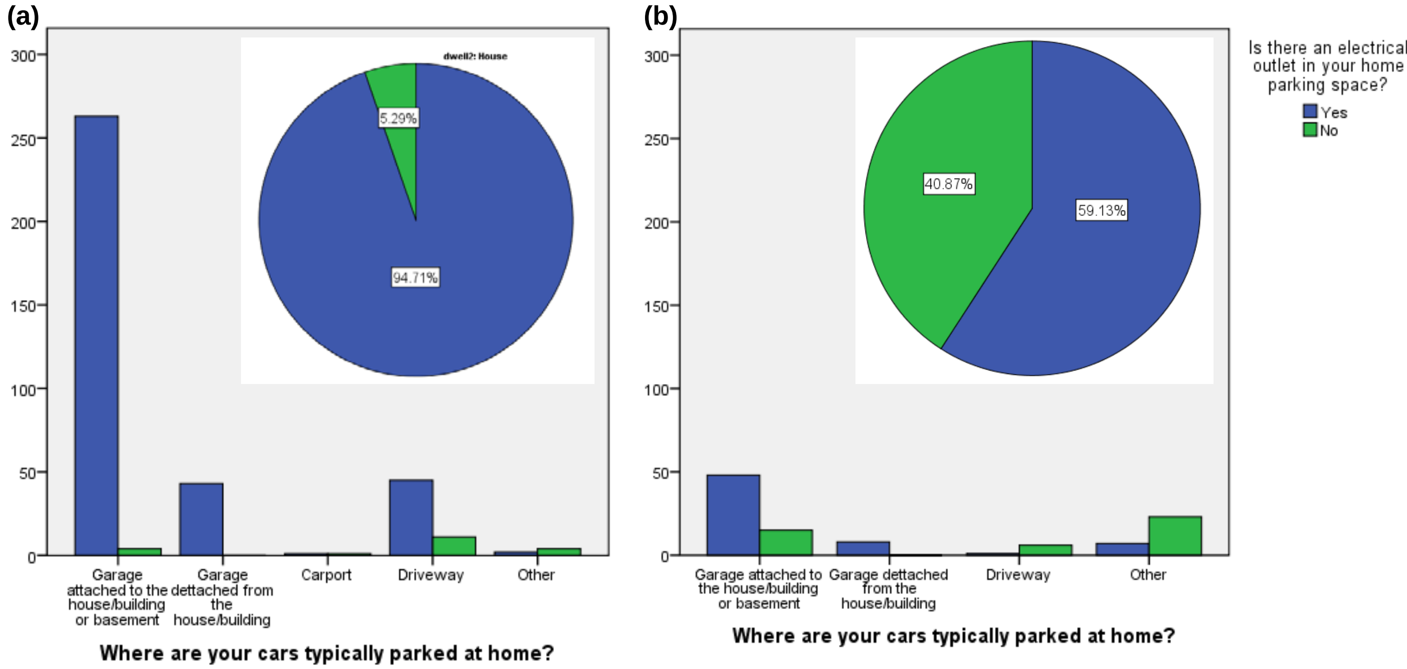


Figure 4-1. Question and response summary on parking facility among (a) single detached houses (77.6%) and (b) apartments, condos, townhouses and other housing (22.4%).

4.3.2 Current Vehicle Holding

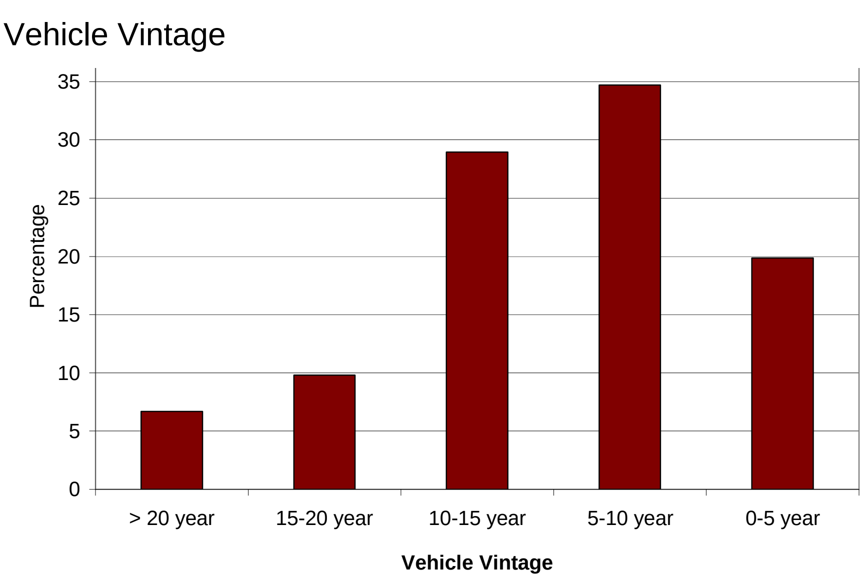
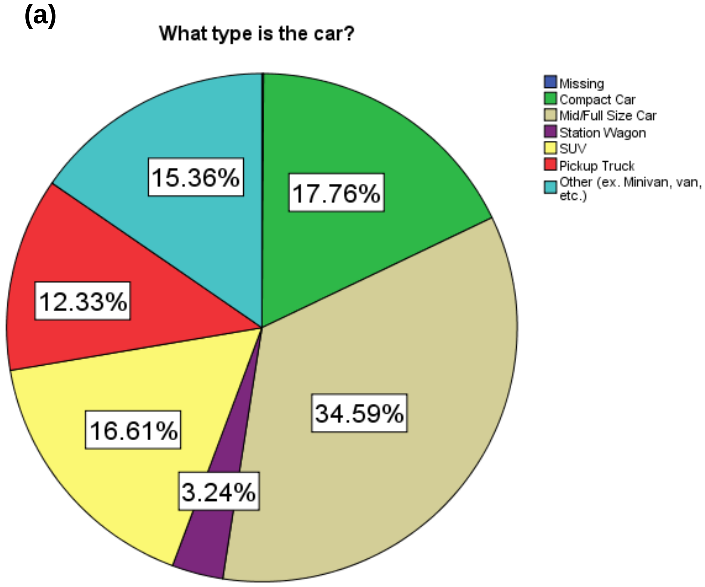


