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The UC Davis MINI E Consumer Study

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Executive Summary

Pioneer drivers in Los Angeles and New York / New Jersey leased a MINI E electric vehicle for the period of June 2009 to June 2010. The MINI E is a conversion of the popular BMW Mini Cooper developed for trials with drivers, and deployed in several test sites world wide, including Germany, UK and new sites in France, Japan and China. The following report from the Plug-in Hybrid & Electric Vehicle (PH&EV) Research Center at UC Davis tells of the USA pioneers' experiences during the MINI E field trial. The goals of this study are to understand their responses to these vehicles and how their responses inform the value pathways the electric vehicle market could take.

We organize the following discussion of the MINI E field trial around:

- A three phase learning process drivers go through during their year-long use of the MINI E; we label these phases *discovery*, *translation* and *application*
- MINI E drivers' responses to the various new attributes and overall experience of electric vehicles
- Three emerging areas of value for consumers:
    1. The Intersection of Clean and Fun
    2. Expanding Mastery of Energy Use
    3. Developing the Electric Vehicle Territory

The MINI E Field Trial

The MINI E is a conversion of the popular BMW MINI Cooper to an electric drive vehicle. The MINI E demonstrated 111 miles of electric range in the FTP72 test cycle; MINI E drivers experience a wide distribution of real world ranges, often between 80 and 100 miles. The MINI E has a powerful electric motor to match the MINI's reputation for sporty performance. BMW supplied MINI E pioneers with a 240-volt charger for their homes as part of the lease. BMW leased about 450 of these vehicles in the Los Angeles and New York / New Jersey areas. About half were placed in private households and the rest in private and public fleets. PH&EV Center researchers surveyed a subset of the private household

drivers and interviewed in greater detail about 50 of those; the fleet drivers were not part of this study.

MINI E pioneers were interested in trying out or buying electric-drive vehicles. However, the MINI E drivers were not a homogenous group, rather they represented a broad spectrum of lifestyles, values, and interests. Some drivers were most interested in advanced car technologies. That group was divided between those who were interested specifically in high tech electronics or power systems and those who were most interested in high performance vehicles. Other MINI E pioneers were most interested in the environmental benefits of battery electric vehicles (BEVs). Of those, some were primarily concerned about local emissions (especially Los Angeles residents) while others were more concerned about climate change and greenhouse gas emissions. A third group of pioneers was most interested in BEVs as a way to reduce the United States' dependence on foreign oil. A fourth group of pioneers was motivated by the excitement of their colleagues, friends, and children to embark on a new adventure by leasing the MINI E. Despite the broad lifestyles and sensibilities of this group, the drivers had similar experiences and reactions using the MINI E during the one-year lease.

Due to the high cost of leasing the MINI E, participants as a group were more affluent than the broader population of new car buyers. Therefore, we are cautious when extrapolating what we learned from these pioneers to the general population as well as buyers who will follow these pioneers. On the other hand, these are not a group of radically different drivers and households that are outside normal lifestyles or sensibilities.

The MINI E Learning Process

Electric vehicles differ from gasoline vehicles along many dimensions-from drive feel, energy and refueling systems to economics, and social meanings. MINI E drivers went through a learning process while driving the MINI E. The analysis in this report is framed

around understanding this learning process by splitting it into three phases: Discovery, Translation, and Application[1].

Figure 1 shows the three phases of the learning process, and an example for each of the two routes that drivers may follow through these phases.

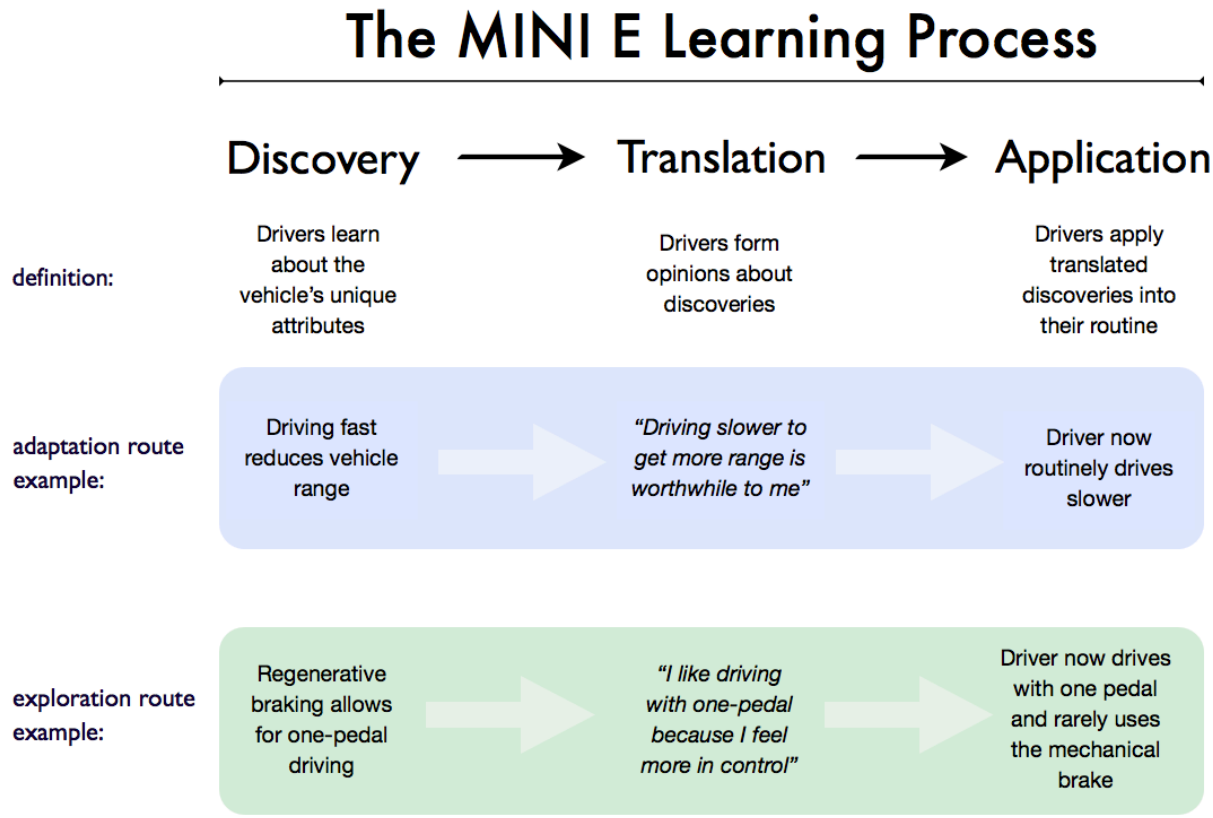


Figure 1 - The MINI E Learning Process

In **Discovery**, drivers learn about the unique attributes of an electric drive vehicle, such as its drive feel, regenerative braking system, range, using electricity as a fuel, and how vehicle speed and accessories affect range. Drivers also discover what their co-workers, friends, or families think of their new-technology vehicle.

[1] The inspiration for this particular framework is Nobel Laureate Tim Hunt, who uses the three steps to describe the social process of science.

In **Translation**, drivers evaluate their discoveries both individually and through dialogue with family, friends, and other BEV drivers. For example, drivers may evaluate whether they prefer charging at home to refueling at gasoline stations. As another, drivers take the technical fact that the added energy required to run the HVAC systems under very cold or hot conditions will reduce the vehicle's driving range and determine whether or not that is actually a problem for them. In translation, drivers decide if they and their households like the process of exploring the lifestyle package BEVs offer.

In **Application**, drivers incorporate translated discoveries into their lifestyles, deepening the value and commitment. For example, drivers who discover that they like how quiet the vehicle is at low speeds or the vehicle's rapid acceleration seek out driving contexts in which they can enjoy these features.

There are two *routes* that a driver can follow through the MINI E Learning Process. In one route, **expansion**, drivers explored new lifestyle opportunities resulting from these dimensions. One example of expansion is a newfound interest in energy use. Several MINI E buyers became interested in solar electricity through their experience with the MINI E and bought photovoltaic panels for their home. In the other route, **adaptation**, drivers found ways to compensate for the limitations of the MINI E. For instance, drivers swapped vehicles with other drivers in the household when they needed additional seats, cargo space or driving range. In some cases, this allowed other drivers in the household to get to use the MINI E.

Response to the MINI E

The central findings of this report relate to MINI E drivers' responses to the following attributes:

1. The unique performance and driving characteristics of electric vehicles and particular aspects of MINI E powertrain design
2. The impacts of the 104-mile range of the MINI E and its compact size
3. The impacts of extreme weather on vehicle performance

4. The use of a home based Electric Vehicle Service Equipment (EVSE) for recharging and the use of electricity as a fuel.
5. The experience of driving a MINI E and the impact on future BEV purchase decisions
6. The value of environmental aspects of BEVs, including global climate change, local emissions, and petroleum use.

1. Performance of the MINI E

Many drivers were interested in the MINI E because of the promised high performance of the vehicle and most drivers we interviewed were pleased with the performance of the MINI E. We talked to several performance enthusiasts and former MINI Cooper drivers who expected a fast and fun car, but many of the participants in this study were unaccustomed to such a nimble vehicle and told us a lot about the fun they discovered. In particular, the combination of "clean and fun" was important. Many interviewees described driving the vehicle faster than previous cars and impressing their friends and families.

Two particular findings of interest are the drivers' responses to the MINI E's regenerative braking system and to the integration of new types of information displays in the car. The MINI E has an aggressive regenerative braking system integrated into the accelerator pedal. This can be difficult to use in the first minutes or hours of driving. However, all drivers we interviewed said they learned to like this system and *discovered* that they could travel more smoothly in traffic, and learned to control almost all acceleration and braking events with a single pedal. At the same time, they *discovered* via instrumentation that they recovered energy proportional to their expertise with the single pedal. Many drivers played with driving techniques to maximize their use of the regenerative braking system and minimize their use of the conventional brakes unless absolutely necessary. This *translated* to a sense of expertise and feeling more control over the vehicle and energy system. Their expertise was related to driving performance on hills, at stop signs and signal lights, and in traffic. Drivers *applied* their expertise to various driving situations and described in interviews how this worked on specific driving routes.

2. Range and Cargo Space in the MINI E

To convert the gasoline MINI Cooper to an electric drive with a large battery, the only place to locate the battery was the back seat. Despite the MINI E's limited range and cargo space, most MINI E drivers drove the MINI E as their primary vehicle, the one they liked to choose first for trips, even when roomier conventional vehicles were available. Many of our drivers described the daily range of the MINI E as practical for 90 percent of their daily driving needs- not an exact measurement, but a judgment by pioneers about the practical application of the MINI E to their needs. For some drivers, the MINI satisfied all driving needs. However, most households liked the MINI E enough that they wanted more driving range on the vehicle to expand its use for occasional recreational trips or family visits.

Many MINI E drivers found that having only two seats and limited cargo space were more restrictive than the limited range. Drivers described having difficulties carrying unplanned passengers or cargo: one couple described coming back to the vehicle only to find they could not carry home all they had bought and were forced to return some items. To adapt to these limitations, drivers sometimes shifted the responsibilities among the vehicles in their fleet. Drivers also *discovered* that the limited cargo space meant that they could not do all their weekly shopping in one trip. Some drivers *translated* this into an opportunity to drive their MINI E more often and *applied* this to their lifestyle by making more frequent, smaller shopping trips.

3. Weather

While the preponderance of the MINI E households described the daily range of the MINI E as meeting 90 percent of their needs, under certain conditions, such as high speed driving and hot or cold weather, the range is decreased. Drivers in the New York and New Jersey areas suffered particularly cold weather during this study and discovered an unacceptable drop in the range of their vehicle when using the heater. In California, hot days in August 2009 resulted in some loss of range and battery thermal management problems that required attention from BMW. However, these events were infrequent for most California drivers. A few drivers in our interviews described adapting to these occasions by driving

slower, turning off the air-conditioning or heater, employing what many call "hypermiling" techniques, and switching to an alternate vehicle.

4. Charging

MINI E drivers had a 240-volt charger at their home and a 120-volt charger that could be carried in the vehicle. Charging a vehicle was a new activity for almost all drivers. About half the drivers made nightly charging a habit, a few charged every time they parked at home and at other locations if available, and another third of drivers charged every other night or third day depending on their use patterns.

While we discussed potential public charging infrastructure with the drivers in our sample, these households themselves never raised the lack of infrastructure as a hurdle to their ownership. We asked MINI E drivers where they would want access to public charging. Drivers wanted access to their favorite recreation spots and relatives' homes. Most drivers chose to place public chargers at or along routes to these destinations. About a quarter of drivers stated that workplace charging would be important to them. Drivers considered shopping locations less important because those locations were close to home. Very few households made use of the 120-volt charger or charged at locations away from home. Furthermore, most MINI E drivers did not view public charging as a prerequisite for buying a BEV.

5. Buying a BEV in the Future

A significant majority of participants in this study, about three quarters of the sample, said they were more interested in owning BEVs after driving the MINI E for a year. In choice experiments employed in the interviews, however, most drivers opted for more seats, longer range (often 120 miles), and some form of public charging. Few drivers chose a faster charging system for their homes, saying they were content with the system provided.

6. Environment, Energy Use and Green Vehicles

Interviews and surveys revealed a broad range of values and beliefs among pioneers about the social and environmental importance of electric vehicles. In Los Angeles, pioneers expressed more concern about the issue of local clean air, something they had learned to

value living in Los Angeles, and the MINI E seemed to have superior air quality benefits. While renewable energy sources for electricity production were given a very high value in survey results among almost all drivers, the importance of CO_2 reduction and energy independence were secondary motivations for drivers in Los Angeles. In particular, there was uncertainty among drivers about the CO_2 content of electricity production in their region. In *discovery*, MINI E drivers said they were questioned, even challenged by co-workers, acquaintances, and relatives about whether BEVs really reduce greenhouse gas emissions. Most were uncertain and concerned about whether BEVs are better for the climate. Another similar size segment of the sample was more interested in reducing oil use for energy security reasons.

Conclusions

A central concern in this study is to understand consumer response to BEVs in a comprehensive way in order to guide development of the market. Three significant lifestyle values emerge among driver's responses to the field of new attributes of BEVs.

- **The Intersection of Clean and Fun**: The MINI E meets drivers' desire for a vehicle that is both environmentally friendly and fun to drive.
- **Expanding Mastery of Energy Use:** Drivers find value in using electricity as a fuel and mastering their energy use through driving behaviors, regenerative braking, and charging.
- **Developing their Electric Vehicle Territory:** Drivers *adapt* to and *explore* limited range through better understanding of their activity space, and seek to expand their clean driving territory through the use of available tools.

1. Introduction

Researchers at the UC Davis Plug-in Hybrid & Electric Vehicle (PH&EV) Research Center conducted a one-year study of a group of pioneers who leased BMW battery electric vehicles beginning in June 2009. BMW converted over 500 MINI Coopers into high performance battery electric vehicles, called MINI E's, with about 100 miles of range. Of these, 450 were placed in the United States in 2009-2010. About half of the MINI Es were leased to private individuals, with half of those in California and the other half in the New York and New Jersey area. The PH&EV Research Center worked with BMW to conduct surveys with most of these households and more detailed research with a subset of about 50 volunteers. The following is a final report on the responses of these MINI E pioneers.

2. Background

2.1 BEV History

Battery electric vehicles (BEVs) were a significant part of the emerging automotive market in the early 20th century, particularly in urban regions. BEVs were initially successful because they were easy to drive, quiet, clean and used electricity which was becoming easy to connect to at the turn of the century. BEVs were popular with women and the wealthy because early combustion vehicles required hand cranking to start, which was strenuous and dangerous. Furthermore, gasoline combustion engines were, noisy, dirty and the gasoline refueling structure was not yet extensive. However, with the development of starter motors and mass production of internal combustion engine (ICE) vehicles, BEVs lost market share and dropped out of the main markets in the United States by the 1930s. The primary limit of these early BEVs was that they could only be driven for a very limited range before charging. The lead acid batteries used to store energy on board the vehicles were heavy, bulky, expensive, and took many hours to recharge. While functional in urban settings, BEVs were impractical in rural and regional travel due to their limited range.