Figure 4-2. Response summary on vehicle ownership vintage

Vehicle Type

(a)



(b)

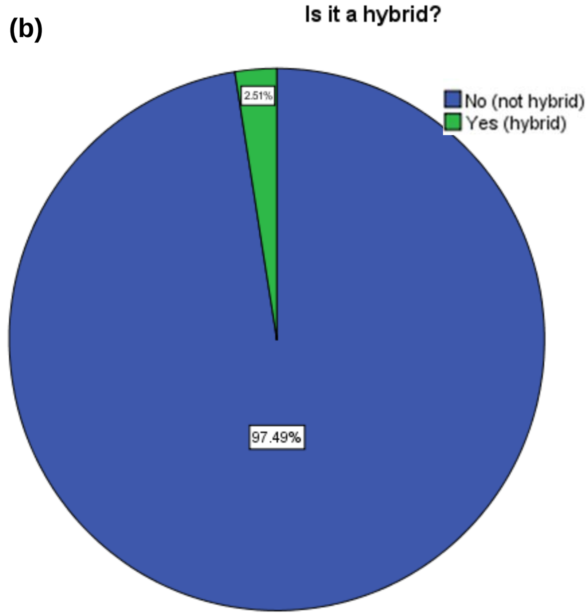


Figure 4-3. Question and response summary on (a) type of vehicle and (b) whether the vehicle is a hybrid.

Vehicle Vintage by Type

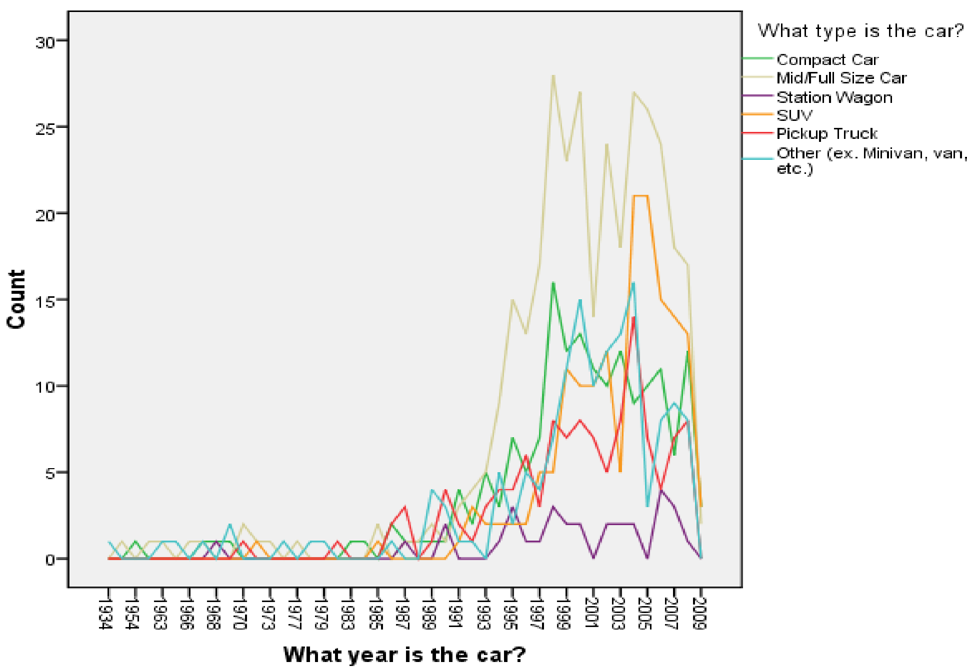


Figure 4-4. Question and response summary on type of car

4.3.3 Future Vehicle Purchase

Purchase Interest

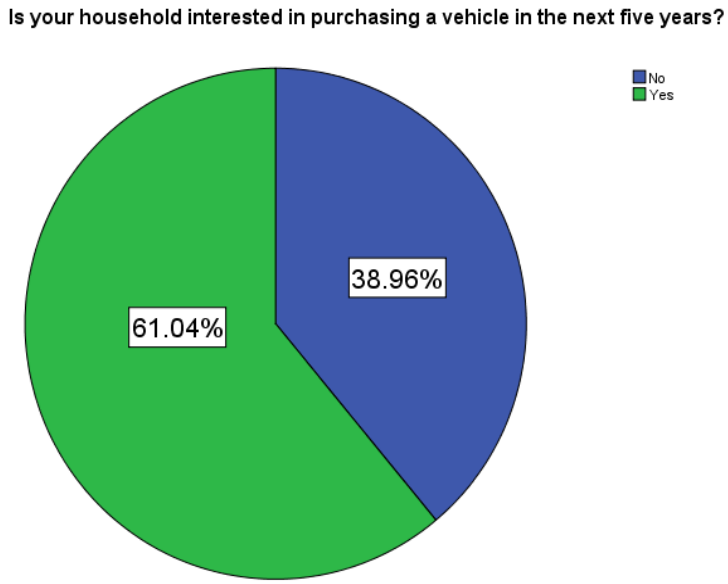


Figure 4-5. Question and response summary on vehicle purchase plans

This translates to approximately 87,000 households considering purchasing a vehicle within the next five years.

Purchase Timeframe

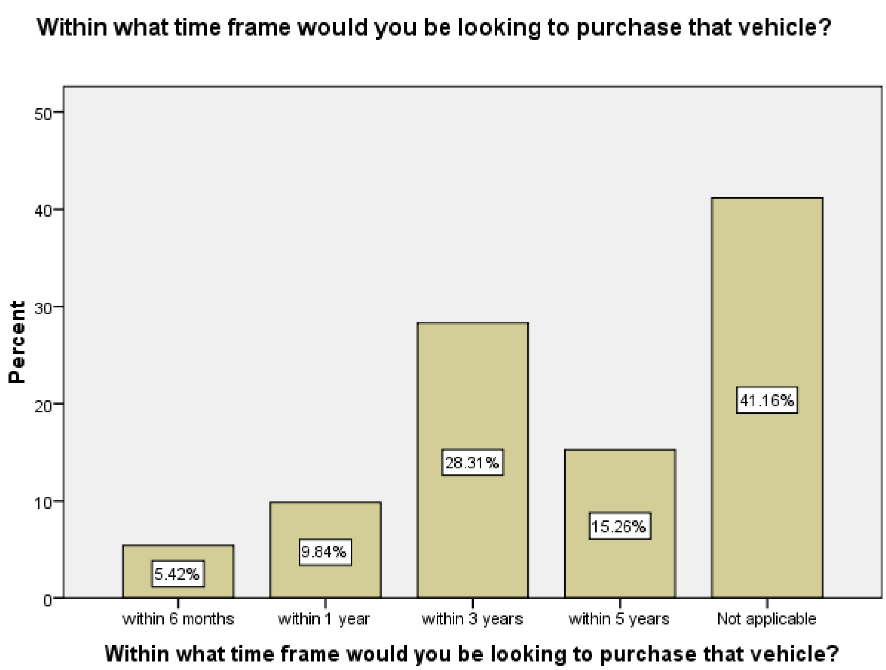


Figure 4-6. Question and response summary on vehicle purchase timeframe

Purchase Reason

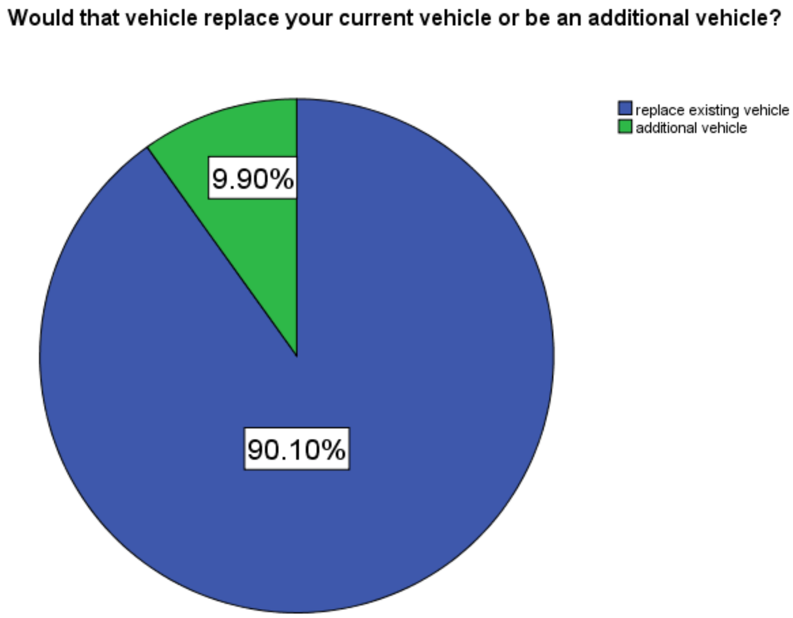


Figure 4-7. Question and response summary on vehicle replacement/addition case

Type of Purchase

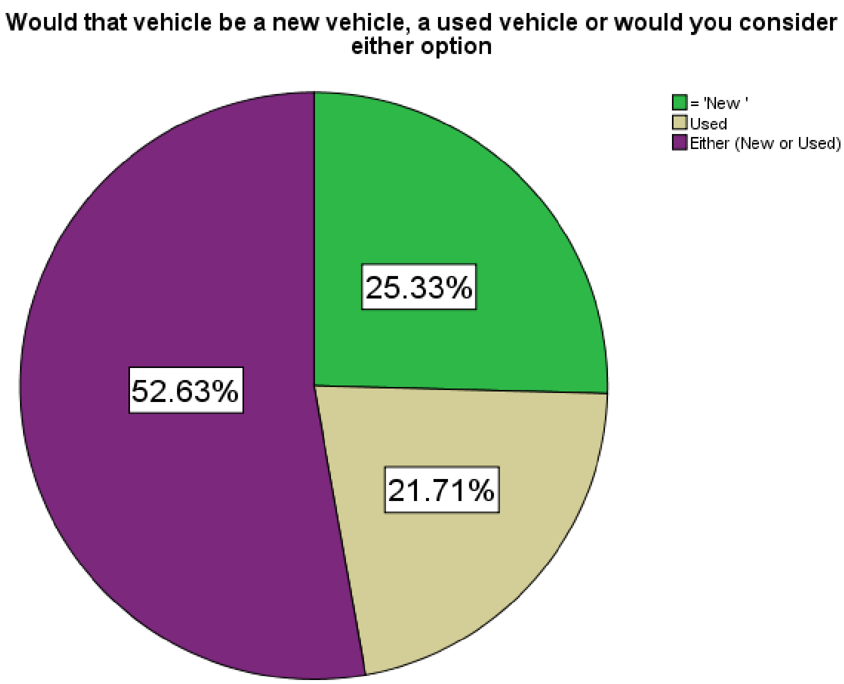


Figure 4-8. Question and response summary on vehicle purchase option (new/used)