2.2 Return of BEVs

In the decades following World War II, urban air pollution—in part, from combustion vehicles—arose as a serious problem and many oil-consuming nations became increasingly dependent on oil from the Middle East and other politically turbulent areas. Vehicle designers and hobbyists revived interest in BEVs as a solution to these problems. In response to the 1970s oil crises, governments initiated BEV research programs and some small BEV companies were developed. When the price of oil dropped in the late 1980s interest in BEVs waned, except among energy researchers who saw BEVs as a solution to environmental concerns and declining known petroleum reserves. While batteries had not advanced much in the preceding decades, solid-state electronics for controllers and inverters were beginning to revolutionize BEVs.

In the 1990s, car manufacturers deployed BEVs in small numbers throughout the world. The most famous push toward electric vehicles was the Zero Emission Vehicle (ZEV) mandate in California, which required automakers to market zero tailpipe emission vehicles to reduce emissions in California's polluted air basins. The ZEV mandate did not bring the expected number of ZEVs to market at that time. Automobile manufacturers were not yet interested in producing BEVs due to the high cost of batteries. However, manufacturers' efforts toward meeting the ZEV mandate lead to progress in advanced automotive grade batteries, high-powered electronics, and other electronic components for future electric drivetrains.

In the first years of the 21st century, BEVs have experienced a revival coinciding with increasing concern about dwindling oil reserves, greenhouse gas emissions from vehicles, air quality in urban areas, and progress in improving battery technology. Several original equipment manufacturers (OEMs) have begun to roll out limited and mass-produced BEVs for the first time in many decades. The MINI E has been a vanguard into this new automotive market.

2.3 Consumers and BEVs

Although electric vehicles face some of the same challenges in the market that they did nearly 100 years ago, improvements in batteries, electronics, and vehicle design have resulted in a more sophisticated generation of BEVs, even compared to 1990s BEVs. Internal combustion engine vehicles, including hybrids and advanced diesels, have also advanced in recent years to become more efficient and cleaner vehicles. Moreover, BEVs will be competing with recently developed Plug-in Hybrid Electric Vehicles (PHEVs) and someday Fuel Cell Hybrid Vehicles (FCHVs) in the new market of advanced vehicles. The MINI E field trial offers an early glimpse into consumer response to modern BEV technologies

Many analysts doubt the ability of BEVs to compete in the market, given the limited energy storage of even advanced lithium batteries and the relatively long refueling/recharging time. On the other hand, BEVs have some interesting features that may help them compete, including the drive feel of the vehicle, regenerative braking, home charging, quiet low speed operation, and environmental benefits.

2.4 Previous Research Findings on BEVs at UC Davis

The MINI E study is the most recent BEV consumer research project at UC Davis. Researchers at UC Davis's Institute of Transportation Studies (ITS-Davis) have been exploring consumer response to alternative fuel vehicles (AFVs) including diesel, methanol, compressed natural gas, hybrid electric, hydrogen fuel-cell, battery electric and plug-in hybrid electric vehicles for over two decades. ITS-Davis researchers have customized and developed a variety of specialized consumer research tools, including reflexive phone, mail-out, and online surveys that focus on consumer consideration of the lifestyle impact of technologies comparative AFV drive tests with households, detailed gaming interviews with households which incorporate tracking of vehicle use by diaries and vehicle data collection into the interview methods. These experiments resulted in development of a UC ITS-Davis multi–method and multi-year research process for BEV markets. In the 1990s, ITS-Davis pioneered a four-step approach to explore the BEV market, to determine

potential markets for BEVs in California. This four-step method involved interviews with 100 early adopters, test drives and follow up focus group with over 200 new car buying households in Pasadena California, specialized gaming interviews (called PIREG for Purchase Intentions and Range Estimation Games) with 54 households, and a final reflexive statewide survey with over 500 new car-buying households in California (Kurani et al., 1995).

The four-step method developed at ITS-Davis focused on the functional utility of the vehicles, given their limited driving range between refueling. Phone interviews with BEV owners in the early 1990s revealed two primary findings: BEV drivers were committed to using their vehicles and these drivers found solutions to limited range, including charging their batteries at 120-volt outlets that they discovered away from their homes. Test-drives with Pasadena households—who drove compressed natural gas (CNG), methanol, and battery electric vehicles—gave researchers insights into consumer attitudes toward these alternative fuel vehicles.

Two major findings about BEVs emerged. First, drivers were not very interested in the CNG vehicles, noting that the only reason to be interested in those vehicles was if they offered substantial savings on fuel. However, a majority of drivers liked the drive feel of the BEVs, even though they were not comfortable with the small size of the BEV-conversions used in this drive test. Second, focus groups with the Rose Bowl drivers showed that in the absence of longer experience, drivers could not estimate with any certainty what range of BEV they needed or wanted or what price they would pay. The drivers' statements showed that they lacked the experience needed to assess the value of BEVs' features.

Based on interview methods pioneered at the Oxford Transport Group for mode choice and Martin Lee Gosselin's work on household response to fuel rationing, the PIREG home interviews used detailed one week diaries of household vehicle travel to examine the impact of short range BEVs on weekly travel in 54 multi-vehicle, new car-buying households in several areas of California (Turrentine and Kurani, 1994). Turrentine and Kurani also used this gaming scenario to investigate the households' infrequent travel needs. This research showed that households, settled on three primary attributes to estimate a practical vehicle range if they were to purchase a BEV:

1) Routine activity space: This is a set of daily, weekly and sometimes less frequent but repeated travel activities and their destinations; some examples include shopping, commuting, schools, churches, friends, errands, exercise, movies, and restaurants. These activities are usually done on a daily, weekly, or monthly basis. In the gaming interview, the researchers and drivers determined the number of miles and minutes per day required to carry out these routines.
2) Critical destination: In addition to routine activity space, drivers would also propose destinations they wished to go to on a spontaneous, emergency, or ideal basis if they had an electric vehicle. Often these destinations were the locations of drivers' favorite recreation, shopping, friends, or other destinations that were so important they could not be forgone. While a small group of drivers proposed critical destinations outside the regions in which they lived, which would not be practical for BEVs, most proposed locations, within the region (Kurani and Turrentine, 1995). In some cases, households indicated their critical destinations were ones they had never visited (e.g. beaches or recreation areas), but they wanted to have access to them at all times. Some households were more practical and focused on hospitals and family emergency destinations.
3) Safety buffer: households proposed a safety buffer; a minimal amount of range that would have to be on the vehicle at any time. This was often the range to get home from work or to the hospital from home. In most cases, households chose a safety buffer of around 20 miles (32 km).

The PIREG study provided the methodological concepts and techniques for eliciting a more valid and reliable estimate the size of the market for alternative fuel vehicles. One important assumption in the PIREG study was that manufacturers would offer a variety of electric vehicles, from neighborhood electric vehicles (enclosed and higher speeds than recent current codes specify) to cars and SUVs. These hypothetical BEVs had 60 to 120 miles of range and had prices similar to ICE and CNG vehicles. The choice options for consumers in that study did not include hybrids and had limited PHEV options, but CNG was available in many vehicles. At the end of a month-long survey using driving diaries, activity space mapping, and reviewing purchase histories, households engaged in a choice

exercise. Results of the statewide survey estimated the market for battery electrics at around 15 percent of California's market annually.

However, later research at UC Davis using in-household vehicle demonstrations and early adopters of advanced vehicles revealed that previous research focused too much on practical aspects of vehicles and not enough on symbolic and social influences. Research at ITS-Davis with hybrid vehicle buyers from 2003 to 2006 revealed decision processes not shown in the PIREG study. ITS-Davis researchers (Heffner et al., 2007) found that early market hybrid buyers were focused on the symbolic meanings of HEVs. Furthermore, fuel economy research (Kurani and Turrentine, 2007) demonstrated that households buying ICE vehicles were not choosing fuel economy based on rational calculations and did very little cost accounting to understand the payback impacts of hybrids or other vehicles. Most buyers were instead relying on information from personal networks and prices at the pump to form attitudes and opinions.

During the most recent ITS-Davis project on PHEV buyers, UC Davis researchers placed plug-in hybrid cars in 79 households in Northern California for up to six weeks. Researchers tracked vehicle use by GPS and conducted up to eight hours of interviews with each household. The data contributed to a new understanding of potential responses to vehicle charging regimes and the use of electricity as a fuel (Kurani et al., 2010). One prominent finding was that, for the most part, participants found recharging at home to be convenient.

Another major component of the research has been Axsen and Kurani's study of the influence of drivers' social networks in shaping their experience and understanding of plug-in hybrids. In particular, they analyze a process they called Translation in which drivers determine the significance of the new vehicle for their values and lifestyle, often in dialogue with friends, co-workers and acquaintances (Axsen and Kurani, 2011). We incorporate this idea in describing one phase of BMW MINI E drivers learning.

3. The MINI E Study

The early, premarket studies at ITS-Davis reviewed above indicated that there are more complex market variables and social processes at work in BEV markets development than found in conventional automobile markets. The MINI E study provides a more realistic context in which to expand these ideas from previous UC Davis research. Below we first describe the MINI E, MINI E drivers and the MINI E field trial, and then go on to describe their experiences.

3.1 The MINI E: A BMW MINI Cooper Conversion

The popular BMW MINI Cooper provided an attractive platform for this trial to test ideas for a subsequent series of electric vehicles being designed by BMW. While the battery could not be placed into a special compartment, and therefore took the back seat and storage area away, the sportiness of the MINI Cooper image allowed BMW to explore the market response to a sporty electric vehicle with a powerful battery and motor.

3.2 The MINI E Drivers

BMW offered MINI E leases to consumers based on an online screening recruitment survey administered by MINI USA. Households were chosen only if they lived in the Los Angeles area or the New York / New Jersey area, where BMW would be able to provide support for the vehicles. A critical component to this process was determining the consumer had an appropriate place to install the charger. In addition, the $850 (+tax) monthly lease price acted as a filter that led to mostly affluent households receiving MINI Es.

Once the selection process was complete, 235 private U.S. households leased MINI Es. Fifty-four of those households volunteered to be part of a more intensive study by the UC Davis team. Figure 2 shows the home locations of the MINI E leaseholders in our study. Throughout this report we will refer to the group of 235 households as the *full sample*, the subset of 54 households as the *UCD sample,* and the remaining 181 households as the *non-UCD sample*. Section 4 of this report shows the response rates to each data collection tool.

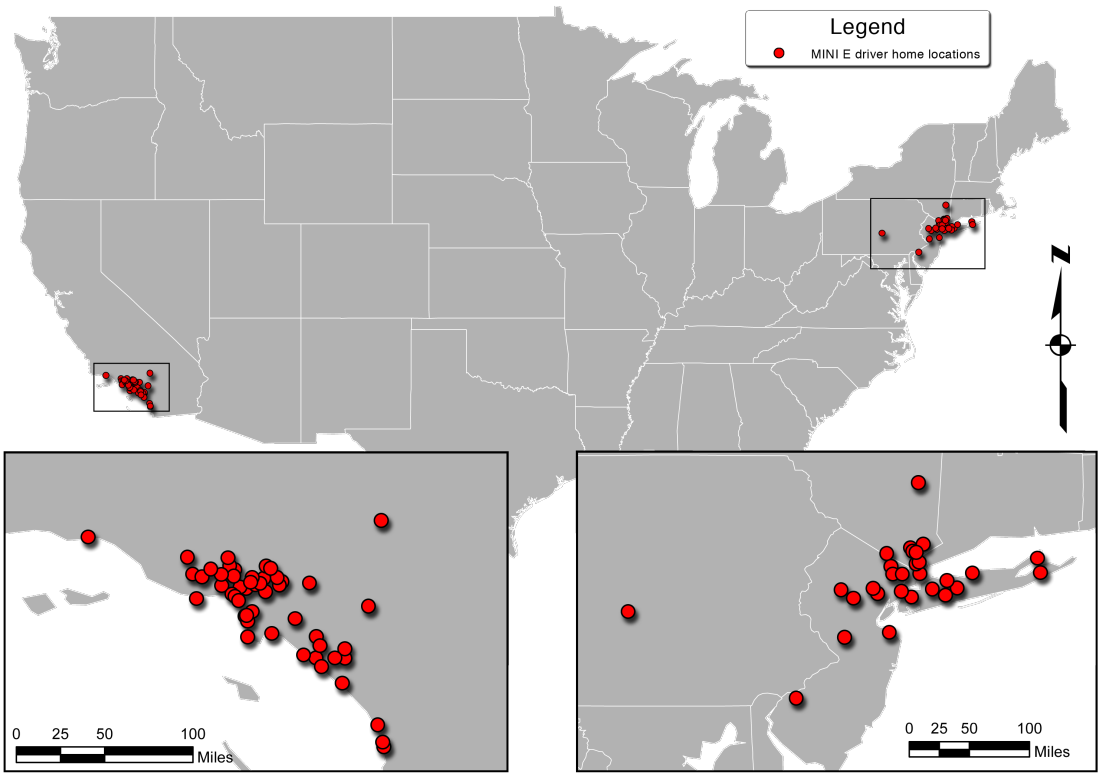


Figure 2 - Locations of MINI E Driver participants who took final End-of-lease survey.

3.3 Lifestyle Exploration

Battery electric vehicles introduce a wider set of differences into the consumer experience than do hybrids or other alternative fuel vehicles. These differences include new social meanings, unique vehicle drive feel, new sounds, a shorter range (50-150 miles), longer refueling times, completely new refueling locations (home, work, parking lots, etc.), new units of energy (kWh), new payment systems (home electricity bill), new maintenance regimes, different ways of measuring emissions (at power plants) and other differences arising from using electricity rather than gasoline or diesel. In fact, the shift to electricity puts the users in a new system so distinct that simple comparisons are hard to make.

One challenge to understanding how consumers might evaluate these new technologies is that their evaluation will unfold over a long period of use. Even with conventional vehicles, buyers often suspend judgment on a new purchase – a "honeymoon period" - during which

they learn to use and enjoy the particular features of a new vehicle. BEVs have a much broader variety of new attributes for buyers to experience; this honeymoon period is expanded, and can include greater sense of discovery and adventure.

Analytic approaches often compare ICE vehicles and BEVs in a non-historical, quantitative format and attempt to assign monetary values to a set of vehicle attributes, not all of which have an explicit monetary value. In some cases, these analyses use survey data from respondents who have no experience with BEVs. However, with new technologies like BEVs, the functionality, pleasures, problems, meanings, and values of vehicle purchases unfold over time, a process we call lifestyle exploration.

MINI E drivers were willing to put up with challenges and situations that from the outside seem impractical. However, these drivers were engaged in a period of lifestyle exploration during which they found value in attributes of BEVs beyond the obvious. Despite their unique experiences as early adopters with electric drive technology, it would be unwise to discount their discoveries as inapplicable to the broader market. The well-known limitations of range and long recharge times may be outweighed by a whole new set of activities and benefits discovered through their lifestyle exploration.

In the 1990s, BEV advocates illustrated the idea of a new lifestyle sector with the example of microwave ovens, which were originally thought of as too small and unable to cook foods in an appealing way. We now realize that microwaves were not going to replace conventional ovens. In fact, they resulted in the creation of a whole new market, including the development of frozen and convenience foods. Microwave owners and food companies created a whole new market for easy foods. Indeed, microwaves were so easy to use that they have been repurposed for additional tasks like reheating coffee or tea, which were probably unexpected.

The MINI E trial offers the largest and most recent investigation of driver response to BEVs. The MINI E is a useful platform for this investigation, in that its nostalgic design (redesign of an iconic, popular, British-made vehicle of the 1960s) is well liked, but is distinct from other BEV designs, which are more futuristic or untested in the public. The MINI E provided an almost perfect test of driver response to BEV attributes separate from vehicle

design. We discuss the lifestyle exploration of our MINI E drivers in Chapter 5 of this report.

3.4 The MINI E Learning Process

The analysis of the MINI E drivers in this report is framed around understanding the learning process that drivers experienced with the MINI E over a one-year lease. This learning process is conceptualized in three phases: **Discovery, Translation,** and **Application**.