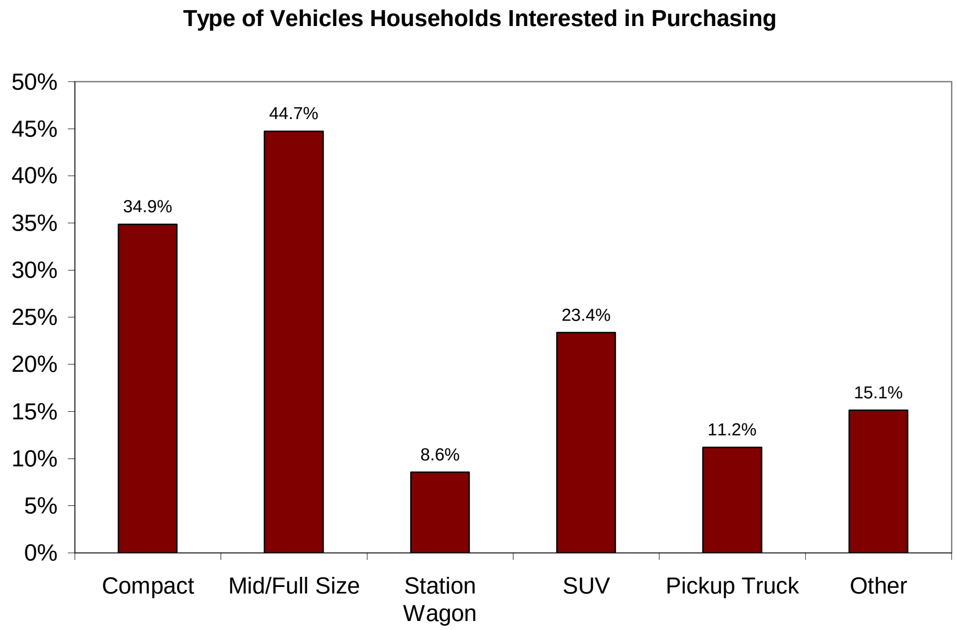


Figure 4-9. Response summary on vehicle purchase type

Price Range

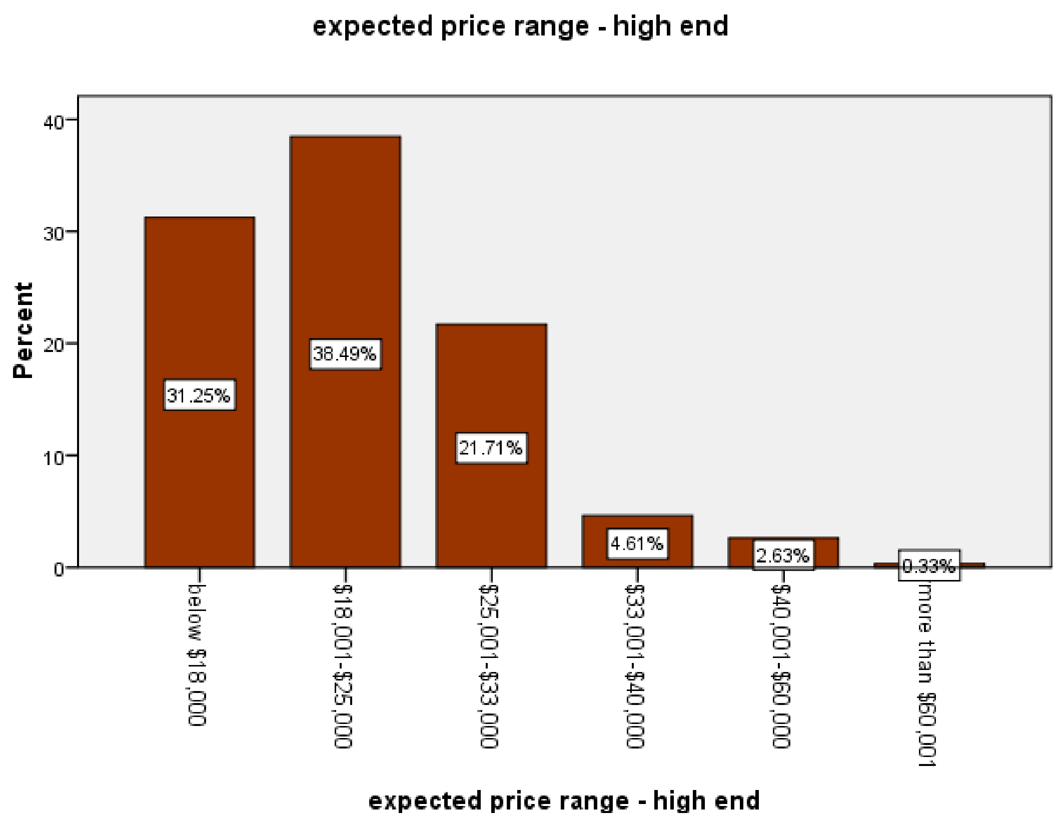


Figure 4-10. Question and response summary on vehicle purchase price

70% of the respondents are not willing to spend over $25K. Given the current expected price of PHEV, this leaves us with only 30% of the buying market; not all 30% would be willing to consider non-ICE vehicles.

PHEV Possibility

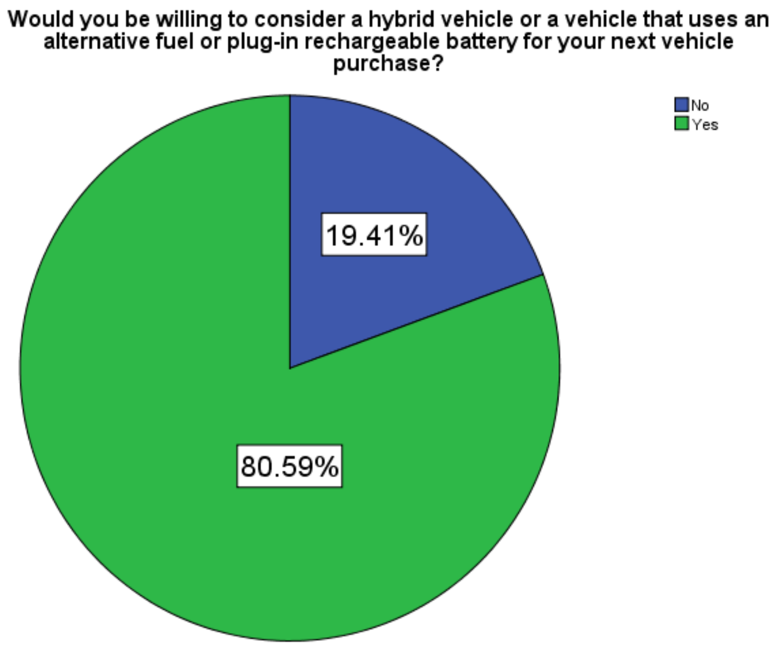


Figure 4-11. Question and response summary on PHEV purchase

For those households who are not willing to consider PHEV purchase, their reasons included:

“Believe there is plenty of oil and gas”; “It is impossible to drive it long enough to make up for the extra cost in price and global warming is a total hoax”; “Prefers conventional vehicles, not concerned about mileage”

“I like to travel, don't think on the road there will be enough places to stop to fill up or recharge the vehicle”

“Not at my age, its too much to learn”; “Lack of knowledge about technology”

“I don't believe in hybrid vehicles.”; “Don’t think tech is there yet”; “don’t believe they are trustworthy”; “Not enough mechanics to fix hybrids”

“I don’t think they are going to be in my price range ($18,000)”; “Too expensive”; “maintenance cost”; “battery cost”

“Not enough speed at this point with those vehicles”; “Not capable of being used for work, to pull things”; “hybrid doesn't have enough power”; “won't be available for the type he wants”

“I'm very happy with what we have now, and it takes a lot for me to change.”

“College kid could not use”

“Don't want to deal with replacing batteries”

4.3.4 Factors correlating with PHEV Market

Current Vehicle Holding

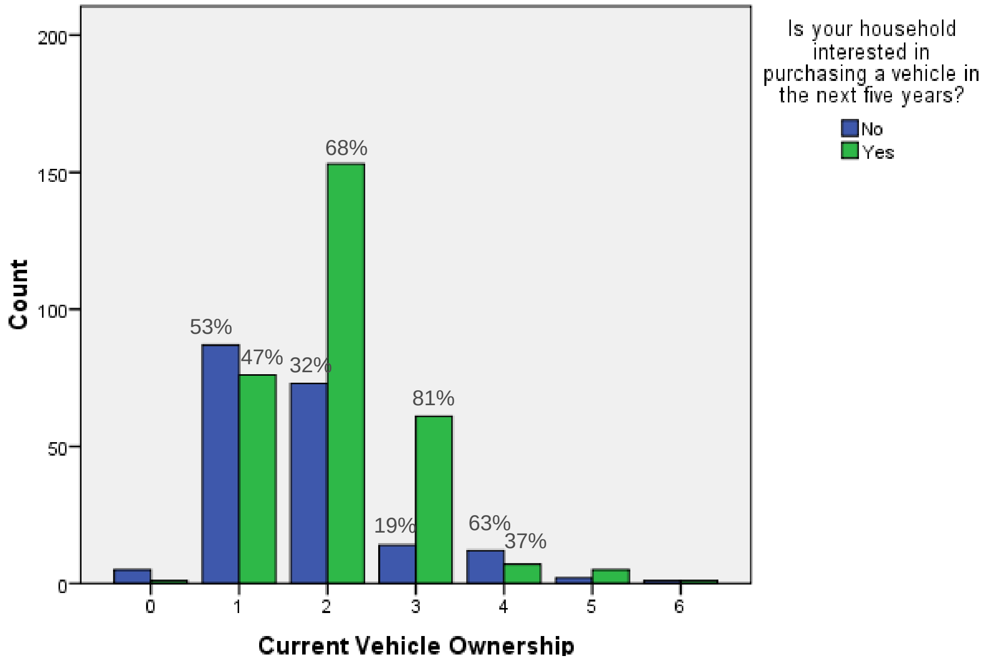


Figure 4-12. Correlation of PHEV market with current vehicle ownership number

Purchase Timeframe

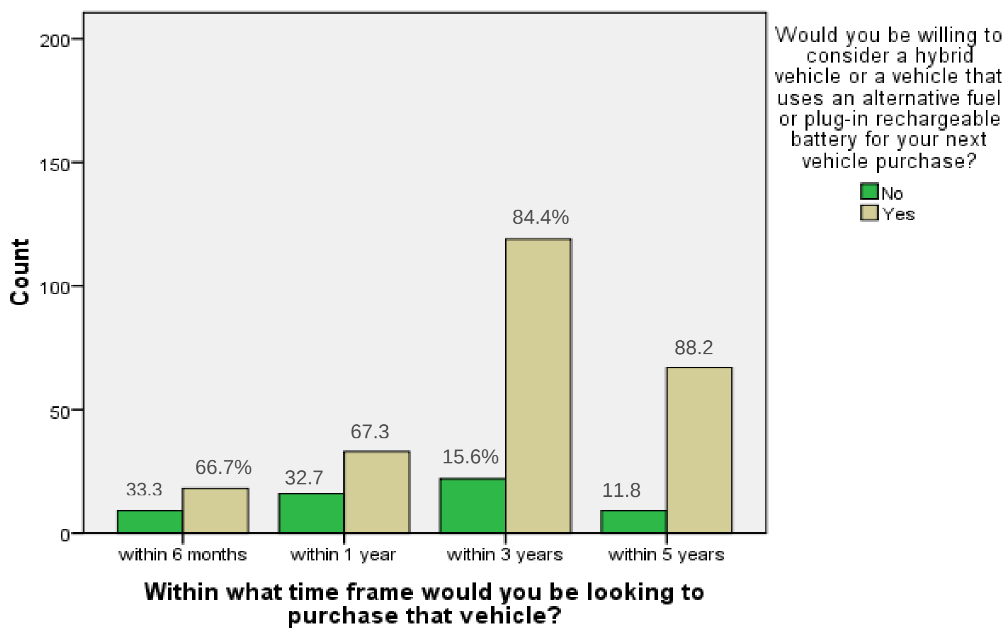


Figure 4-13. Question and response summary on PHEV purchase timeframe

Budget Range

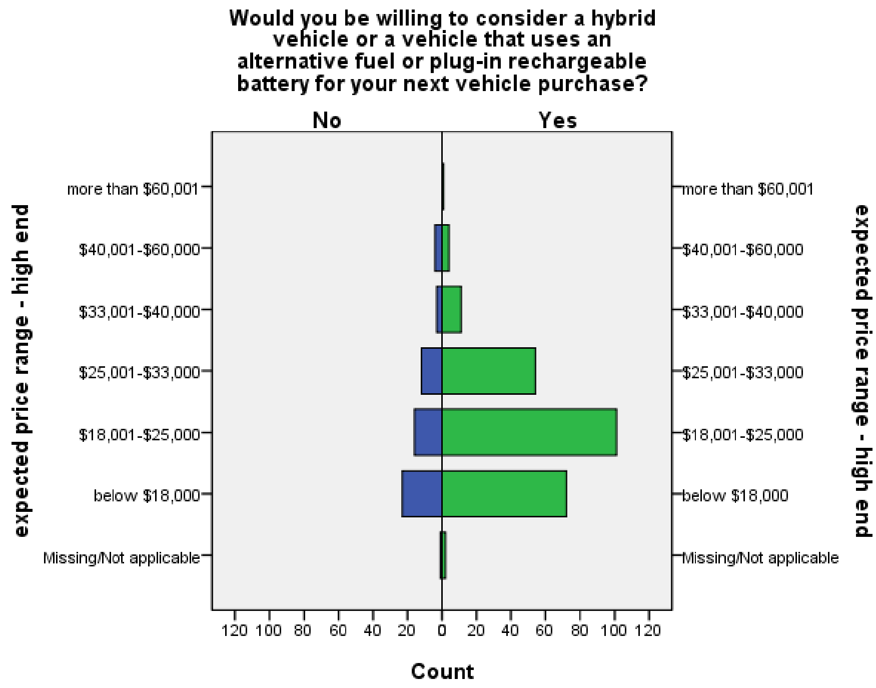


Figure 4-14. Question and response summary on PHEV purchase budget

Income

Households' income does **not** appear to influence willingness to purchase alternative fuel vehicles.

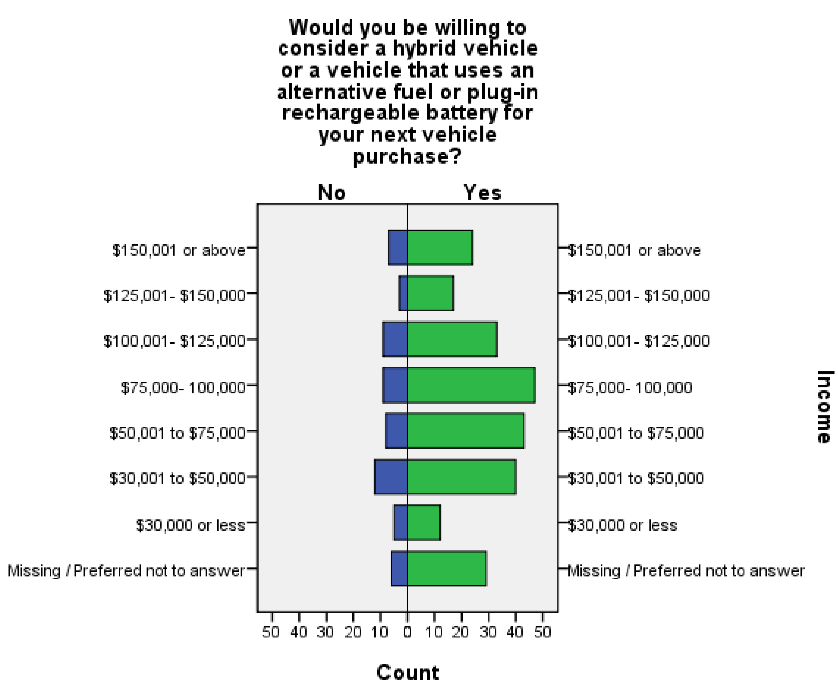


Figure 4-15. Question and response summary on PHEV purchase correlated with income

4.4 Conclusion