In **Discovery**, drivers learn about the unique attributes of the vehicle, such as its drive feel, regenerative braking system, range, using electricity as a fuel, and how vehicle speed and accessories affect range. Drivers also discover what their co-workers, friends, or families think of their new-technology vehicle.

In **Translation**, drivers evaluate their discoveries both individually and through dialogue with family, friends, and other BEV drivers. For example, drivers may evaluate whether the drop in range due to air conditioner use is a problem for them, or whether they prefer charging at home to refueling at gasoline stations. In translation, drivers decide if they and their households like the overall lifestyle package BEVs offer.

In **Application**, drivers incorporate translated discoveries into their lifestyles. For example, drivers who discover that they like how quiet the vehicle is at low speeds or the vehicle's rapid acceleration seek out driving contexts in which they can enjoy these features.

There are two *routes* that a driver can follow through the MINI E Learning Process. In one route, **expansion**, drivers explored new lifestyle opportunities resulting from these dimensions. One example of expansion is a newfound interest in energy use. Several MINI E buyers got interested in solar electricity and bought panels for their home. In the other route, **adaptation**, drivers found ways to compensate for the limitations of the MINI E. For instance, drivers swapped vehicles with other drivers in the household when they needed additional seats, cargo space or driving range.

In our interview with Household 46, we had a conversation that clearly illustrates the type of learning process that drivers went through with their MINI Es.

> **Interviewer 2:** *…So we want to revisit the issue of range a little bit and we're wondering have you noticed any -- kind of any variables or anything that have affected the range at all? I mean you seem to be pretty satisfied with the range overall, but to the extent that you've been monitoring that, have there been any kind of factors that seem to affect it?*
>
> **MINI E Driver:** *Well, there was one experience, after I did my test, it was last weekend actually, where I had about 50 percent in the car because I had been driving around, my wife and my daughter were gone, and I had to go to an event at LAX. So it's about 20 some odd miles each way. I figured it's going to be pretty critical, but first I did the numbers in my head… I'd never taken the car down to -- near the end of its range and what happens basically between ten and zero or after zero. Do I still have something left after that or what? So I was going to just go and see what happened. So I did that and I had about … 15 percent left to come home and they were saying that I had… maybe around 15 to 20 miles…I think it was showing 20 miles.*
>
> *So I was thinking I may or may not make it. So my thinking at that point in time is I'm going to be conservative. I'm not going to put the air conditioning on, it was kind of hot, and I'm going to drive this car very carefully -- not the same way that I typically drive it, just having fun and zipping in and out of traffic…I learned quite a bit by doing that. I learned that by being on the freeway, really focusing on conserving energy…and keeping it basically at one dot or…right at that point as much as possible…and then when you slow down and the regenerative has the opportunity to work, I used practically nothing the whole way home…*
> *It had 15 percent [when I left LAX] and I had 10 percent by the time I got home. And I had never had that kind of efficiency driving a car. I opened the windows,*

I turned the air conditioning off, and I basically drove that car as carefully as I could.

4. Data collection tools & methods

In this study we used surveys, interviews, and driving diaries to learn about the MINI E drivers. Figure 3 shows the timeline of the study. BMW, Chemnitz and UC Davis researchers often worked together on much of the content of the surveys, ensuring coverage of the many technical and behavioral issues that were of interest.

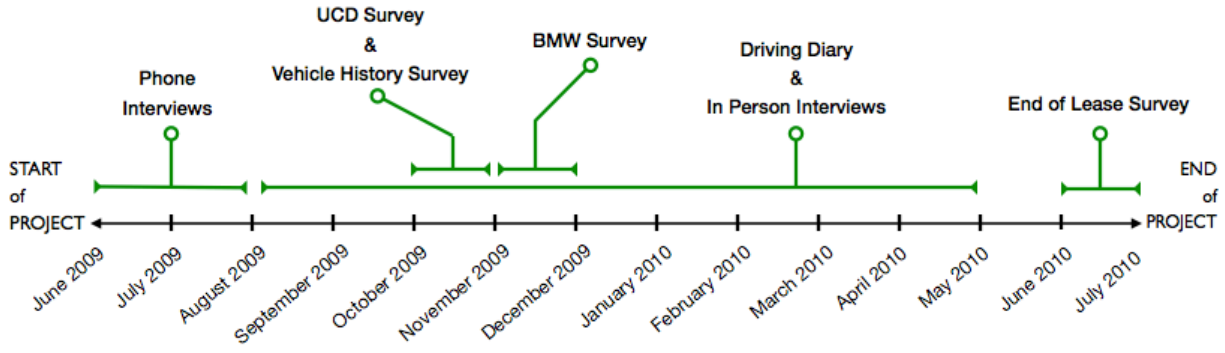


Figure 3 – MINI E study timeline

Table **1** shows the number of respondents to each data collection tool we implemented over the course of the MINI E field trial. Each of these tools is described in more detail below.

Data Collection Tool	Sample Size
UCD Survey	41
Vehicle History Survey	41
BMW Survey	72
End-of-Lease Survey	102
Driving Diary	24
Phone Interviews	54
In-person Interviews	39

Table 1 - MINI E sample sizes for data collection tools

4.1 Online Surveys

We administered four online surveys throughout the one-year lease period to different sets of the MINI E drivers. This section describes the content of each of the surveys in time order of their administration. UC Davis researchers, BMW researchers, including Max Schwalm, Andreas Kleinath, Aaron Singer-Englar as well as University of Chemnitz researchers under direction of Joseph Krems often collaborated on development of questions and survey approaches, with some of the surveys being primarily BMW designed while others primarily designed by UC Davis.

UCD survey

The first UC Davis survey was sent to the 54 volunteer households that make up the UCD sample. The questions focused on the following areas of interest to BMW and the UC Davis research team. This survey was conducted during October 2009.

1. The MINI E Experience
    - Information on why households applied for leases, how they use or expect to use the MINI E, and their general expectations about the vehicle.
2. Range
    - Households estimated their comfortable, minimum, and maximum ranges in the MINI E.
3. Attitude toward Battery Electric Vehicles
    - Households responded to questions about the usefulness of the vehicle in terms of range and cargo space, the manner of driving in the MINI E, general attitudes toward electric vehicles and the sources of electricity for electric vehicles.
4. Environmental attitudes
    - Households were asked for their opinion on the impact of BEVs on the environment and the importance of energy and environmental conservation.
5. Purchasing behavior

- Information on how households shop, the meaning of cars to them, how they drive, BEV purchase intentions, and what vehicle characteristics most influence opinions of BEVs.

6. Driving behavior
    - General questions about how household drivers operate their vehicles

Vehicle history survey

The UCD sample was asked to complete a vehicle history at the same time as the UCD survey in October 2009. This entailed listing the last five vehicles the household owned so we could observe any trends in their purchase behavior and try to put the MINI E in the context of their past purchases.

BMW survey

This survey was sent to the non-UCD sample of 181 US households leasing the MINI E and was primarily developed by BMW.

1. Driving Range
    - Assessed drivers' experiences with the MINI E's range, expectations and understanding of the MINI E, and range preferences. It also examined driver behavior to see if they are conscious of energy use while driving.
2. Opinions about Battery Electric Vehicles
    - Respondents were asked to come up with advantages of BEVs and barriers to their acceptance. The survey also examined how each household viewed BEVs in terms of the environment, how important they are, and their general drivability.
3. Charging Process and Batteries
    - The households answered questions about charging time, the readiness of electric vehicles for daily use, how people prolong the battery life, the usability of the charging system, and charging time preferences.
4. The MINI E as a whole product
    - This section addressed the complexity and functionality of the MINI E and consumer confidence in using the MINI E.

5. Acoustics
    - The households answered questions about the noise, and lack of noise, coming from the MINI E. The topics included safety and quality of the sound coming from the vehicle.
6. Regenerative Braking
    - Households addressed how much they use regenerative braking, how it has affected their driving style, and their general opinion of the braking system.
7. Dashboard Displays
    - This section contained questions about the quality and amount of information being given to the driver of the MINI E.
8. Safety
    - Households gave their opinions on the safety of the MINI E under various driving conditions.
9. Mobility and the MINI E
    - Households answered questions about the effect of the MINI E on their use of other transportation modes and how well the MINI E met their travel needs.
10. Purchase Intentions
    - Households answered questions about how electric vehicle characteristics, price, and leasing the MINI E affect their purchase intentions.
11. Environment
    - This section focused on the particular impacts of BEVs on the environment as well as attitudes toward human impacts on the environment.

End-of-Lease Survey

At the conclusion of the first year of MINI E leases, we sent a survey out to the full sample of 235 MINI E drivers to ask some new questions as well as see if their opinions had changed over the course of the year. This survey was conducted in July 2010.

1. The MINI E Experience

- Information about total mileage, rating the MINI E experience, rating how well the MINI E met expectations, and if the household chose to renew the lease for a second year.

2. Attitudes toward electric vehicles
    - How leasing the MINI E affected households' opinions of electric vehicles, influenced likelihood of purchase, and what barriers to the acceptance of BEVs households perceive.
    - BEV and PHEV purchase preferences and likelihood of purchase in the next five years.
3. Technical aspects of the MINI E
    - Any change in range over the year, temperature effect on the MINI E, opinions on suitability of use in extreme temperatures
    - Reaction to regenerative braking and the power display
    - Effect of driving the MINI E on thoughts about energy and electricity use
4. Charging and Range of the MINI E
    - Frequency of charging, battery state of charge (SOC) when plugged in
    - How range affected planned and unplanned trips and adaptation to range
    - Frequency and method of planning trips
    - Uncertainty of reaching destination while driving
    - Locations of places drivers wanted to go, but couldn't due to range limitations
5. Pricing
    - The range of prices the MINI E drivers would pay for a BEV like the MINI E

4.2 Driving Diaries and Maps

Prior to interviewing the households in the UCD sample, we sent them driving diaries to fill out for a week. We asked the households to indicate their destinations, how far they traveled to each destination, the SOC at the end of each trip, whether they had a passenger or cargo in the vehicle, and whether they charged the vehicle once it returned home. For the 24 households that completed driving diaries, we used the diaries in the in-person

interviews to better understand how each household used the MINI E, both their driving and recharging habits. The diaries also indicated whether additional trips were made with another vehicle in the household, and why that was necessary. Since we discuss the driving diary in our interviews the diaries were only mailed out to households we would be interviewing in the near future so that the travel was in the recent memory of our households. Due to the schedule of the in-person interviews, households completed their diaries between August 2009 and May 2010.

Some MINI E drivers supplemented their driving diaries with Google maps, which showed drivers' home locations and all of the destinations they traveled to that week. We used these in the interviews to aid discussions of activity space and critical destinations. The Google maps tool was a new research device that we used to try to explore the activity space of a household in a clear, visual manner. Not all households completed the Google map, and when a map was unavailable, we used a general paper map of their region during the interviews to visualize and understand their current and desired activity space.

We asked drivers to enter their regular destinations into a personalized Google map and color-code those destinations according to the frequency of travel. Blue pushpins were used for daily destinations, red pushpins for weekly destinations, green pushpins for monthly destinations, and yellow pushpins for less frequent destinations. If the household numbered their destinations as shown in Figure **4**, the numbers could be used on their driving diary to simplify the process and correlate the two data collection methods.

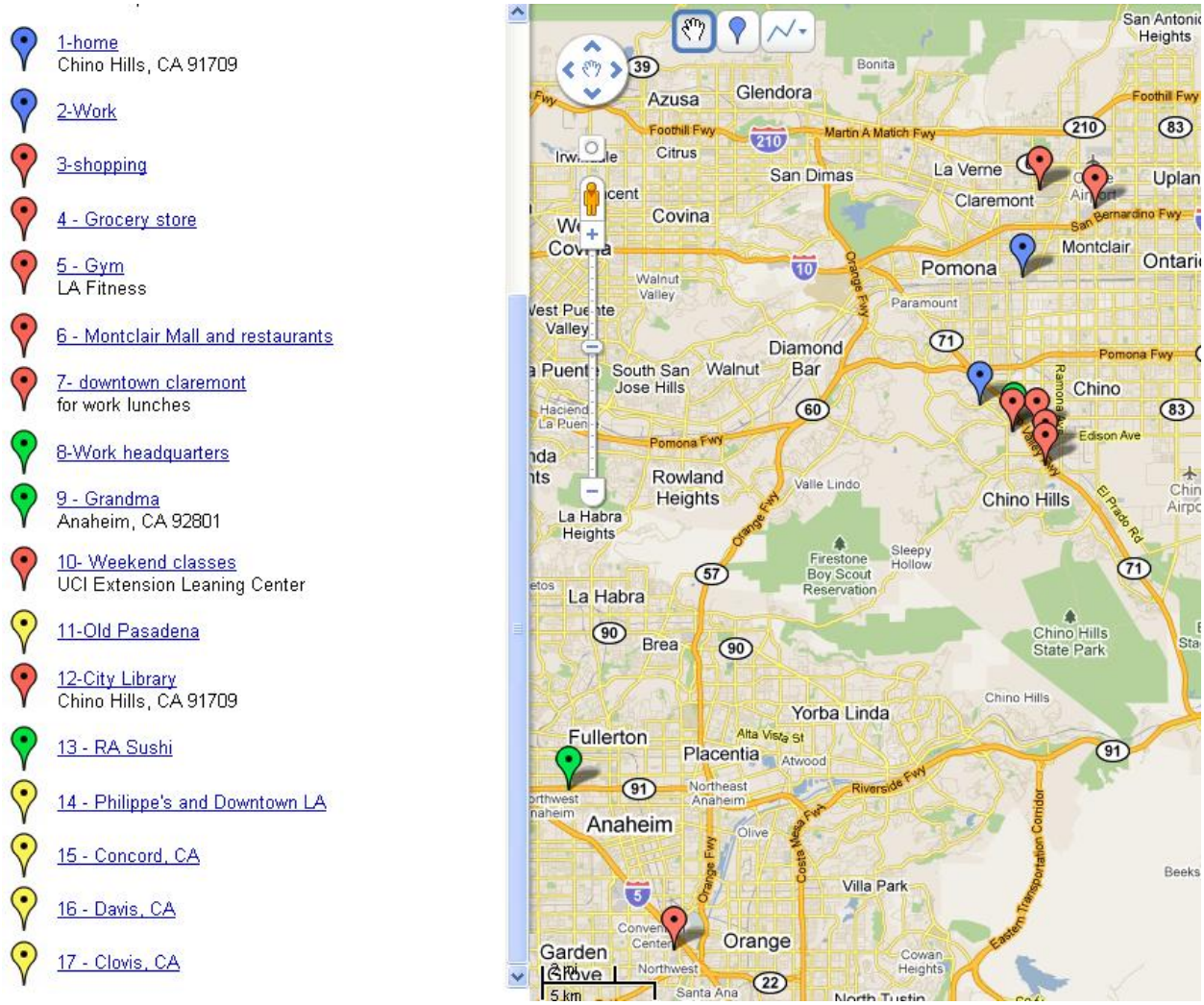


Figure 4 - Example screenshot of a Google map used by MINI E drivers

4.3 Interviews

We administered two interviews throughout the one-year lease period to different sets of the MINI E drivers. This section describes the content of each of the interviews.