Out of the 61% respondents that are interested in purchasing a vehicle in the next five years, 80.59% are willing to consider purchasing an alternative vehicle. This equates to 49% of the sample being willing to consider purchasing an alternative vehicle in the next five years. Applying this proportion to the population gives an estimated 70,000 households as the PHEV willing households in the Madison area in the five-year timeframe. However, when one considers the expected price of PHEVs in the range of $30,000 and upwards including subsidies, this translates to about 21,000 households that are able and willing to purchase PHEVs in the next five years. This would represent an annual increase of about 4.3% of the residential electrical utility customer base of the Madison Gas and Electric. The present level of survey data does not definitively develop the geospatial location of the households where this growth would occur, particularly in light of sharing confidential consumer information of the survey respondents for correlation with Madison Gas Electric's customer information database. Thus more detailed studies on the resulting impact of the near term PHEV adoption potential by 4.3% of households connected to the distribution grid becomes highly speculative. On the other hand, PHEV readiness analysis and worst case transformer loading studies results presented in Chapter 3 indicates that the impact of PHEVs that call for concern tend to occur in rare occasions at rare locations. Therefore, in light of such uncertainties, it would rather be effective to focus on creative solutions that avert such rare events as opposed to developing guidelines or roadmaps for additional infrastructure investments in the distribution network. Preliminary investigations indicate that existing demand side management approaches may be effectively tailored for this purpose, as discussed further in the following chapters.

5 CONCLUSIONS

5.1 Project summary

This study focuses on assessing the demand for PHEV in Wisconsin and provides near term recommendations to manage its impacts on the State's electric grid.

PHEVs are expected to provide a range of about 40 miles per drive cycle using plug-in recharging from the electric grid, in addition to the virtually unlimited range offered by conventional and hybrid vehicles. Given the concern over global warming and the need for reducing America's dependence on foreign oil, PHEV are among the emerging 'green' alternatives to conventional fossil-fuel vehicles. Although they are recognized to have the potential to play a key role in climate change and energy security strategies, projected levels of market adoption, charging patterns, and impacts on electricity market and infrastructure supply are uncertain.

To date, most PHEV-related analysis has focused on technology assessment, lifecycle analysis, battery R&D, and vehicle modeling. Also, a number of recent studies explored the environmental consequences of shifting transportation energy use from conventional fuels to electricity through wide deployment of PHEVs and showed promising GHG impacts and air quality benefits at the national and global levels. Yet, much uncertainty remains regarding the infrastructure and economic impacts of PHEVs at the local level.

This study has two main objectives:

- Enhance the understanding of consumers' perception of and demand for PHEVs, thereby informing policy development for wider PHEV deployment.
- Assess the market potential of PHEVs in Wisconsin and estimate the associated vehicle charging patterns, electricity consumption, and infrastructure needs.

In view of the time frame for the study, our analyses were limited to the Greater Madison area. As such, the project serves as a demonstration of research methodology as well as a preliminary study for future expansion to analyzing the PHEV impacts to the entire state of Wisconsin.

The objectives outlined above have been accomplished through three major research components: infrastructure readiness assessment, consumer preference analysis and grid impact recommendations.

5.2 Project Findings

5.2.1 Infrastructure readiness

A PHEV readiness analysis at the community level using parcel level has been completed using Tax Assessment data for the City of Madison, WI. Nearly 70% of all residential parcels in Madison are found to be PHEV ready. That is, these parcels are occupied by single detached homes with either attached or detached garages. Based on results on the readiness analysis, a scenario analysis of electrical grid impact due to varying levels of PHEV adoption is also described. Compared to past studies of PHEV readiness that typically utilize aggregate data provided for census geographies, our parcel-level analysis provides much higher spatial accuracy regarding where the PHEV-ready households are. Both analyses serve to demonstrate the benefits and the need for parcel-level analysis to support utility planning and PHEV market promotion at a refined geographic scale. The methods allow electrical utilities to analyze their distribution network under scenarios of maximum near-term PHEV load.

However, recharging capability (at home or elsewhere) being a necessary but not a sufficient condition for early PHEV adoption, the likelihood of a household becoming an early adopter depends on a suite of factors ranging from infrastructure availability, charging methods, vehicle and fueling costs, vehicle performance characteristics, to household's income, life style, and attitudes towards environmental issues. Future studies are needed to better understand the relationship between PHEV preference and PHEV readiness, between the true market and the potential market pool.

In the long run, the possibility for recharging PHEV at commercial sites or public stations will not only change market behavior but also load distribution across the utility network. This aspect of PHEV is not covered herein, but to do so in the future would require an analysis of commercial/industrial geographic areas where such opportunities are more likely to be installed. It is hoped that our work presented here would assist with those expanded efforts.

Additionally, agencies that wish to adopt policies encouraging denser built environments with goals of fewer road miles may reveal a contradiction with PHEV home charging. If single unit personal garages remain the universal primary charging locations, the inclusion of those garages will use more land. Further, residents who choose to live in denser urban environments may be served well by PHEV if they must own personal vehicles, yet may not have adequate access to PHEV charging opportunities. It is anticipated that our geospatial approach would be extended to assist in these future assessments.

5.2.2 Consumer Preference

An in-depth consumer survey was conducted among consumers in the Madison area using a specifically designed survey instrument to study the impact of consumer preference on PHEV adoption.

Out of the 61% respondents that are interested in purchasing a vehicle in the next five years, 80.59% are willing to consider purchasing an alternative vehicle. This equates to 49% of the sample being willing to consider purchasing an alternative vehicle in the next five years. Applying this proportion to the population gives an estimated 70,000 households as the PHEV willing households in the Madison area in the five-year timeframe.

However, when one considers the expected price of PHEVs in the range of $30,000 and upwards including subsidies, this translates into an *upper bound* of about 21,000 households that are able *and* willing to purchase PHEVs in the next five years. This would represent an annual increase of about 4.3% of the residential electrical utility customer base of the Madison Gas and Electric. The present level of survey data does not definitively develop the geospatial locations of the households where this growth would occur, particularly in light of the inability in sharing confidential consumer information of the survey respondents for correlation with Madison Gas Electric's customer information database. Thus any extrapolation on the resulting specific grid impact of the near term PHEV adoption by households connected to the distribution grid becomes highly speculative. On the other hand, infrastructure readiness analysis and worst-case transformer loading study results indicates that critical aspects of PHEV adoption that lead to circuit overloading tends to occur in rare occasions at rare locations. Therefore, in light of such uncertainties, it would rather be effective to focus on creative solutions that avert such rare events as opposed to developing guidelines or roadmaps for additional infrastructure investments in the distribution network. Preliminary investigations indicate that existing demand side management approaches may be effectively tailored for this purpose.

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SURVEY INSTRUMENT

1. Interviewer Last Name

2. List participant name and address. Copy address to QUESTION 27

ID:

Title:

Name:

Address:

Hello, I would like to speak with _______ (Title) ____________________________ (Name)

(A) (If Female prefers different title (Ex. Mrs. vs Ms.) go back to question 2 and update)

(B) (If Title=Mr. and Female answers phone) Oh, I'm sorry. Is this Mrs. ______?

(C) (If Title= Mrs. and Male answers phone) Oh, I'm sorry. Is this Mr. ______?

(D) (If Child answers) Is ________ (title) ________________________ (name) available?