Phone Interviews

During the first two months of the project, June and July 2009, we interviewed all 54 households in the UC Davis sample over the phone. This was timed such that the households had either not yet received the MINI E or had only had it for a short time so we could get an idea of their early views on BEVs. This interview focused on the following topics:

1. Interests/Motivation – Why the household was interested in the MINI E and in volunteering for our study
2. Electric Mobility – Households' perceptions of advantages, disadvantages, and barriers to adoption of BEVs
3. Adaptation and Exploration – Effect of the MINI E on daily life, how the household expects to use the vehicle, perception of limited range
4. Knowledge about electric vehicles – Households' perceptions of the biggest differences between BEVs and combustion engine vehicles

In-Person Household Interviews

Between August 2009 and May 2010, we conducted in-person, interviews with 39 of the 54 households in the UCD sample. Most of the in-person interviews took places in the drivers' homes. These open-ended interviews covered the following topics:

1. Prior vehicles purchase patterns and current household fleet
    - Information on vehicle make, model, year and attributes that caused household to purchase those vehicles
2. The MINI E Community
    - How the household interacted with the MINI E community, which includes in-person gatherings, blogging, Facebook, etc.
    - Reactions of friends, family, and other drivers to the MINI E
3. Google Map and Driving Diary
    - These questions focused on the household's travel patterns and how well the diary and map represented those patterns to get a sense of the household's activity space
    - We also asked if the MINI E was suitable for the trips the household needed to make and if using the MINI E had changed the household's travel patterns in any way
4. Experiencing the MINI E
    - Driving experience

        - How the household feels about BEVs in general and the MINI E in particular
        - How the household adapted to using the MINI E
    - Vehicle Range
        - How the household feels about and adapted to limited range and assessing what the household understands about what affects the range of the vehicle.
        - Satisfaction with the range and need for public charging
    - Instruments
        - Which instruments the household focused on, what information the instruments conveyed, desired information not provided, and record-keeping other than the diary
    - Cargo
        - Frequency of use of cargo space and suitability of limited cargo space
5. Charging
    - Basic questions about charging behavior: when, how often, how long, workplace charging, safety of the process, knowledge of electricity prices, differences from gasoline
6. Environment (Externalities)
    - Opinions of BEVs related to the environment, national security, eco-friendliness
    - Opinions of other vehicle technologies in terms of environmental responsibility
    - Effect of MINI E on environmental consciousness of household
7. Priority tables
    - Households traded range against: number of seats, charging speed, Level 2 charging time, Level 2 public charging density, and availability of fast charging
    - Asked to locate desired charging locations on a map.

5. The MINI E Experience

5.1 Performance

Electric vehicles have had a reputation in the past for low performance. One reason for this reputation is that the most common electric vehicle experience for many American drivers has been golf carts, low speed neighborhood electrics, and in some cases (seeing on the news) "solar electric vehicles." None of these specialized vehicles come close to matching the acceleration of common ICE vehicles.

The MINI E is sporty compared to many previous BEVs deployed in the past. The GM EV1, produced in small numbers in the 1990s, also offered a 2-passenger sports car feel. The MINI E, built on the MINI Cooper platform, comes with an established reputation for go-cart handling, speed and is popular for its nostalgic design. One of the goals discussed by BMW in early phases of this research project was to explore the hypothesis that there could be a positive market stemming from the idea that "clean vehicles" could be fun.

The sample did include a number of drivers looking for "fun." Part of the sample consisted of former and current MINI drivers, BMW drivers, and sports car enthusiasts who were interested in a high-performance BEV and knew that BMW would deliver with the design of the MINI E. However, a sizable number of drivers in this sample had no experience with MINI or BMW and were not sport car enthusiasts, so driving the MINI E was a new experience for them.

In general, responses to the MINI E's acceleration, handling and top speed were overwhelmingly positive. Of the drivers we interviewed, many spent much of their time talking about how much fun the car was. Drivers especially enjoyed the fact that the vehicle could be both sporty and clean.

The following quotes from the end-of-lease survey reflect the general response of drivers to the MINI E's performance:

> *The instant torque, the agile handling, the tight steering and the fun of driving a MINI made me appreciate driving even more than any of my past-owned vehicles. This was*

the closest I ever got to a "sporty" car and I really, really liked it. Just thinking about having it in my garage or knowing I was going home or to work or to wherever made me smile. – Household 12

The MINI E has been reliable and fun to drive. – Household 18

There were two times that if I was driving in my other car, I would have been in one [an accident]. Fortunately, the quick deceleration when stepping off the accelerator helped in both instances. I wish all cars had the "go cart" start and stop ability. It made driving in traffic much more easier and enjoyable. Handling and quick maneuvering was wonderful. – Household 67

The quote from Household 2, regarding the performance of the MINI E, goes into more detail about the expectations and learning process that the driver went through.

When I applied for the Trial Lease program I knew very little about electric cars. I thought the car would be interesting to drive for a year but that it probably wouldn't be capable of holding up to my high mileage and my demanding driving needs. I drive cars hard, and I thought I might need to pamper this car just to make it through the year. Also, I thought the lack of public charging stations would prevent me from driving as much as I usually do. My fears were unwarranted and I drove the MINI E hard and it held up fine. Also, with the addition of a charging station at my job, any range issue I may have had went away. – Household 2

While this driver initially expected a car that was incapable of fully meeting his driving needs, he *discovered* that the vehicles performance was sufficient, and allowed him to drive as usual.

5.2 Regenerative Braking

Regenerative braking is a new aspect of vehicle design in hybrids and plug-in vehicles. Regenerative systems recapture energy otherwise lost or left unutilized in braking, coasting, and downhill driving. No other energy consuming devices used by consumers recover energy in this way.

Vehicle manufacturers implement regenerative braking systems in three different ways: integration with the mechanical braking system by using the brake pedal, integration with the accelerator pedal, and integration with both the brake and accelerator pedals. In the MINI E, regenerative braking is integrated only with the accelerator pedal; the brake pedal controls only a hydraulic brake. This differs from most hybrid vehicles that have regenerative braking integrated with both the accelerator pedal and the brake pedal so the vehicle coasts and decelerates more like an ICE vehicle. The implementation of regenerative braking in the MINI E results in a significant change from driving a conventional vehicle – the car will not coast when the driver releases the accelerator pedal. Instead, releasing the accelerator causes the MINI E to slow down rapidly.

We were interested in several questions about MINI E drivers' interactions with this new technology. How do drivers react to this very different type of braking? How do drivers interact with the integration of pedal and dashboard energy displays? Do drivers think about energy use and recapture when they drive? For many drivers, this level of feedback in a vehicle and regenerative braking is new.

Figure 5 indicates that the overwhelming majority of MINI E drivers liked the way the regenerative braking system works in the MINI E.

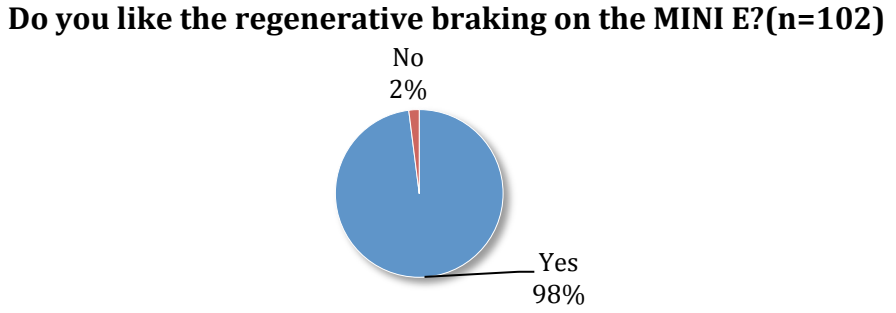


Figure 5 - Do you like the MINI E's regenerative braking? (End-of-lease survey)

In interviews, our researchers found that MINI E drivers responded positively to the regenerative braking scheme. The following selected quotes from household interviews indicate the general response:

"I love the regenerative braking. In fact, I miss it when I drive my other cars." - Household 31

"I love that I rarely use the brakes. You stop where you want to stop without using your brakes." – Household 51

Furthermore, responses from the end-of-lease survey we conducted in August 2010 provide even more insight into drivers' responses to regenerative braking.

"You can basically drive with one foot." - Survey Household 2

"It is like driving a slot car. It is exciting; it is as much fun as accelerating" – Survey Household 11

The previous two quoted concepts also came up often in interviews; people enjoy single-pedal driving and not having to use the brake.

"Just knowing that I don't have to worry about the reaction time. Just by lifting -- I mean, just by adjusting your, I don't want to say gas pedal, but acceleration pedal…. You can control the amount of speed when you're going down a really steep hill. It just gives you more of, to me, in a sense of control, and like safety actually" – Household 6

Figure **6** further illustrates this, with all of the survey respondents agreeing to varying degrees that they like accelerating and decelerating using one pedal.

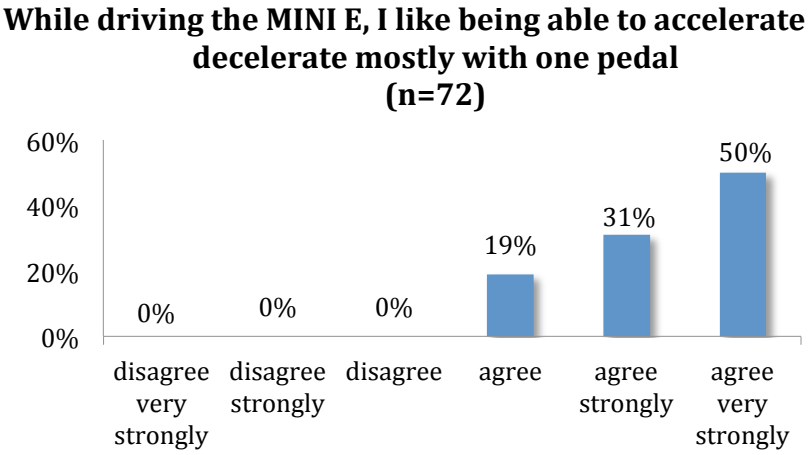


Figure 6 - Single-pedal driving (BMW survey)

In addition, driving the vehicle becomes interesting and engaging – a number of drivers describe in interviews how they try to maximize their range and the amount of energy they capture through regenerative braking while driving, or test how much they can drive without touching the brake pedal.

> *"[I was] fascinated by the ability to regenerate and see it actually gain. That's fun. …sometimes you play with your driving to see what you can do…Certainly when you see it really suck energy as you go uphill I start to think about where I can regain that, not just on the return trip by going downhill." – Household 5*

> *"I stopped using the brake, I think I might use the brake once a month. It's just been kind of fun to play with it and drive it, and it has a lot of zip and a lot of energy." – Household 8*

Playing with the regenerative braking system would be considered part of the *discovery* phase of the learning process with the MINI E. Drivers *translate* overall enjoyment and satisfaction with the regenerative braking system into continued *application* of their newly acquired driving techniques. Drivers' acceptance of the regenerative braking system in the MINI E continues throughout the lease period, as we saw from responses to the end-of-lease survey question in Figure **5**.

In spite of their overwhelming satisfaction with the MINI E's regenerative braking, Figure **7** shows that about two thirds of respondents to the end-of-lease survey wanted to make changes to the system.

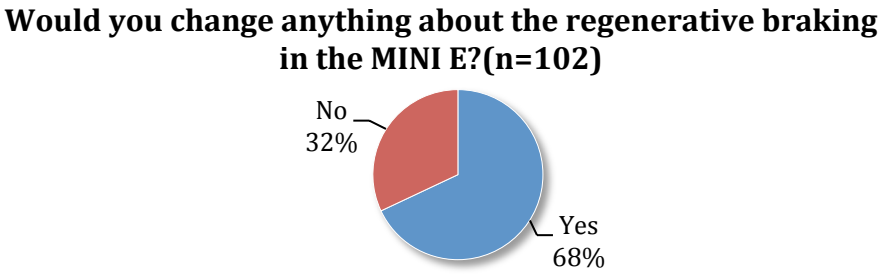


Figure 7 - Desire to modify regenerative braking system (End-of-lease survey)

When asked to elaborate, respondents commented on the strength of the regenerative braking. Several people mentioned that they would like the strength of the regenerative braking to be adjustable. Tied in with adjustability is a desire for the car to be able to coast. Other drivers commented that they preferred the strength of the braking when they first received the MINI E – BMW reduced its strength in an early vehicle service visit. Finally, one driver commented that braking strength is inconsistent; both hot weather and having the battery fully charged seemed to reduce the strength of the regenerative braking. Drivers also noticed that the regenerative braking disengages when the MINI E hits a bump in the road.

5.3 Dashboard Displays

Electric drive vehicles have different information to display about energy than conventional vehicles, including the percentage, or kWh of electricity stored in their batteries and how far they can expect to drive on a kWh. Due to their reduced driving range, such information is critical to drivers. Information must be reliable and precise as well as presented in a way that drivers can understand quickly and easily while driving.

MINI E drivers were for the most part inexperienced with driving electric vehicles, and so had limited experience with electric energy measurement and ways of displaying that information. However, we did ask questions about their response to the energy information available on-board, and we asked if they trusted the information, if it was reliable and useful, and what information they felt was missing from the display. In the interviews, households generally responded that the energy information was clear and easy to understand.

The drivers in this sample are accustomed to having and using navigation systems (GPS) on board their vehicles. Many complained that this was missing. Most importantly, as we can see in Figure **8**, MINI E drivers want GPS navigation devices to plan their driving and to know the exact distance to the next destination.

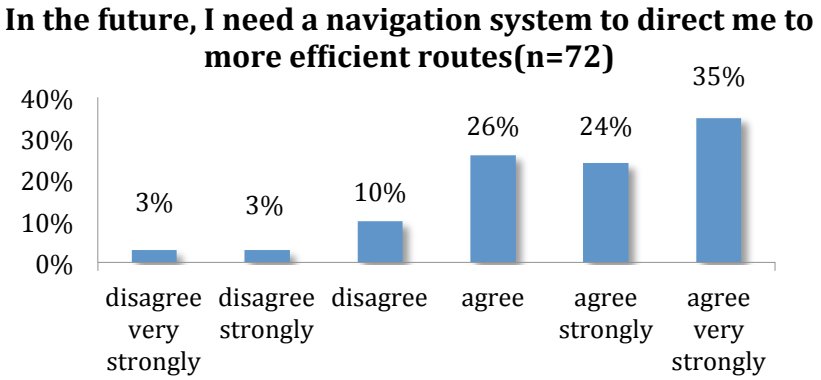


Figure 8 - Need for a GPS system (BMW survey)

Figure **9** shows three-quarters of respondents to the end-of-lease survey found the power meter to be a useful dashboard display. Given the simplicity of the display compared to more detailed displays in other advanced vehicles, this is an interesting result. Perhaps the detail of the display is not critical and a general indicator of whether the car is using power or regenerating power is sufficient.

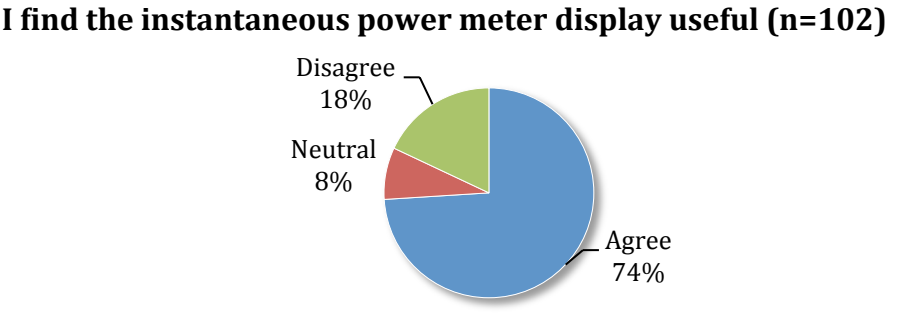


Figure 9 - Usefulness of the MINI E power meter (End-of-lease survey)

We also asked, "When you accelerate or slow down, what does the instantaneous power meter tell you about what the car is doing?" Most of the respondents offered a matter-of-fact explanation along the lines: the power meter tells me if the car is using or regenerating electricity. However, there were a few more insightful responses that delved into the usefulness of the display. As the following quotations indicate, the power meter was a polarizing display – people either found it very useful or not useful at all.

> *"It gives me a relative indication of power consumption or regeneration. Frankly, I don't really look at this indicator much because (a) it's in an awkward place on the MINI E, well out of the driver's field of view and (b) I never am low on charge, so I drive my MINI E hard all the time. I don't particularly care if it's using a lot of energy or regenerating a lot of energy. Every day I will recharge it in the evening to come back to a 100 percent charge the next day" – Survey household 41*

> *"I would prefer a meter rather than "idiot lights." After one year, I never felt comfortable with the idiot lights, but I could have related better to a meter with more precise readings. (I'm an engineer)" – Survey household 42*

> *"It tells me precisely what I am doing and helps me to adjust my speed accordingly. It essentially helps to increase proficiency." – Survey household 26*

> *"It explains how much energy is being consumed or regenerated. It was fascinating to know just how much power was being used based on how high or*

low the bars peaked at. It implied that not all acceleration is the same. It takes more energy to accelerate on the freeway or going up a hill than the amount of deceleration one gets when going 60 miles per hour and then releasing the brake to quickly slow down."- Survey household 60

5.4 Experiencing MINI E Range

The driving range of a BEV is lower than that of an ICE vehicle due to there being less energy stored on board a BEV than on board an ICE vehicle. Conventionally fueled vehicles can go over 300 miles on a single tank and can be refueled quickly at gas stations. The test range of the MINI E is 180 km (111 miles) and on the FTP72 test cycle 240 km before it is fully discharged and must be plugged-in for approximately four hours to recharge. Highly efficient vehicles, like the MINI E, are very sensitive to weather conditions, speed, driving style, accessory loads, and route detail (such as hills). Therefore, BEVs like the MINI E show a wide distribution of ranges for drivers across drivers, seasons, and trips. Given the limited energy of batteries, this wide distribution of "ranges" makes learning about range an important process for drivers, especially if their lifestyles, driving style, or climate challenge the energy storage of a particular design. Given these technical constraints of BEVs, it is generally expected that BEVs like the MINI E will be used for "daily" regional driving, and not for longer trips, that would require multiple recharging events in a single day or journey.

Researchers often assume that ownership of a BEV will result in lower vehicle miles traveled (VMT) and that drivers will avoid using the vehicle, opting instead to use their conventionally fueled gasoline or diesel vehicle. Our households did drive their MINI Es less than the average vehicle in the US, which is 12,800 miles; based on self-reported estimates in the end-of-lease survey, the MINI Es averaged 8,639 miles over the course of the year, with a wide range of mileage between households. According to our surveys and interviews, a significant portion of the lost mileage can be attributed to the vehicle being a two-seater with reduced storage. In addition, there was no public or workplace charging for most drivers, so the MINI E trial is not yet a test of the average mileage for a sample of BEVs. We found that households *adapted* their driving around the capabilities of the vehicle

and even *explored* ways to maximize the use of the MINI E. Households mentioned not being able to do specific trips due to range limits, but did not express an overall feeling of losing mobility.

Learning about MINI E range

This discussion focuses on limited range, which is a characteristic of all BEVs. The MINI E also has limited cargo and passenger space. Some survey questions targeted range whereas others address limitations of the MINI E, which may include range, cargo space, and passenger space.

As shown in Figure **10** in our end-of-lease survey 95 percent of the respondents reported driving the MINI E 80 or fewer miles per day on average. Only five percent reported driving between 80 and 100 miles on average. From this, we can see that MINI E drivers were generally not pushing the limits on the range of the vehicle in between charging events.

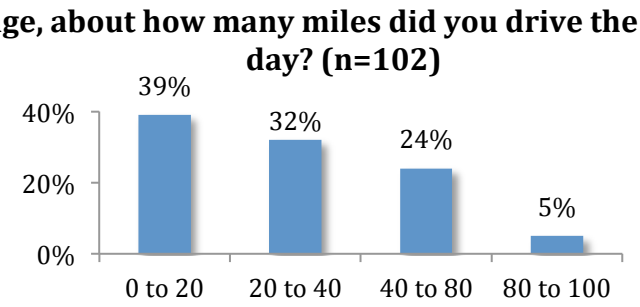


Figure 10 - MINI E miles per day (End-of-lease survey)

Many households learned that they were driving the MINI E more than expected; the following is one example of a trend that we heard in the in-person interviews.

> *"The MINI E has been reliable and fun to drive. It has definitely exceeded my expectations in terms of general utility. I expected to be able to use it for 70 percent of my driving but I have actually used it for 97 percent of my driving." – Survey household 15*

Figure **11** shows that 100 percent of the BMW Survey respondents agree that electric vehicles are suitable for daily use, based on their experiences with the MINI E. Although

this question asked about general suitability of BEVs, range would be one of the considerations for daily use.

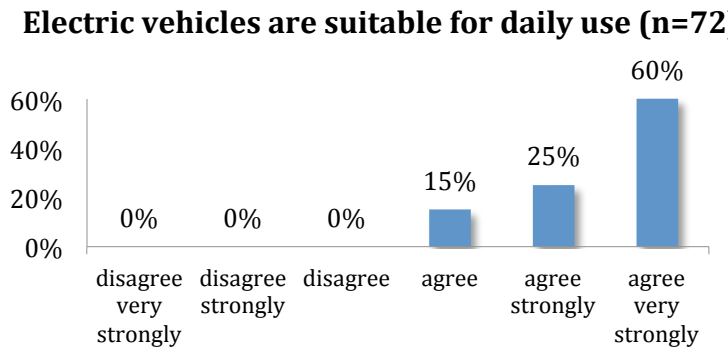


Figure 11 - EVs are suitable for daily use (BMW Survey)

Despite their stated satisfaction with the range of the MINI E, we see from Figure **12** that 81 percent of people learned that they wanted to access places in their MINI E that the range did not allow. It seems that drivers desired destinations were primarily infrequent destinations rather than routine driving. Out of all the desired destinations reported by drivers, 77 percent of them would be visited once a month or less.

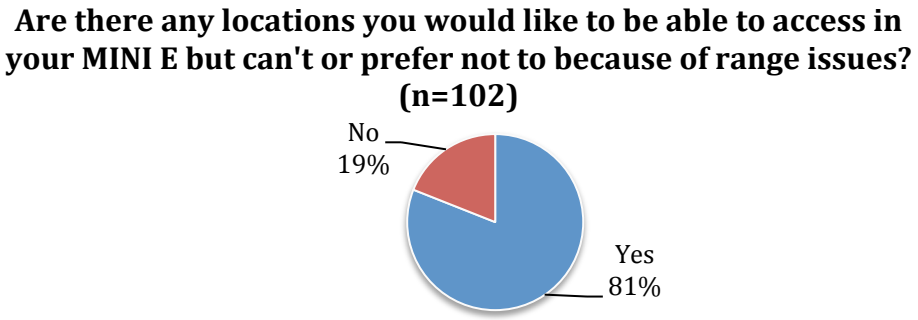


Figure 12 - Are there locations you can't access in the MINI E due to range issues? (End-of-lease survey)

The following discussion of desired destinations focuses on the responses from the 81 percent of people who responded that they did want to travel outside of the range of the MINI E. Drivers' desired destinations varied by trip type (e.g. work, shopping, family, etc.), trip frequency (e.g. monthly, annually), and distance. Figure **13** shows a breakdown of these

desired destination types, the most common of which are recreation/entertainment and family/friends.

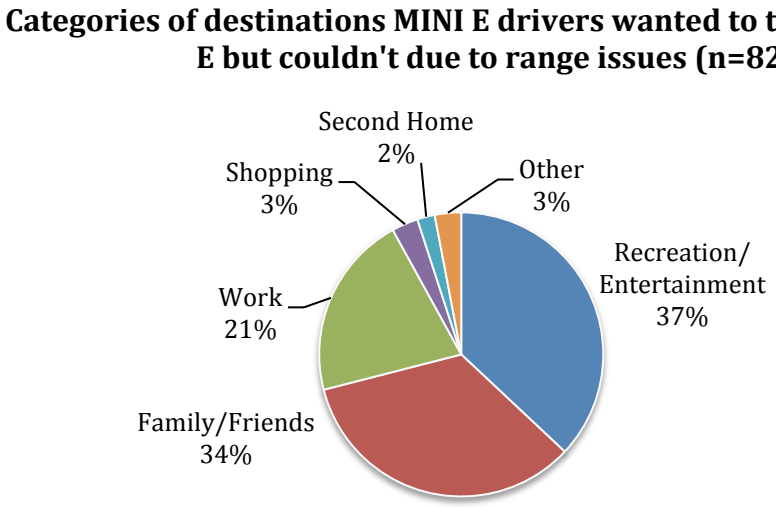


Figure 13 – Types of locations MINI E drivers wanted to drive their MINI E, but couldn't because of range (End-of-lease survey)

Figure **14** shows the distribution of distances between people's home locations and desired destinations. The one-way distances were calculated using shortest distance network paths between each driver's home location and desired destinations. Of these desired MINI E destinations, 89 percent are within 160 miles of drivers' homes.

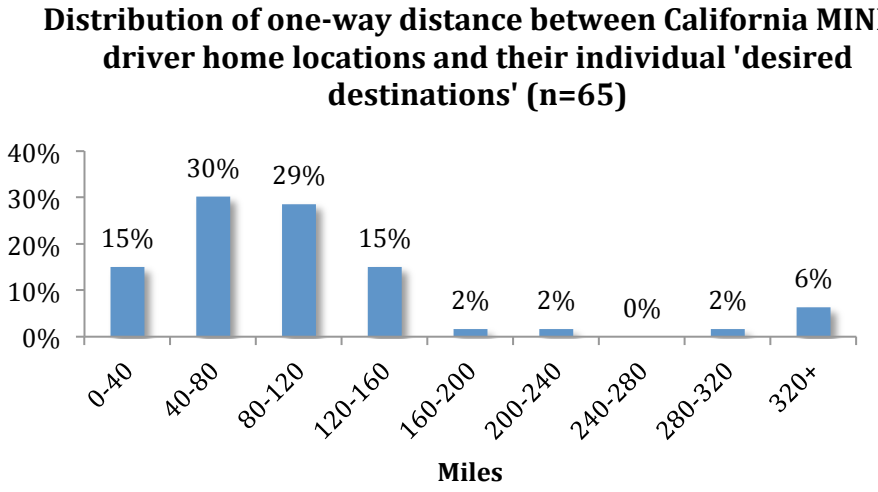


Figure 14 - Distribution of distances between MINI E drivers' home locations and desired destinations (End-of-lease survey)

In Southern California, since most home locations were concentrated around Los Angeles, neighboring regional cities like San Diego, Santa Barbara, and Palm Springs were among the most common places drivers would like to drive to in the MINI E. Another common area was downtown Los Angeles, Los Angeles International Airport, and nearby cities. Although most drivers lived around Los Angeles, a few lived on the outside edge of the city, like Victorville and were unable to drive the MINI E to and back from the Los Angeles without either additional range or charging. Another explanation for the high number of desired destinations in the city center was people chaining multiple trips together throughout the day. The sum of multiple short trips' distances exceeded the range of the vehicle and they were therefore unable to make it to destinations that would appear to be accessible if considered a single trip.

The home locations and desired destinations of the California end-of-lease survey respondents are shown in Figure **15**. Drivers' desired destinations are aggregated at the city level; the size of each bubble on the map represents how many drivers listed a given city in the survey that wanted to access in their MINI E but couldn't or preferred not to because of range issues.

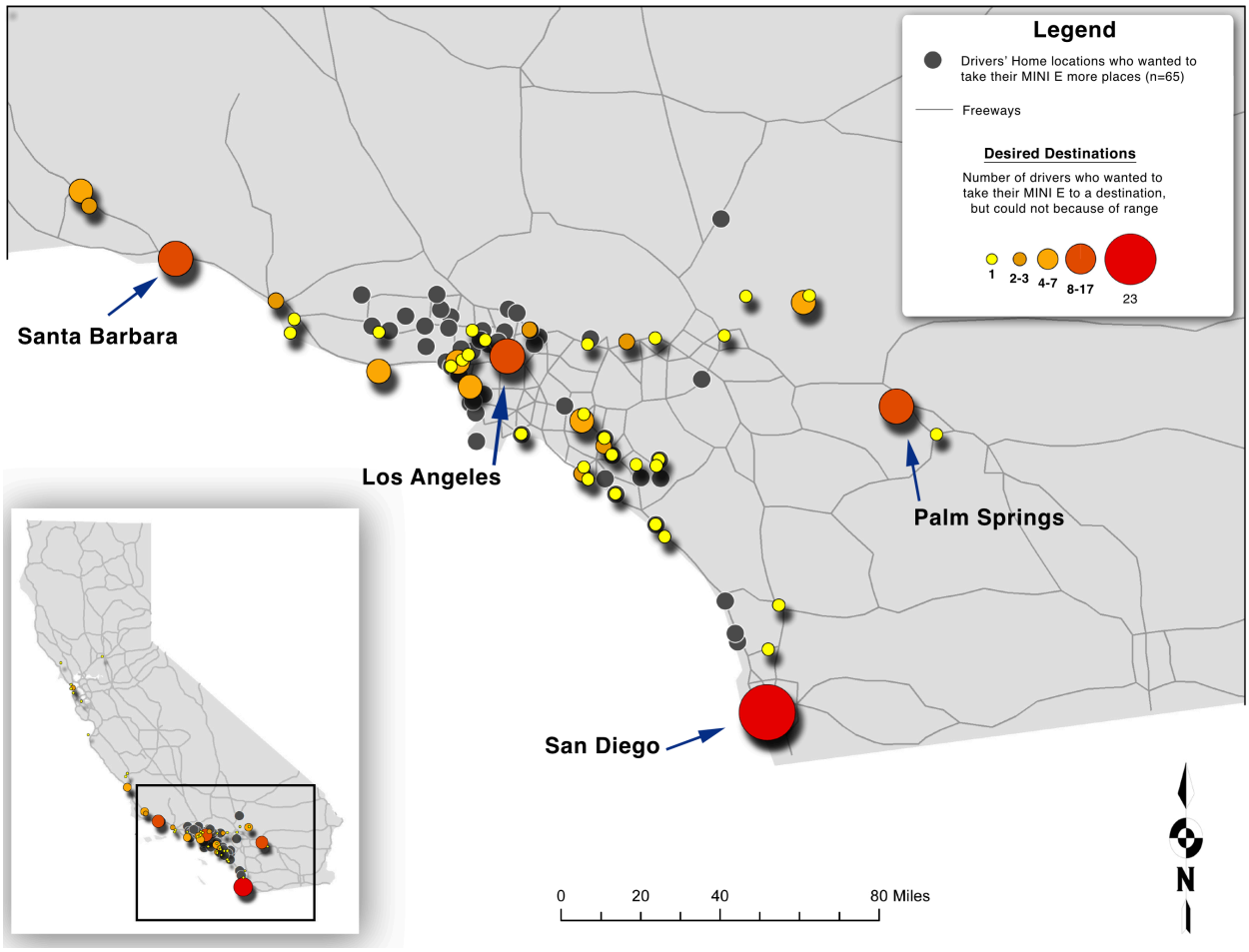


Figure 15 - Map showing home locations and desired destinations for California MINI E drivers who wanted to travel beyond the range of the vehicle.

A line density of the road network routes used to calculate the distance between home and desired destinations from the data in Figure **14**. The calculated route density is illustrated spatially in Figure **16**, where the dark red colors show the sections of road network that had the highest number of generated shortest-time routes between home locations and desired destinations. The sections of freeway around Santa Barbara, San Diego and downtown Los Angeles have the highest density, which coincides with popular desired destinations and areas near the home locations.