(If Respondent answers "NO"): Thank you for your time. Have a great night/day. (END CALL)

(If Respondent says "YES" to any of the above, proceed)

(Title and Respondent name) ________, my name is ______________. I'm a student at the University of Wisconsin and I am conducting research for my university on the potential market for the next generation of automobiles.

If you have a few minutes, we would like to ask you some basic questions about your household and vehicle preferences. As part of the university's strict privacy policy, I can assure you that your information would not be disclosed to any other party.
Is this a convenient time for you to help with our study?

(If Respondant answers "NO"): Thank you for your time. Have a great night. (END CALL)

(If YES, proceed)

Great, I will continue with the survey now.

3. How many motor vehicles in working condition does your household have available for use? This would include cars, minivans, trucks and SUVs.

4. (If only one car) What type and what year is the car? And it is a hybrid? (If multiple cars) What type and what year are the cars? Any of them a hybrid car?

If participants want an explanation of Compact, state that a Compact car has an interior volume of less than 110 cubic feet. An example of a Compact would be a Honda Civic and Ford Focus.

	Compact Car	Mid/Full Size Car	Station Wagon	SUV	Pickup Truck	Other (ex. Minivan, van, etc.)
Vehicle #1	◯	◯	◯	◯	◯	◯
Vehicle #2	◯	◯	◯	◯	◯	◯
Vehicle #3	◯	◯	◯	◯	◯	◯
Vehicle #4	◯	◯	◯	◯	◯	◯
Vehicle #5	◯	◯	◯	◯	◯	◯
Vehicle #6	◯	◯	◯	◯	◯	◯
Vehicle #7	◯	◯	◯	◯	◯	◯
Vehicle #8	◯	◯	◯	◯	◯	◯

5. (This is part of Q4. Enter vehicle year and any supplementary information here)

	Year	Hybrid? (enter 'x' if yes)	Supplementary Note
Vehicle #1			
Vehicle #2			
Vehicle #3			
Vehicle #4			
Vehicle #5			
Vehicle #6			
Vehicle #7			
Vehicle #8			

6. Is your household interested in purchasing a vehicle in the next five years?

◯ Yes

◯ No (If NO, proceed to question 13)

7. Within what time frame would you be looking to purchase that vehicle?

◯ 6 months

◯ 1 year

◯ 2-3 years

◯ 4-5 years

◯ Other (list range)

8. Would that vehicle replace your current vehicle or be an additional vehicle?

- ○ Replace
- ○ Additional

9. Would that vehicle be a new vehicle, a used vehicle or would you consider either option?

- ○ New
- ○ Used
- ○ Either Option (New or Used)

10. From the following selection, what type of vehicle would you consider buying? Feel free to include more than one vehicle type in your answer

Again, If participants want an explanation of Compact, state that a Compact car has an interior volume of less than 110 cubit feet. An example of a Compact would be a Honda Civic and Ford Focus.

- ☐ Compact Car
- ☐ Mid/Full Size Car
- ☐ Station Wagon
- ☐ SUV
- ☐ Pickup Truck
- ☐ Other (ex. Minivan, van, etc.)

11. What is the expected price range for your next vehicle purchase? Again, please feel free to include more than one price range in your answer.

These figures outline common price ranges for various types of vehicles

- ☐ Below $18,000
- ☐ $18,001-$25,000
- ☐ $25,001-$33,000
- ☐ $33,001-$40,000
- ☐ $40,001-$60,000
- ☐ more than $60,001

12. Would you be willing to consider a hybrid vehicle or a vehicle that uses an alternative fuel or plug-in rechargeable battery for your next vehicle purchase? (If NO, ask why not)

- ○ Yes
- ○ No - reason:

13. Where are your cars typically parked at home?

- ○ Garage attached to the house/building
- ○ Garage dettached from the house/building
- ○ Carport
- ○ Driveway
- ○ On-street
- ○ Other, please specify

14. Is there an electrical outlet in your home parking space?
Parking space refers to the response to the previous question

- ◯ Yes
- ◯ No

In order for us to make sure this survey represents all residents in the Madison area, I need to ask you some questions about you and your household.

15. This might sound obvious, but what is your gender?

- ◯ Male
- ◯ Female

16. What is your age? Are you between...?

- ◯ 18-25
- ◯ 26-35
- ◯ 36-45
- ◯ 46-55
- ◯ Over 55

17. What is the highest grade or year of school that you have completed?

- ◯ High School or less
- ◯ High School Diploma and GED
- ◯ Some College, Trade, or Vocational School
- ◯ College Graduate
- ◯ Graduate Work beyond College Degree
- ◯ Master's Degree
- ◯ Doctorate

18. Which of the following ranges would include your total taxable income for your household, when you consider the income of all employed individuals? Was it above or below $75,000?
Taxable income would be all wages, salaries and income from investments earned last year.

- ◯ Below $75,000 (Go to Question 19)
- ◯ Above $75,000 (Go to Question 20)
- ◯ Preferred not to answer

19. Please stop me when I state the range that best describes your household's total annual income...**
If respondent seems hesitant to answer, offer the last choice

- ◯ $30,000 or less
- ◯ $30,001 to $50,000
- ◯ $50,001 to $75,000
- ◯ Preferred not to answer

20. Please stop me when I state the range that best describes your household's total annual income...

If respondent seems hesitant to answer, offer the last choice

- ○ $75,000- 100,000
- ○ $100,001- $125,000
- ○ $125,001- $150,000
- ○ $150,001 or above
- ○ Preferred not to answer

21. How many people live in your household currently?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ more than 4, please specify

22. Are you a licensed driver?

- ○ Yes
- ○ No

23. How many of the other people in your household are licensed to drive?

(Enter number below:)

24. From the following choices, which would best fit your current dwelling?

- ○ Apartment/ Duplex
- ○ Condominium
- ○ House
- ○ Other, please specify

25. Do you own your home or are you renting?

- ○ Own
- ○ Rent

That completes the first phase of our research.

(Title and Participant Name)__________, we want to thank you for helping us with our study.