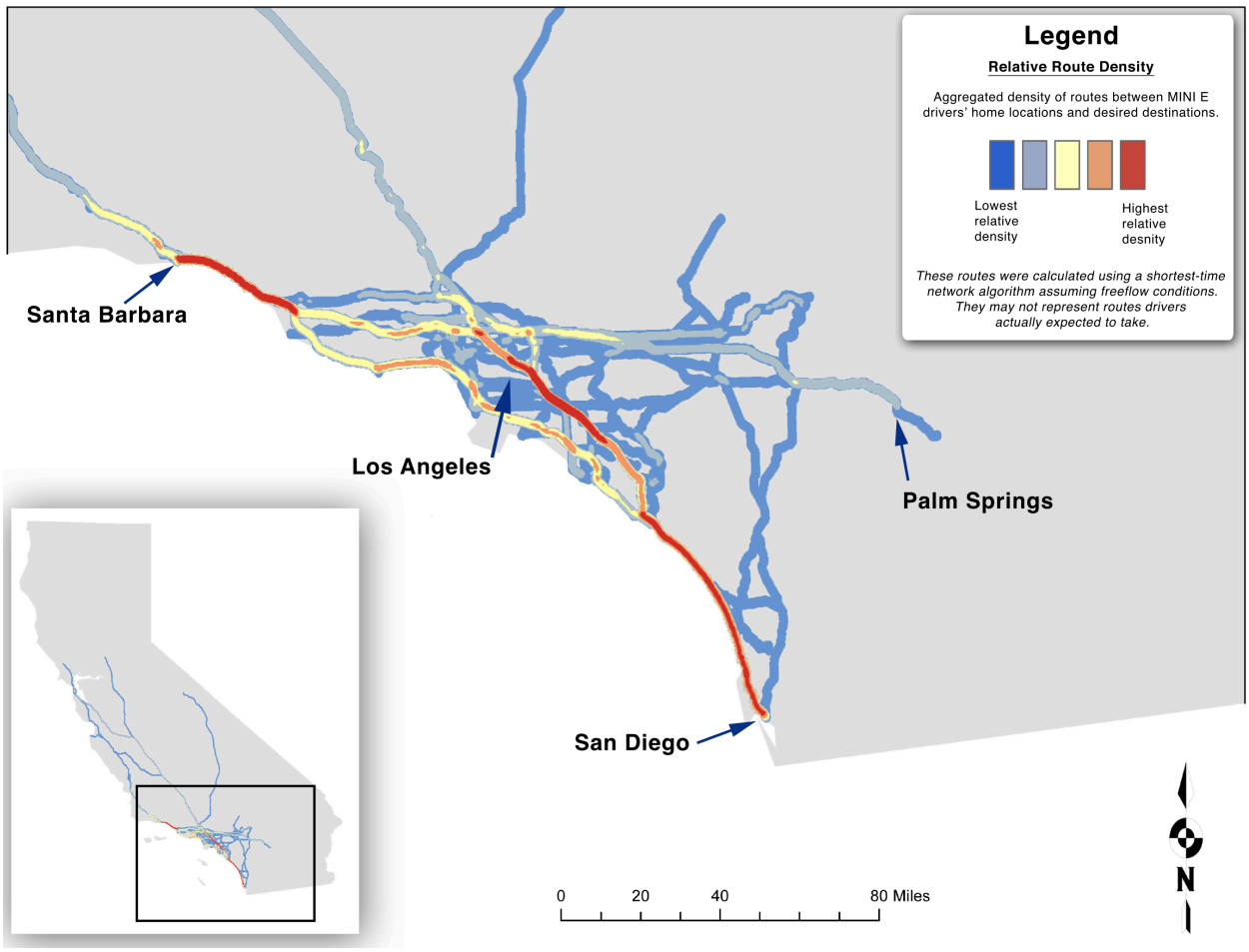


Figure 16 - Map showing a line density of the routes between California MINI E drivers and their desired destinations

Given that 89 percent of the destinations that drivers wanted to take their MINI E are within 160 miles of their homes, it appears that strategic placement of charging stations could allow drivers to make it to most of their desired destinations with a 90-100 mile range electric vehicle.

Drivers learned that the MINI E was capable of satisfying the bulk of their driving needs. Most households preferred to drive the MINI E and wanted to use it for more trips. In interviews, we asked households what their ideal range for a BEV would be and the most common response was 120 miles. Most drivers learned that they wanted to access more lifestyle sectors with their MINI E. Drivers explored the ideas of increased vehicle range and the availability of public charging stations as possible ways to expand their clean driving territory.

Adaptations to the MINI E's Range

The limited range of electric vehicles leads to a set of adaptations and new behaviors on the part of BEV drivers. Turrentine and Kurani discuss adaptations from simulation games in the 1990s (Turrentine and Kurani, 1995). These adaptations included:

1. Using a gas vehicle for long trips
2. Trip chaining
3. Eliminating trips

MINI E drivers developed additional adaptations that were not foreseen in the simulation work:

1. Learning the distance between personal activity locations (work, shopping, post office, friends) and sometimes finding alternate locations within range
2. Planning trips using GPS or online mapping tools
3. Turning off the air-conditioning or the heater to increase range
4. Driving slower
5. Employing hypermiling techniques
6. Switching to another vehicle when the MINI E had a low battery
7. Using the 120 volt convenience charger at work or other destinations

The MINI E was limited not just by range, but also by seating capacity and cargo space. In fact, many MINI E drivers found that the two seats and limited cargo space were more restrictive than the limited range, which made it difficult to carry unplanned extra passengers and cargo. While several households were able to fit impressive quantities of cargo into the vehicle, the limited interior space was mentioned frequently in interviews. For example, one couple described having to return some items after arriving at their MINI E and discovering that they could not carry home what they had purchased. To compensate for the limitations of the MINI E - whether it be by range, seats or cargo space - the primary adaptation was for households to use a second car, as seen in Figure **17**.

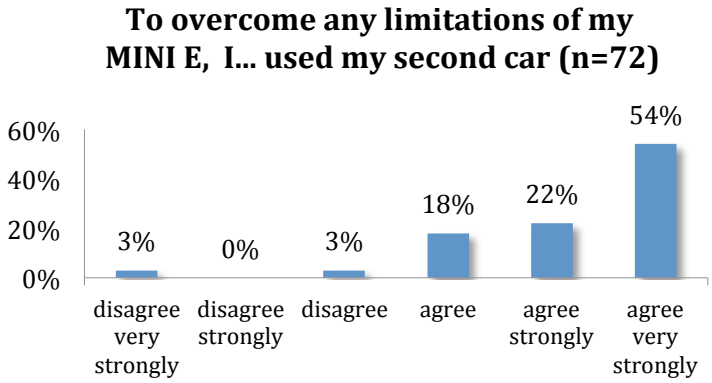


Figure 17 - Percent of respondents who used a second car to compensate for the limited range of the MINI E (BMW Survey)

Other measures that households took to adapt to the limited range of the MINI E were to employ multi-modal driving, for example using various modes of transportation for different legs of a trip. The other modes may include carpooling, using the train, or even renting a car.

One significant method that drivers employed to learn and adapt to the limited range of the MINI E was the use of GPS devices or online mapping tools to plan their routes ahead of time, and ensure that the MINI E would be able to complete the trip. Household 4 noted that this might be a challenge for BEV drivers:

> "*Most people wouldn't have the patience to drive this car because of all the brain power it takes to plan the trips.*" – *Household 4*

Other households did not find planning to be an inconvenience and employed a trip planning process using online mapping or GPS, similar to the one described below:

> *"First, [I used] Google maps to … plan my route. Second, … I know it's going to be… 81 miles round trip or something like that. I would either not use the car before hand [to do] errands or school runs or whatever, or I would do that and then plug in before I [left].*
>
> *(Interviewer clarification: Make sure you started with 100 percent?)*

Right. Secondly, trying to do my homework…is there a facility or someplace where I could plug in?" – Household 42

MINI E drivers were willing to adapt to the limitations of the MINI E that they discovered. Most drivers were not seriously inconvenienced by having to make changes to their lifestyles to accommodate the use of the MINI E. In fact, these pioneers moved past adaptation and explored new uses of the MINI E.

Exploration of MINI E Range

Pioneers described many outings with the MINI E that were more like exploration than routine activity. Several households talked about driving more with the MINI E than with their other cars. For example, one household commented on the expansion of their driving using the MINI E compared to the vehicle it replaced:

"I'm driving more with the MINI E than with the normal car, and that has been an absolute shocker for me. …..Expectation was that it would be my commute car, but we wouldn't use it, and whats happened is the reverse is absolutely true…..there's one trip we haven't made in the car….when we're home the MINI E is always the car that we take." – Household 50

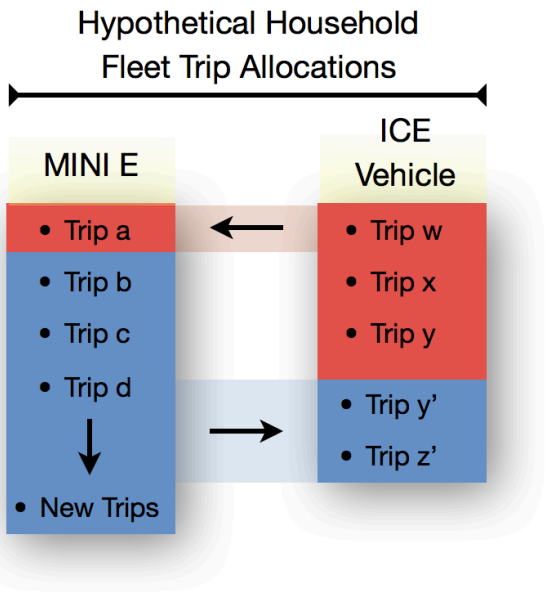
Most MINI E drivers preferred to use the MINI E as their primary vehicle even when roomier conventional vehicles with a longer range were available in their driveways. Across our sample, drivers learned that the MINI E's range satisfied most of their driving needs. Drivers described a process of shifting the responsibilities among the vehicles in their fleet to maximize their utilization of the MINI E as seen in Figure 18.

1. Exploration of BEV in the household fleet

Some trips, like 'Trip a' can't be done in the MINI E because of limitations. However when possible some drivers replace trips (trips y' and z') with the MINI E. This happened for a few reasons:

- It's driving performance (fun and quiet)
- Fuel/operating costs are lower
- Less polluting

Some individuals change their driving locations and even create new trips not taken before having the MINI E.



2. Expansion of the green territory

The MINI E trip composition can expand and change as drivers get comfortable with the car, learning distances to destinations via Google maps, and as infrastructure is deployed, allowing people to expand their EV driving territory.

Figure 18 - Exploring BEV Range within household fleets

Drivers often used trips that they would normally take in another car as opportunities to use and show off the MINI E. For example, one business-oriented pioneer wanted to engage visiting investors in talking about integrating BEVs into housing developments they were planning. He described "planting" the MINI E near the front door of a restaurant so the investors would notice the MINI E when they entered the restaurant. The MINI E driver was particularly pleased to find another MINI E also parked near the door on the same day. This driver explored using the MINI E to start a discussion about broader environmental efforts, which was a role that his conventional car could not perform.

MINI E drivers spent much of the interviews discussing the territory in which they were operating the vehicle and the uses they were discovering. They were often proud of having driven the vehicle to distant locations or organizing a long and complicated day. For example, if they lived in Pasadena, they described driving to the beach for dinner, or if they lived near the coast, they described driving to the inland areas. Based on one driver's hand-

drawn map during an interview, we created Figure **19**, which compares the respondent's MINI E territory to his gasoline vehicle territory.

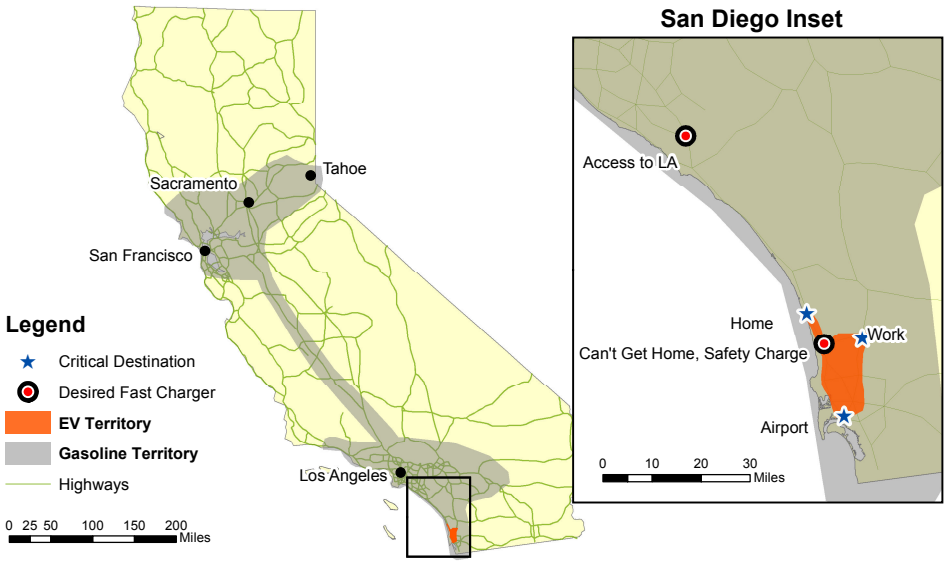


Figure 19 - MINI E territory versus gasoline vehicle territory

Despite the difference in the sizes of the gasoline vehicle and MINI E territories, this MINI E driver discussed the MINI E's range as meeting most of his driving needs. The one exception was that he wanted to drive to Los Angeles in the MINI E (hence his selection of downtown LA as a desired spot for a fast charger). The driver did not refer to his MINI E territory as small or limiting. In fact, he described his use of the MINI E in terms of adventure. This framing of the use of the MINI E as a discovery of BEV territory was normal, not exceptional, in our sample.

5.5 Impacts of Weather on MINI E Performance and Driver response

Perhaps the greatest challenge to the energy storage of the MINI E was cold weather. The batteries used in the MINI E have reduced capacity and ability to charge in very cold weather. In hot weather, the batteries can come close to overheating Additionally, cold and hot weather require heating and cooling the passenger space. Since there is a limited amount of energy stored in electric vehicles, cabin climate control sometimes competes with driving range. On days when the vehicle is only driven a few miles, the reduced range

due to high heating, ventilation and air conditioning (HVAC) loads may not impact vehicle use, but when the vehicle is expected to drive near its maximum range capability, drivers may have to moderate HVAC use or seek other solutions.

MINI E drivers experienced both high and low temperatures, as well as some severe weather, such as snow and rainstorms. In particular, drivers in the NY/NJ area experienced some severe cold and snow and the drivers in LA experienced some hot summer weather. The experience in the NY/NJ area was most severe; drivers complained of severe drops in performance of the battery, inability to keep the cabin warm, loss of the defrost function, and unexpected shut-downs in wet conditions. Drivers in LA complained about the battery overheating, which resulted in lower ranges, inability to charge, and loss of regenerative braking.

Sixty-seven of the 102 respondents were based in the greater Los Angeles area, where we do not believe cold weather to be a serious issue. However, Los Angeles is susceptible to hot weather, with average high temperatures in the summer around 85 °F (29 °C) and peak temperatures exceeding 100 °F (38 °C) (The Weather Channel, 2011).

To filter our responses, we first asked MINI E drivers if they experienced any problems with the MINI E when it was cold outside. The results are shown in Figure **20**.

Did you experience problems with the MINI E when it was cold outside? (n=102)

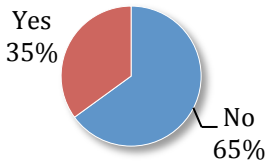


Figure 20 - Problems caused by cold weather (End-of-lease survey)

Of the drivers that responded "Yes" to experiencing problems with the MINI E when it was cold outside, 75 percent of them lived in the northeast. We asked all respondents who reported cold weather problems more detailed questions about the severity of the impact

the cold weather had on various aspects of the MINI E. The following discussion focuses only on these 36 drivers.

Based on the interviews we conducted with MINI E drivers in New York and New Jersey, we had some evidence that the range of the MINI E was adversely affected by cold weather. Figure **21** provides further evidence that this was the case, with 58 percent of respondents indicating that the cold weather had a strong effect on reducing the range of the MINI E.

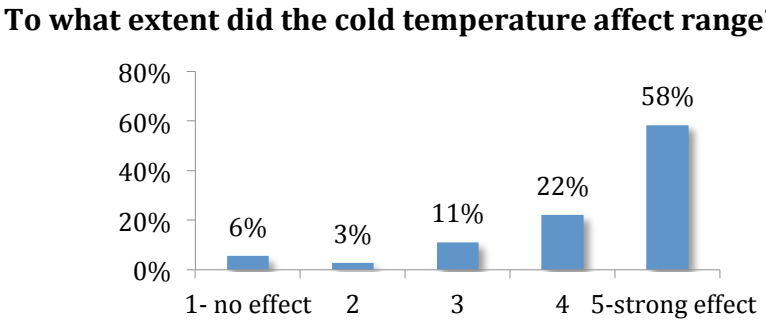


Figure 21 - Cold weather's effect on range (End-of-lease survey)

Some drivers told us that the MINI E's remaining range was less predictable in cold weather than in more temperate weather. Drivers watched the MINI E's estimated range display decrease at a faster rate than its odometer miles climbed. This meant that the drivers were uncertain about the actual range remaining in the vehicle. Figure **22** shows that 94 percent of these drivers felt that the cold reduced the predictability of the MINI E's range.

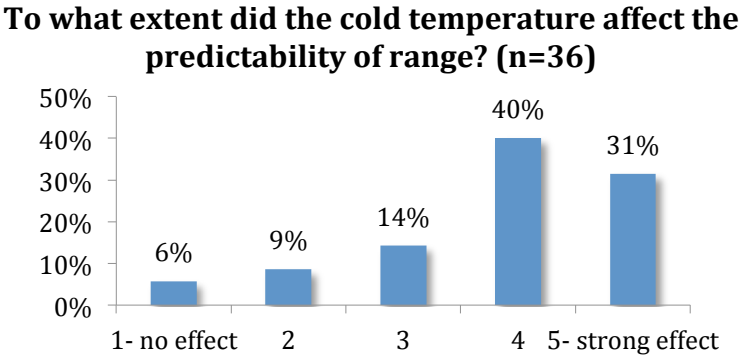


Figure 22 - Cold weather's effect on predictability of range (End-of-lease survey)

Drivers who stated that the cold caused problems with the MINI E did not however tend to raise strong complaints about the reliability of the MINI E in cold weather. As shown in Figure **23**, one-third of MINI E drivers who stated cold caused problems said the cold had no effect on reliability and fifty percent indicated the effects on reliability were slight to moderate.

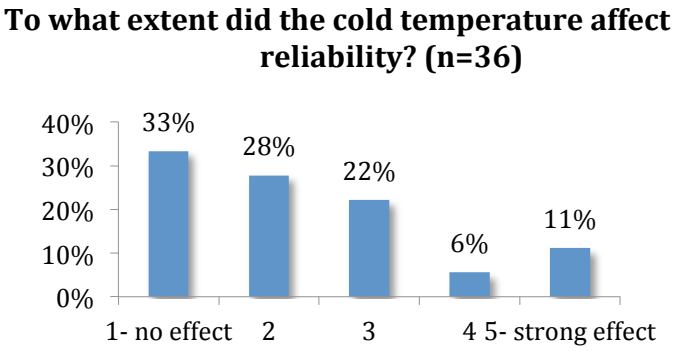


Figure 23 - Cold weather's effect on reliability (End-of-lease survey)

The primary cold-weather problem reported in the survey was reduced vehicle range. Most of the changes in behavior that occurred were adaptations in order to compensate for the reduced range. In the open-ended question "How did you adapt to the cold?" drivers reported that they adapted by using the MINI E less, not using the heater, using as little heat as possible, driving slower, parking in the garage and even installing a heater in the garage, bundling up with coats, gloves, and blankets, charging more frequently, and charging immediately upon parking at home while the vehicle was still warm.

Figure **24** shows that half of the MINI E drivers who experienced issues with the car in the cold felt having to adapt to the cold weather was not acceptable, 39 percent of the drivers were willing to adapt, and a few drivers didn't have a strong opinion one way or the other.

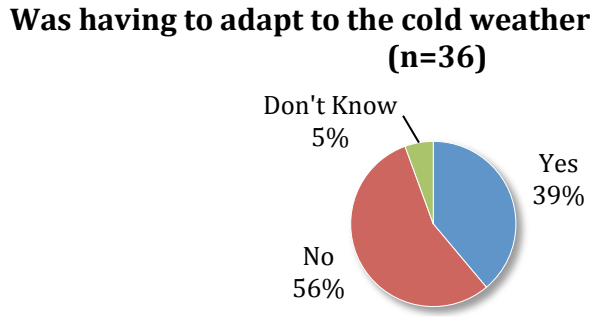


Figure 24 - Adapting to cold weather (End-of-lease survey)

We asked MINI E drivers a similar series of questions regarding adverse effects of heat on the MINI E. Figure **25** shows that just over one-third of respondents experienced some problem with the MINI E when it was hot outside.

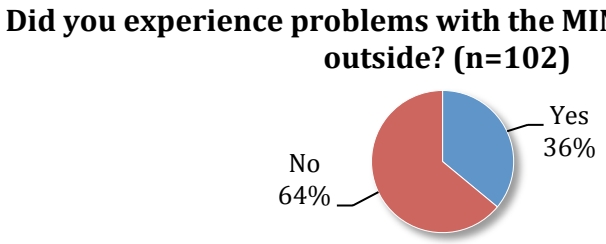


Figure 25 - Problems caused by hot weather (End-of-lease survey)

Of the 37 drivers who stated that they experienced heat-related problems with the MINI E, 30 (about 80 percent) were from the Los Angeles area. As shown in Figure **26**, 84 percent of the drivers who reported problems in hot weather found that heat affected the reliability of the MINI E. Furthermore, on a scale of 1= no effect to 5 = strong effect, 46 percent of respondents indicated the effect of heat on reliability was a 4 or 5.

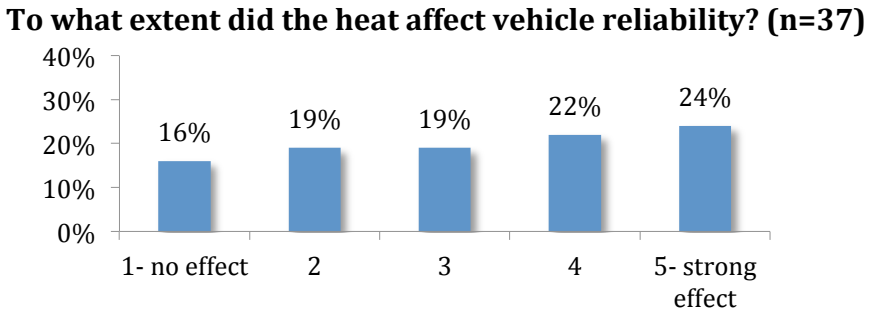


Figure 26 - Heat affected the reliability of the MINI E (End-of-lease survey)

Drivers' reactions to heat-related problems were mixed. In our end-of-lease survey, the most important heat-related problem was vehicle reliability. MINI E drivers reported the following specific problems in the end-of-lease survey:

- Failure of regenerative braking
- Reduced vehicle range
- Reduced vehicle performance
- Car shuts down while driving
- Charger will not start
- Personal discomfort (air-conditioner ineffective)

In the open-ended question "How did you adapt to the heat?" drivers responded that they adapted by not driving the vehicle in hot weather, driving slower or on less intensive routes, parking in the shade, or delaying charging, among other solutions.

The MINI E drivers were willing to tolerate some discomfort, or adapt their driving, in order to maximize the range in cold and hot weather. Extreme weather rarely prevented MINI E drivers from using the car. The problems that drivers experienced did not seem to affect their enjoyment of the MINI E or their perception of BEVs in general.

5.6 The Charging Experience

One of the most prominent differences between conventional and electric vehicles is that conventional vehicles are refueled in a few minutes at special stations, while electric vehicles are charged slowly and can be charged while parked at home locations (assuming, as was the case for all MINI E drivers, that home is suitable recharging location). Based on

our observations of MINI E drivers, we expect most BEV charging to take place at night, especially by homeowners who park their car in garages and driveways at their homes.

MINI E drivers were all provided with a home charging unit. Table **2** below shows that the charge time for drivers using their home chargers was on the order of 3-4 hours. Faster 240-volt charging was available at select MINI E dealerships.

Charging Category	Full Charge Time (0% - 100% SOC)	Circuit Voltage	Circuit Amperage
Dealership	~ 3 hours	240v	48
Home	~ 4.5 hours	240v	32
Convenience	~26.5 hours	120v	12

Table 2 - MINI E Charging Regimes

MINI E drivers were required to have either a garage or similar home parking location to charge the vehicle. MINI E drivers did not have access to public charging systems. Some MINI E drivers charged their vehicle at work and a few other locations, such as the home of a friend or relative, using a 120-volt "convenience charger" they could carry in the car.

One clear finding was that the charge speed for the MINI E was sufficient for these drivers. Almost universally drivers said in interviews and surveys that the charge time was adequate: they wanted the car fully charged in the morning, and it was. Only a few drivers thought they might want a faster charger at home to top off the vehicle quickly between activities. However, few were willing to consider paying extra for that benefit.

Part of the MINI E learning process involved exploring how often and when to charge their MINI Es at home. As drivers *discovered* their daily driving distances and the impact driving had on the battery SOC, they *applied* different charging routines based on how they *translated* their experiences. Figure **27** shows two contrasting charging behaviors using data collected from driving diaries.

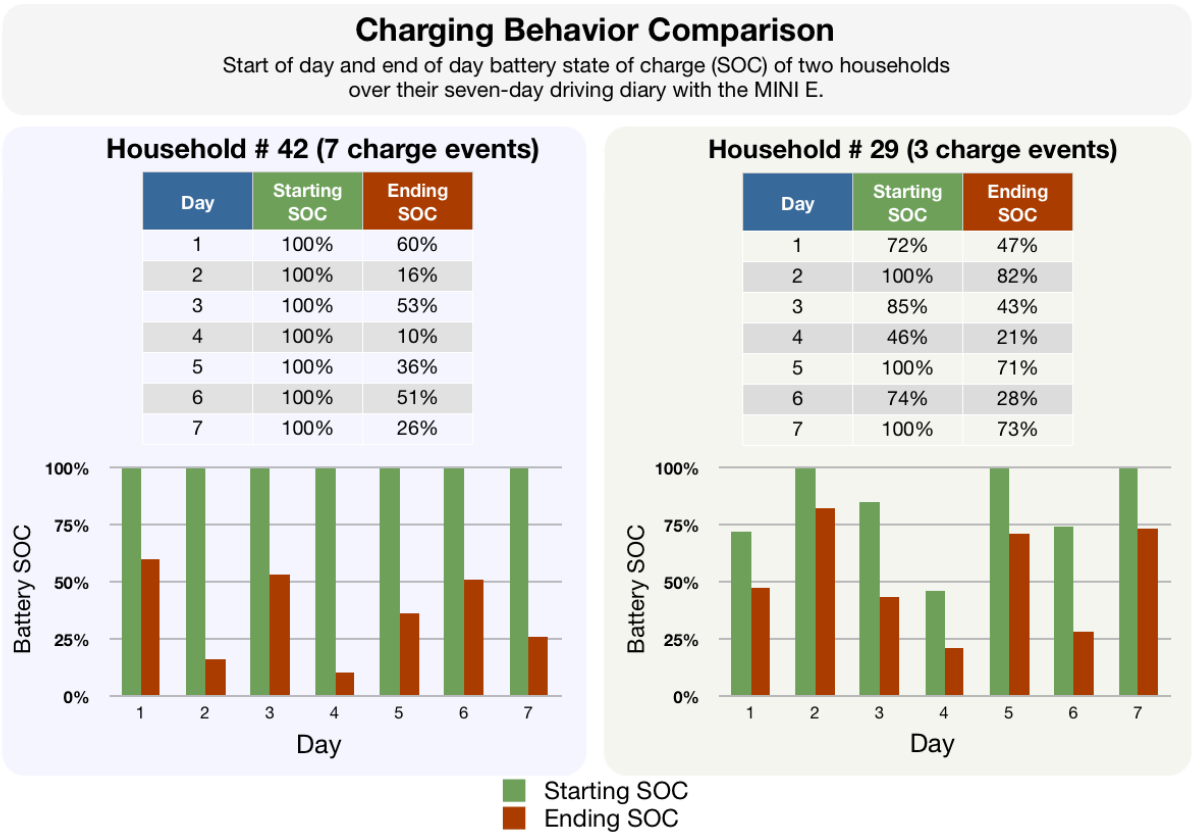


Figure 27 - MINI E Drivers varied in their charging behavior (Driving Diaries)

Household 42 utilized most of the MINI E's battery capacity each day and charged every night. In contrast, Household 29 utilized less of the available battery capacity each day and charged only three times over the week. These are just two examples of the variety of charging routines we observed in the MINI E households; some people charged every day, and others charged every couple of days as needed. Of the 24 completed driving diaries, 13 households charged daily (at least once per day on at least six of the seven days of their diary week). The remaining 11 households charged less than once per day.

Drivers also commented on a variety of aspects of charging the MINI E:

- At night or in other low light settings, some people had difficulty trying to correctly insert the plug into the car. They mentioned wanting a light, or glowing dot to assist properly aligning the plug with the outlet.

- People wanted to have an easy way to check the SOC of the battery during charging. Some ideas from drivers included display of SOC information on the charging unit, on the car dashboard (simply by peeking in the window without the need to insert a key), or remotely via mobile or web application.
- For some drivers it was troublesome to be required to manually change the charging power setting to match the charger being used (e.g. 240-volt, 32 amp for the home charger). If not set properly, the car would not charge at all.
- Drivers who were on time-of-use electricity rates wanted to be able to set a timer on the charger, allowing them to "set and forget" their vehicle charging, i.e., plug in their car when they arrive at home, and know it will be charged when electricity prices are lowest.

Although the MINI Es did not have access to a widespread public charging network, some users tried to maximize the use of the vehicle through the use of the 120V convenience charger. Household 4 stated that the only thing missing from his driving diary is looking for public charging in Manhattan, which he didn't do during that week. He later went on to say that he "*got creative about finding places to plug it in, and… sometimes had to ask for a manager to get permission to plug-in the vehicle*" at certain locations.

Figure **28** shows that 90 percent of survey respondents agreed strongly or very strongly that the charger was easy to use. Some compared the simplicity of charging their MINI E to charging their cell phone.

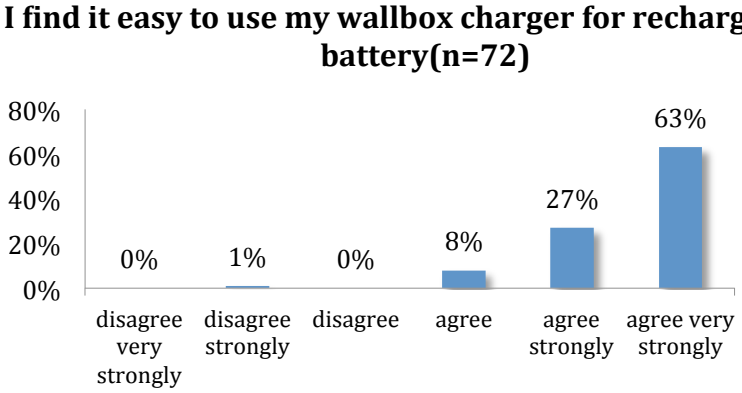


Figure 28 - Ease of charging (BMW survey)

In addition to finding the home recharging easy and convenient, Figure **29** shows that 93 percent of respondents felt that they were saving money by recharging the MINI E with electricity instead of refueling an internal combustion engine vehicle

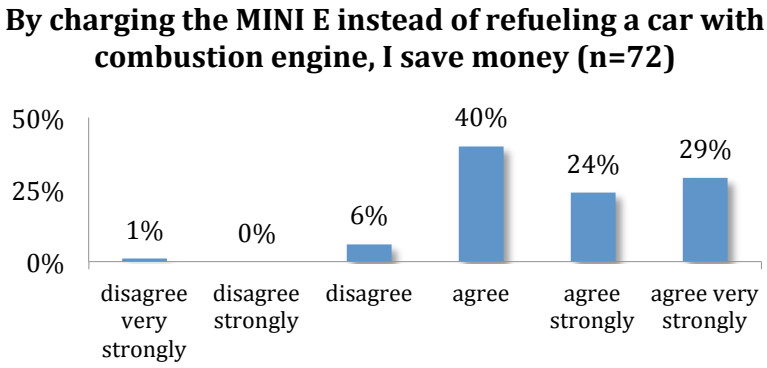


Figure 29 - MINI E fuel cost savings (BMW survey)

MINI E drivers enjoyed the simplicity and convenience of home recharging. Drivers developed a charging routine that fit their specific lifestyles, which often included the total avoidance of gas stations. Charging gave drivers a feeling of more control over the fueling behavior, cost and source of fuel for the MINI E than an ICE vehicle provided. Electricity gives drivers the option to envision a situation in which they can supply their own vehicle fuel through solar panels.

6. Buying a BEV in the future

Electric vehicles are expected to cost more than ICE vehicles due primarily to the high cost of the batteries. At the same time, the reduced driving range and slow charge time reduce traditional notions of practical value. On the other hand, BEVs do offer some superior features that are not available for ICE vehicles, such as home refueling. Additionally, BEVs offer important environmental and fuel security benefits. In this trial, MINI E drivers found added value in having a vehicle that they perceived to be both fun to drive and clean. They also valued the convenience and opportunities provided by using electricity as a fuel. Figure **30** shows that the opinions of two-thirds of respondents were affected by their experience leasing and driving the MINI E.

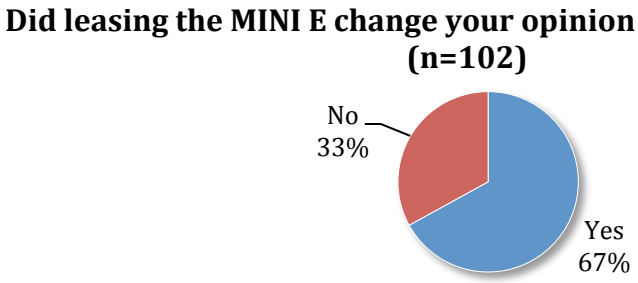


Figure 30 - Experience with MINI E influences peoples' opinions of BEV's (End-of-lease survey)

Following up on that question, Figure **31** shows that 71 percent of respondents are now more likely to purchase an electric vehicle than they were a year ago. Only nine percent answered that they are less likely to purchase a BEV than they were one year ago.

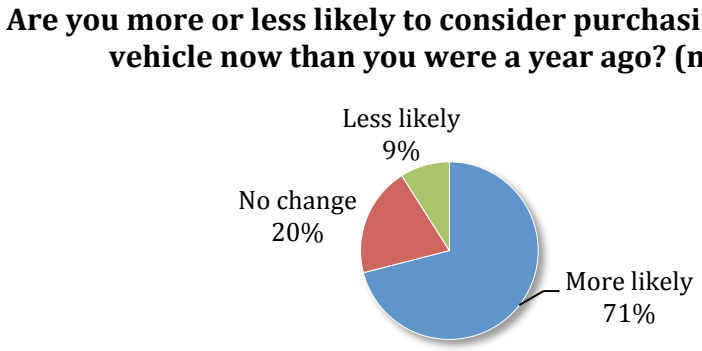


Figure 31 - Most drivers are more likely to purchase a BEV after leasing the MINI E (End-of-lease survey)

Some households explained further in the in-home interviews, describing how their preference for high-end vehicles has changed from rare conventionally fueled vehicles to high-end electric vehicles. Several mentioned already being on the waiting list for purchasing or leasing an electric vehicle or plug-in hybrid once their MINI E lease is over. Figure **32** shows that 88 percent of MINI E drivers who responded to our end-of-lease survey expressed an interest in buying a BEV or PHEV in the next five years.

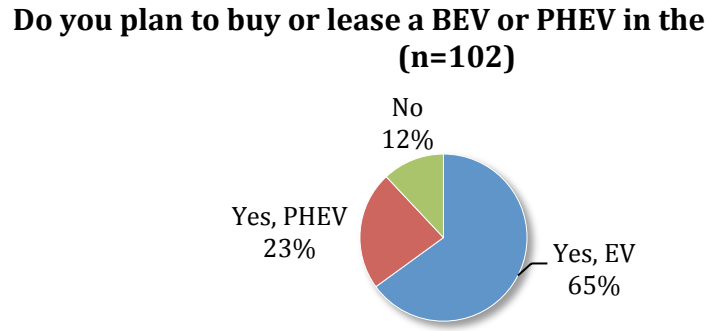


Figure 32 - 88 percent of drivers plan to buy a BEV or PHEV in the next 5 years (End-of-lease survey)

Drivers overwhelmingly expressed having had a positive experience with the MINI E and looked forward to buying a BEV or PHEV in the future. MINI E drivers liked the benefits and opportunities provided by using electricity as a fuel and the unique characteristics of electric drive.

7. Environment, energy use and green vehicles

"Green" or environmentally friendly vehicles are a recent development in the automotive market. In addition to hybrid vehicles, a variety of other environmentally friendly options are becoming available, including plug-in hybrid vehicles, battery electric vehicles and biofuel vehicles. As each of these technologies has certain limitations, primarily the lower energy density of their energy storage systems compared to gasoline, the issue is raised as to whether consumers will pay a premium for environmental benefits.

This "green" aspect of the market is so new that we still must turn to theoretical arguments to explore under what conditions consumers may be willing to pay more for a clean vehicles and how much more will they pay. Economic theory famously denies the possibility that individuals act outside their own interest. Those that agree with this view of humans propose that such green actions are intrinsically oriented towards either psychological needs to be good person or self-serving elevation of social status. One might observe that green purchases are only within the reach of the wealthy who can afford to buy green goods. A corollary of this view is that such buyers are few in the market—a small segment of the market. The main market will be motivated by more "practical" concerns when shopping for a new car.

A related theoretical approach is that "green buyers" form a small, but possibly important early market segment, much like the idea of early adopters in "diffusion of innovation" theory. Innovation and green market theorists often portray such early markets as a few percent of "the market" at the most. A particularly well-known theorem in this arena is Market Chasm Theory, which posits that firms often develop innovations to serve a small early set of buyers, who by personality or some other variable are willing to pay more to get something new (or green) but once that segment is exhausted, the specialized design and increased costs keep the new product from reaching the mainstream market (Moore, 1999). The product falls into a design and cost chasm.

However, this model is developed for digital technology markets, while BEVs are more complex combinations of technology, green attributes, and energy alternatives. In particular the green aspects of BEVs are a contested technical issue. BEVs are hoped to reduce local emissions, green house gas emissions, and petroleum use. However, given the great variations in how electricity is produced, including coal, natural gas, biofuels, hydroelectric, geothermal, wind, nuclear and solar, and the mixing of these sources by power companies, regional grids and time of day, the ultimate well-to-wheel emissions of electricity are debated. Further, because emissions are remote from the vehicle, at power plants, BEVs have zero tailpipe emissions. Thus electric vehicles are obviously cleaner in micro-contexts such as parking structures, street level emissions and congested local areas, contexts known to drivers. Electric vehicles in areas with electric grids that are predominately supplied by either nuclear or hydroelectric, wind, or other renewable power sources offer significant reductions in local pollution and global green house gas emissions (EPRI, 2007) BEVs recharged from electrical grids that use coal or even ageing natural gas turbines, do not present such clear benefits. In some regions, the grid maybe high in CO_2 and other emissions today, but is expected to improve over the next few decades. In other situations, BEVs might be driven predominately in a region serviced by one electric utility but predominately recharged in another. The benefits of such vehicles are difficult to calculate, even by experts, and vary day-to-day, hour-to-hour, and season-to-season.

MINI E drivers often leased their vehicles with only minimal information and understanding of these complex possibilities. We learned in many interviews that MINI E drivers were often challenged by acquaintances, friends and family about whether BEVs were really “clean.” In fact, MINI E drivers usually asked the PH&EV center researchers for answers to these questions. We tried to remain agnostic, offering minimal responses to their requests for our expertise.

Throughout this study, we asked MINI E drivers what was important to them with regards to the environmental aspects of vehicles. Below we show what they were thinking, in particular focusing on their thoughts at the end of the MINI E study period. Figure **33** shows

what the UCD sample thought about the environmental impact of various energy sources for the grid.

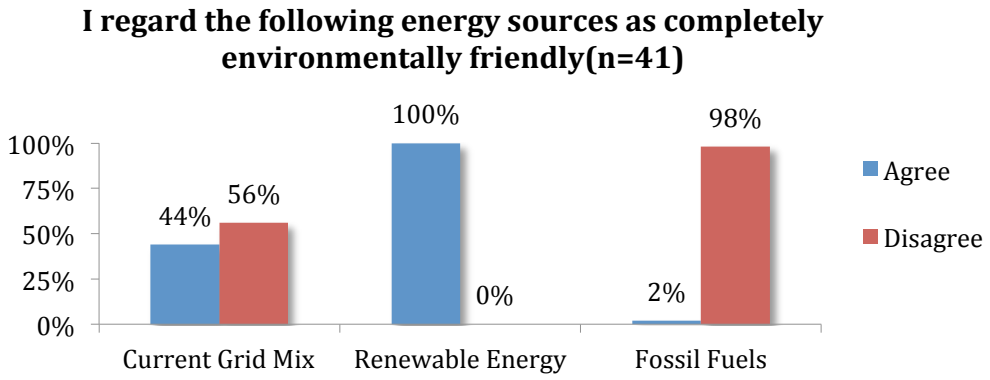


Figure 33 - Drivers thoughts on electricity (UCD Survey)

This group of MINI E drivers does not think that the current grid mix is environmentally friendly, thinks that "renewables are friendly to the environment" but that fossil fuels are clearly not.

Figure **34** shows the UCD sample's opinion of how their electricity for charging should be generated. We see that MINI E drivers think the MINI E should use solar and wind first, and then hydro, with a less enthusiastic suggestion of nuclear and natural gas electricity generation. They are strongly opposed to fueling their vehicles with electricity generated from coal.

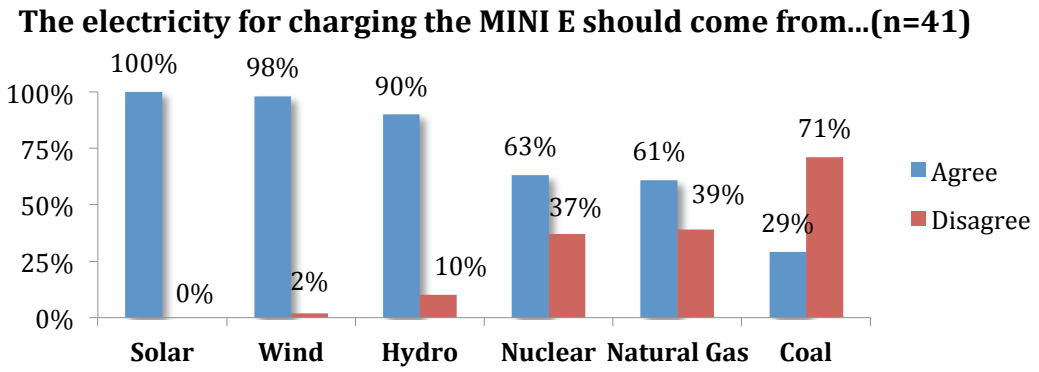


Figure 34 - Drivers opinions on what energy sources should charge the MINI E (UCD Survey)

Several households had photovoltaic (PV) systems on their houses and were excited to be able to use that energy to drive their vehicles, or considered the option of adding PV arrays so that they could charge their vehicles using solar power.

As an example, Household 50 stated that their driving has *"Totally shifted…because it's essentially free for us to drive with the solar and it's fun, doesn't cost us any money and we use it all the time." "We built this house….we built it solar; we put an extra circuit in the garage knowing that we were eventually going to get a plug-in hybrid."*

We also ask whether driving the MINI E has changed the way they think about energy. Figure **35** shows that two thirds agree it did. What does this mean? The interviews hold some answers here. As we noted above, many MINI E drivers entered their lease not knowing much about the emissions from BEVs due to power plants, but were often challenged by others to account for power plant emissions. They were asked to explain what they thought.

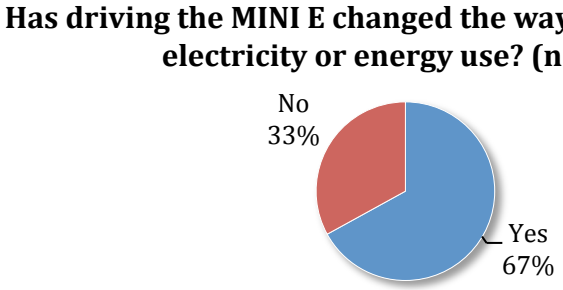


Figure 35 - Drivers changed the way they think about energy (End-of-lease Survey)

Below we offer some illustrative quotes from responses to the end-of-lease survey open-ended questions:

> *"Driving the car has definitely changed how I look at my energy usage. After living with the car for a while I learned I could go further with the same amount of energy if I simply changed my driving style a little. I think that got me thinking that I could also do more and use less at home by making some simple changes. Also, inspired by the MINI-E, I installed a solar electric system*

on my roof a few months ago and now generate the electricity that I use to charge the car as well as power my home." - Survey household 2

"I have also become more environmentally conscious. I pay more attention to my acceleration and deceleration, I pay more attention to using resources in the car such as AC." - Survey household 77

"I've become a more energy conserving driver even in my gas cars." - Survey household 66

"Decided to go solar. Generally I am much more aware of my energy usage." – Survey household 6

"I installed 18 solar panels on garage after learning about electric costs." – Survey household 46

Even if driving the MINI E and learning about electricity did not lead to a household installing solar panels or signing up for an optional "green electricity" rate, it often inspired other environmental measures, such as monitoring parasitic loads in their homes, installing compact fluorescent light bulbs, or bringing their own bags to the grocery store. The vehicle and the surrounding BEV community seemed to increase awareness about environmental issues in general.

8. Conclusion

We observed the experience of MINI E drivers through the framework of a learning process. The drivers went through the phases of *discovery*, *translation*, and *application* of the MINI E to their lifestyles. Three findings stand out as potential areas of significant new values of BEVs to consumers:

1. The Intersection of Clean and Fun
2. Expanding Mastery of Energy Use
3. Developing the Electric Vehicle Territory

The Intersection of Clean and Fun

The MINI E meets drivers' desire for a vehicle that is both environmentally friendly and fun to drive. This opinion of the MINI E is the most pervasive across the interviewed MINI E drivers. The performance of the MINI E was a powerful experience in combination with the environmental aspects. Fun features of electric drive include the power and agility of the MINI E, single pedal acceleration and regenerative braking, smooth acceleration, and quiet drive—all of which combine to create a unique, positive experience.

Expanding Mastery of Energy Use

Drivers find value in using electricity as a fuel and mastering their energy use through driving behaviors, regenerative braking, and charging. BEVs are unique among energy-using devices in offering training to consumers about electricity and energy through experience with the regenerative braking system, energy use displays, limited battery energy and recharging equipment. MINI E drivers find themselves caught up in this new system and typically enjoy the learning process it facilitates, encourages, or requires.

Energy use, especially by vehicles, has gained greater importance in public life. World energy demand, greenhouse gas emissions, and rising costs of energy have resulted in what some social scientists would call a public discourse. BEVs play a prominent role in this

discourse as symbols of environmental friendliness and efficiency in opposition to pollution and waste.

Consumers have grown accustomed to using battery-powered devices in which the amount of electricity used is unobserved. However, BEVs utilize energy over traveled distance and time and uniquely recapture kinetic energy through the regenerative braking system. This use and recapturing of energy by BEVs is measured and dynamically displayed to drivers in their vehicles. This feedback creates a unique way for people to experience energy and electricity. BEV drivers become more sophisticated users of energy, and their sense of driving mastery become closely tied to energy use. Drivers expand their mastery of energy use, learning about kilowatt-hours, efficiency, aerodynamics, relative use of power for production of electricity, and other relatively esoteric aspects of the electricity system that otherwise are not experienced by appliance users.

Drivers' expanding mastery of energy use is not necessarily limited to their direct experiences with BEVs. Drivers' lifestyles, household budgets, and social understandings are all taken into account throughout the learning process. The experiences of driving a BEV also becomes part of their daily dialogues with family, friends, and acquaintances. The combination of these social aspects and expanding mastery of energy use add value for BEVs to consumers.

Developing their Electric Vehicle Territory

The limited range of BEVs creates a new type and experience of activity space—that set of time-space the drivers wish to or must access to participate in desired or required activities—for drivers. In discovering the sub-spaces of their overall activity space to which their BEV provided them access (Kurani and Turrentine, 2002), MINI E drivers gain mastery over distances between destinations, use tools such as Google maps to plan out a day of travel, experience terrain such as hills more expertly, and consciously expand their "BEV activity sub-space." Together with the clean energy aspect of BEVs, this develops a unique, clean driving lifestyle sector for drivers. They may, for example, seek to avoid gas stations altogether, not even stopping for a soda or candy at a gas station mini-mart.

While it is common for pundits to speak of range anxiety when talking about BEVs, in this study we heard more about range desire as drivers, while accepting to some extent the limited range of their MINI E, actively sought to expand their BEV spaces. Drivers anticipated the growth of public charging infrastructure, which would allow them to expand their clean energy driving territory to include their desired locations.

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